Value Added Evaluation for a Laboratory that uses Augmented and Virtual Reality to Improve Student Learning in Auto-mechanics

Revised in January 2023

Diego F. Angel-Urdinola, Catalina Castillo, Marjorie Chinen
World Bank Group [1]

Robert Dean
Namseoul University

Javier Taipe
Ecuador’s National Secretariat of Higher Education, Science, and Technology

Abstract

This article presents the results of a value-added evaluation assessing the effects of using Augmented and Virtual Reality (AVR) to deliver training in auto-mechanics to a cohort of second-semester students enrolled in the Technology in Automotive Mechanics program at the Cotopaxi Technical Institute in Ecuador. The training program seeks to improve students' learning in the domain of auto-mechanics after being exposed to the basic principles of the operation of internal combustion engines. The curricula consist of nine competency-based learning modules imparted within one academic semester. To assess the effects of the training on learning outcomes, students completed a pre-test and a post-test to quantify the training's value added to student learning. Students also responded to a set of questionnaires about their perceptions of the AVR training on learning, engagement, motivation, and the usability of technology. Results indicate that students who participated in the course had statistically significant learning gains measured by the percentage increase in the post-test relative to the pre-test. Results also suggest that students exposed to the training reported high levels of engagement and motivation with the AVR training but reported some concerns regarding the usability of the technology.

JEL Classification: I20, I24

Keywords: Virtual Reality, Augmented Reality, Education, Learning, Skills Development, Virtual Laboratories

[1] This article has been prepared thanks to a grant from the Korea World Bank Partnership Facility (KWPF). The team acknowledges valuable contributions are support from Dr. Carlos Eugenio (Rector at the Cotopaxi Technical Institute) and Devon Allcoat (Warwick University). The team also thanks Robert Hawkins and Victoria Levin (World Bank peer reviewers) for their useful inputs, suggestions, and contributions.

1. Introduction

Higher technical and technological education is essential to the sustainability of the knowledge economy and the development of specific skills required by different branches of production and innovation (Dill and Van Vught, 2010). Many countries in Latin America and the Caribbean (LAC) are currently expanding and modernizing the post-secondary technical education and training system to ensure the availability of the technicians and technologists required by the region's modernizing industries. One of the main trends in the LAC region in the higher education sector pertains to the rapid expansion of technical and technological programs (Ferreira et al., 2017).

In recent years, Ecuador has expanded and modernized its State technical and technological education network. To achieve these objectives, the government has begun to comprehensively reform its State system of Technical and Technological Institutes (TTIs), a system governed in Ecuador by the National Secretariat of Higher Education, Science, and Technology of Ecuador (SENESCYT). An essential pillar of the reform is consolidating technical and technological education at the local level into provincial hubs with upgraded infrastructure and equipment and offering careers and programs that respond to local employers' needs and the new digital economy. Nonetheless, attaining this reform has been a challenging task. Since 2017, Ecuador has entered a time of tight fiscal constraint, which has substantially limited the State's capacity to invest in the infrastructure and equipment needed to expand the offer of technical programs that require laboratories and workshops. Moreover, the pandemic resulting from the COVID-19 virus has produced additional difficulties for the country's technical and technological education system. As some TTIs shifted to providing digital learning modalities, it has become particularly cumbersome to supply students with engaging and hands-on learning experiences necessary to develop their skills, especially for programs that require laboratories to achieve skills proficiency.

In this context, the critical question is what policy alternatives could provide an affordable and effective mechanism to impart students with practical training? In response to the inherent challenges of setting up laboratories for technical education (cost, maintenance, update), educators worldwide are exploring the possibility of accelerating the development of virtual labs as pedagogical support for imparting content in selected technical programs. A virtual lab is an interactive computer simulation of a laboratory. The purpose of virtual labs is to give students experiential interaction that will lead to learning. While virtual laboratories offer many advantages, it is essential to systematically assess their effectiveness to ensure they adequately contribute to student learning and skills development.

This article reports the results of a value-added evaluation assessing the extent to which a virtual laboratory can contribute to improving student learning in auto-mechanics. This research will inform the ongoing scale-up of the laboratory and the rollout of a planned impact evaluation of the intervention. This value-added evaluation, as a result, is part of a preparatory process to ensure adequate implementation of the virtual laboratory, testing data collection instruments, and identification of possible channels through which this virtual laboratory is conducive to student learning. It is worth noting from the start that, given its objectives, this value-added evaluation has a limited sample size, and its results do not provide definitive conclusions about the effectiveness of the virtual laboratory.

This auto-mechanics virtual laboratory is the first of its kind in the Ecuador's network of State TTIs. This virtual lab seeks to improve student learning in the domain of auto-mechanics of students who are being introduced to the basic principles of the operation of internal combustion engines for the first time. The curriculum and software for this virtual lab were developed by a multidisciplinary group of professors, education and multimedia experts and programmers from the Cotopaxi TTI, the World Bank, and Namseoul University, a leader in VR development, research, and education in South Korea. This virtual lab was developed under the *Active Training Using Augmented and Virtual Reality* (ActiVaR) *Program*, a pilot program financed by the government of Korea through the Korea World Bank Partnership Facility.[2] The results of this evaluation also inform the ongoing higher education policy in Ecuador pertaining to investments on infrastructure, laboratories and equipment, and accelerating access to digital learning.

The article is structured as follows. Section 2 provides a review of the literature pertaining to the use of virtual labs and immersive training to develop student skills. Section 3 provides a brief overview of the system of technical and technological education in Ecuador and the Cotopaxi TTI. Section 4 provides a detailed description of the intervention and its implementation. Section 5 describes the evaluation's methodology and instruments. Section 6 summarizes the main results of the evaluation. A brief conclusion follows.

[2] https://www.worldbank.org/en/programs/korea-world-bank-group-partnership-facility#1

2. Literature Review

In some educational fields, the development of student skills remains a challenge for trainees and their tutors, partly because of the limited availability of hands-on training or access to proper content and learning situations. As a response, educators are starting to rely on Virtual Laboratories, many of which use Augmented Reality and Virtual Reality (AVR), to develop learning experiences that would otherwise not be easily accessible to students (Johnson et al., 2016). [3]

Virtual laboratories can provide students with opportunities for practical training without pressure or danger, as well as allowing for repeated interventions. Simulators for occupational training differ in capabilities and features, and some more advanced virtual labs can provide users with a fully immersive environment. These advanced labs feature high-fidelity imaging (primarily due to advanced physics engines and graphics rendering capabilities), realistic manipulation of physical tools, and real-time feedback (McLaurin and Stone, 2012). Also, virtual laboratories can provide students access to situations and learning environments that would otherwise be very difficult or impossible to access. Such opportunities have the potential of accelerating students learning curve in a simulated environment, reproducing real-life conditions and situations without time or space limitations, and with much fewer risks. The use of VR can also optimize the utilization of real-life equipment. Indeed, developing some skills in the virtual environment allows for a reduction in the material, time, and expert accessibility costs that are associated with traditional training methods (Angel-Urdinola, Castillo-Castro, and Hoyos, 2019). Applications of virtual laboratories for technical education have been most common in aviation, design, auto-mechanics, prevention of industrial risks, and robotic (Angel-Urdinola, Castillo-Castro, and Hoyos, 2019; Buiu & Gansari, 2014; Wei, Dongsheng & Chun, 2013).

Active learning and constructivism are often cited as the main channels supporting the pedagogical value of learning using simulated environments. Constructivism suggests that students learn by building their own knowledge and incorporating it into their existing knowledge structure. Constructivism increases student engagement, motivation, and personalized learning (Madathil et al., 2017). Proponents of virtual laboratories that incorporate

[3] The term Virtual Reality (VR) applies to computer-simulated environments that can imitate physical presence in places in the real world, as well as in imaginary worlds, and simulate the illusion of participation in a synthetic environment with an external observation of such surroundings. VR simulations can be constructed employing 3D graphics using a desktop computer (non-immersive) or using a head-mounted display (immersive). In non-immersive VR, the simulated environment is displayed on a conventional computer with sound and graphics coming through the computer's speaker and monitor, and the interaction is controlled through a regular computer mouse. Augmented reality (AR) is an interactive experience that combines the real world and computer-generated content.

AVR technology argue that simulations that give students a sense of immersion can contribute to higher motivation and engagement, which are two main channels that influence student learning (Dafli, Arfaras and Bamidis, 2017; Klopfer and Squire, 2008); Mikropoulos & Natsis, 2011). Krokos, Plaisant, and Varshney (2019), for instance, suggest that students retain more information and can better apply what they had learned after participating in learning experiences that use VR. More recently, Makransky and Peterson (2021) presented a new model for describing the learning process when using immersive VR, which they refer to as the Cognitive Affective Model for Immersive Learning (CAMIL), and conclude that the use of this model, demonstrates that the use of immersive technology positively impacts the acquisition of knowledge. Hamilton, McKechnie, Edgerton, and Wilson (2020) argue that the skills learned through AVR technology could help trainees face real-world problems and scenarios.

Available research indicates that instruction using AVR is an effective mechanism to improve students' skills in technical education. Román-Ibáñez et al. (2018) studied the development of technical skills using VR. Their research shows that an immersive AVR pedagogical simulator of industrial robotic arms for engineering students could create an enhanced realistic experience for the students, avoiding stuttering and lag in the process. Likewise, Lampi (2013) finds that using virtual laboratories to teach students how to support computer networks can improve students’ network configuration accuracy and time compared to traditional training. Similarly, Zhou et al. (2018) implemented an educational application of computer assembly using AVR. The authors found that the application provided excellent usability and experience for users, although they did not see a difference in performance between reality learners and VR learners. The authors also found a significant positive correlation between the challenge levels and task completion time. Rupasinghe et al. (2011) find that students who trained in virtual laboratories develop better technical skills using a borescope to assess aircraft corrosion.

Finally, some authors indicate that training using AVR can is cost-effective. Dela Cruz and Mendoza (2018) studied the cost implications of using a virtual lab to teach students about pneumatics systems. The authors concluded that virtual labs are a cost-effective solution to address the lack of appropriate laboratory equipment. The study found that using VR reduces the cost of equipment maintenance and repair. Likewise, Stone, Watts, Zhong, and Wei (2011) and McLaurin and Stone (2012) indicate that virtual laboratories can develop welding skills as much as traditional laboratories but at a lower cost.

3. Description of the State System of Technical Education in Ecuador

The National Secretariat of Higher Education, Science, and Technology (SENESCYT) is the governing authority over public policies for tertiary education, including post-secondary technical and technological education. The technical and technological education system in Ecuador comprises 58 public TTIs and three conservatories distributed across the country. The most recent statistics indicate that enrolment in state TTIs reached 45,000 students in July 2022. In the first half of 2022, 80% of students enrolled in the presence-based modality, 8,000 students (17.8%) in dual programs, and 2.2% (1,000 students) in the hybrid/online modality. According to data from the second semester of 2020, the system of TTIs has 6,958 teachers, of which 56% work full-time. About 60% of all teachers have an undergraduate degree, 32% have a graduate degree, and 6.7% hold a vocational one.

Admission to programs offered by TTIs requires a secondary school certificate and is generally subject to an entrance examination. The programs take between 2 and 3 years to complete. Upon completion of the program, students are awarded a post-secondary attainment certificate. Ecuador's system of TTIs offer a total of 172 careers, including, Automotive Mechanics, Electronics, Logistics, Accounting, Early Childhood Development, Gastronomy, Business Administration, Floriculture, Hotel Trading and Tourism, Visual Arts, and Marketing, among others.

Lack of adequate infrastructure and laboratories hinder the development of technical skills among Ecuadorian students pursuing technical and technological degrees. About 45 thousand students use the infrastructure of the public TTIs every academic period. This infrastructure has important shortcomings. Almost half of the students enrolled in the system use facilities that are not owned by the SENESCYT. In fact, 62% of all the buildings (and land) of public TTIs belongs to the Ministry of Education. Existing facilities are used to offer technical and technological courses imparted by the SENESCYT, as well as vocational training courses offered by the Labor Training Service (or SECAP), an institution formerly dependent of the Ministry of Labor. Moreover, 52% of all public TTIs share laboratories with other education institutions while 27% do not have laboratories.

Within the system, there are a total of 16 "elite" public TTIs that have their own infrastructure and recently benefited from investments in workshops and laboratories. The Cotopaxi TTI, where the training pilot was implemented, is one of them. The Cotopaxi TTI was built in 2018 and provides academic offer to over 1,400 students in two shifts (day/night) and employs 86 teachers. The institute has modern facilities, including a library, an auditorium, an exhibition hall, laboratories, workshops, and computer laboratories. The TTI offers seven main academic tracks including Technology in Automotive Mechanics, Floriculture, Preschool Education, Electromechanics, Logistics, Electric Networks, and Climate Change. The institute also has a solid Information Technology team, capable of providing basic technical support to the AVR laboratory.

4. Detailed Description of the intervention

The intervention provides a group of students from the Motor Engine Repair Program at the Cotopaxi Technical Institute with training on generic V-6 gasoline engines using a laboratory that uses Augmented and Virtual Reality (AVR) technology. The laboratory allows students to experience 3D immersive (VR) animations through a desktop computer (zSpace). The zSpace desktop enables learners to see and manipulate the parts of the engine with 360-degree movement freedom. To access the simulations, students wear 3D glasses and use a stylus pointer (held-like pen), which allows learners to naturally move their heads and hands and rotate their wrists as they pick up, explore, and interact with virtual objects (Figure 1).

Figure 1: Virtual Laboratory's Tree Dimensional VR Experience

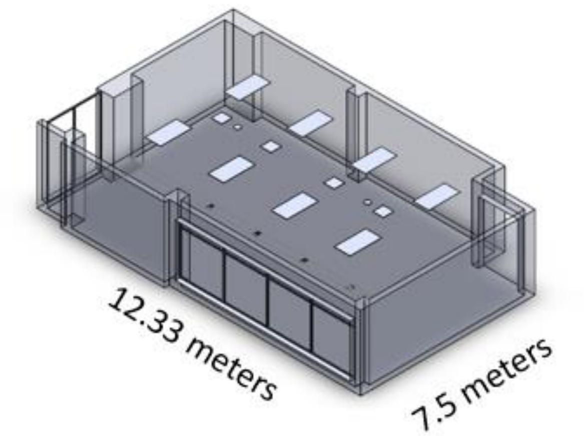
Each laboratory workstation includes one tablet that allows the student to access 2D (AR) animations using a series of markets (QR codes) printed in a guide available in every workstation (Figure 2). The AR experience and content provoke discussion between students. The markers offer problems for students to consider and provide explanations to confirm or correct the students' answers and expand on the students' discussion. Finally, each laboratory workstation includes a touch-mode tablet application that provides students with information through digital flash cards. The content provided by these cards intends to teach students the names and functions of parts, tools, and other basic concepts. Working in pairs, students quiz each other to master the target content. Text can be displayed and hidden easily to facilitate collaborative study.

Figure 2: Virtual Laboratory's Two-Dimensional (AR) Experience

The laboratory requires a room with a minimum of technical specifications to ensure its satisfactory operation. First, the classroom size must be between 75 and 90 square meters to fit a minimum of five workstations. Second, each workstation needs access to an electrical point. The zSpace desktop has an automatic multi-voltage source from 110v to 240v and consumes up to 3Amp. The room must have 20Amp power lines and, at most, the capacity to host six devices on each line. The luminosity of the classroom is an essential aspect ensuring the visibility of the 3D content offered by the zSpace desktop. If the zSpace desktop has direct exposure to sunlight, the room must include curtains to allow adequate visualization of the augmented reality elements. Classroom security (doors and windows) should be a priority, and it is recommended that the room have automated security systems and restricted access.

Based on these technical specifications, the Cotopaxi TTI assigned a room in its premises exclusively to implement the ActiVaR program. The room offered adequate conditions to implement the pilot: access to electrical points, internet, and a total area of 93 square meters (Figure 3). Staff from the Cotopaxi TTI made minor changes to the room to ensure it provided adequate lighting and electrical specifications required by the laboratory.

Figure 3: Laboratory Floor Plan – Cotopaxi TTI



Source: Cotopaxi TTI.

To facilitate this pedagogical approach, each laboratory workstation is designed to serve a maximum of 5 students each. Each group will work with a zSpace Desktop (3D immersive animation) and 2 tablets (2D animation and AR); students using the zSpace Desktop will work independently, while the students using the tablets will work in pairs to perform collaborative tasks (every 15-20 minutes students will switch devices). The laboratory at the Cotopaxi Technical Institute has the capacity to serve a maximum of 6 groups (or 30 students) simultaneously.

The zSpace application also has 3 operation modes for each of the learning modules: a *learning mode* which provides guided lessons, a *practice mode* which allows students to practice independently with instructional scaffolding removed, and an *assessment mode* which enables students to self-assess their learning. Regarding the tablets, the first application (touch screen) identifies engine parts and their functions, and the second application (augmented reality) present students with problem-solving activities that promote collaborative learning. The characteristics of the laboratory are as follow (Figure 4):[4]

- Each laboratory station is designed to serve a group of maximum 5 students.
- Each group works with a zSpace Desktop (3D immersive animation) and two tablets (2D animation).

[4] ANNEX 1 includes detail information about the costs associated to the intervention.

- Students using the zSpace Desktop work independently while students using the tablets work in pairs to perform collaborative tasks.
- Every 15-20 minutes, students switch devices (Total Class time: 90 minutes)
- Equipment for one VR Laboratory: (i) 10 AIO Pro zSpace (6 are kept in use and 4 are kept in stand-by in case of damage), (ii) 2 laptops zSpace (used by teachers to prepare the class and access training modules outside laboratory premises), (iii) 12 Samsung tablets (2 per station), (iv) the Auto-mechanics ActiVaR Application, (v) Accessories (audio speakers, headphones, and AR markers).

Figure 4: Laboratory's Main Technology Components and Layout per workstation

Source: Authors' elaboration.

The training consists of a nine-module curriculum on Motor Engine Repair. Each module was designed to be delivered within a 90-minute class. The objectives of **Module 1, "Engine Overview"** are to (i) identify major components of an Internal Combustion Engine; and (ii) describe how the internal combustion process works. **Modules 2 to 7** set the foundation for students to master engine components, including the functioning of intake systems, valve-trains, crankshaft and flywheel, fuel and injection systems, and pistons and connecting rods. The objectives of these modules are to (i) Identify the parts in each component assembly; (ii) Describe the function of each component; and (iii) Describe the operation of each component.

Module 8 covers the concept of Disassembly; by the end of the module students are expected to be able to (i) Describe the steps to disassemble an internal combustion engine and (ii) Identify the proper tools used to disassemble an engine. **Module 9** encompasses the concept of Assembly; this module's objectives are to (i) Describe the steps taken to assemble an internal combustion engine; and (ii) Identify the proper tools used to assemble an engine.

4.1. *Pedagogical Approach*

The traditional class rollout follows the approved course curricula for the Auto-mechanics Program. The institute revises the class curriculum every three years and submits it to the Higher Education Council for approval. The course curriculum includes three parts: (i) in-class instruction (54 hours per semester), (ii) hands-on practice with motors in the laboratory (42 hours), and (iii) independent work in groups (48 hours) to reinforce class assignments, practice with available equipment, etc. The AVR curriculum fully embeds in the "in-class" instruction portion of the course.

The pedagogical approach for the curriculum is based on blended learning models. The students' initial introduction to content is via AVR-mediated experiences, allowing a customized and integrated approach to learning. The AVR simulations are combined with learner-centered collaborative activities so that students are actively involved in knowledge acquisition. Instead of delivering direct instruction, teachers take on the role of facilitator, allowing them to personalize learning according to student performance, learning preferences and learning goals. As the responsibility of knowledge acquisition shifts to the students, higher level skills such as complex problem solving, social skills (e.g., coordinating with others), process skills (e.g., critical thinking, self-monitoring), systems skills (e.g., analysis, judgement, decision making) and cognitive abilities (e.g., problem solving, creativity) are deepened and reinforced. The pedagogical approach involves a change in the role of teachers, who become facilitators of the learning process. Instead of being the primary source of information, teachers guide students to acquire the information provided by the laboratory resources, encourage the proper use of the laboratory, encourage discussion and analysis, and clarify students' questions, doubts, and concerns. Finally, the AVR curriculum's main objective is to improve student's general knowledge of basic motor operations. Of course, mastering the content of the AVR may eventually help students acquire hands-on technical skills in motor repair, but this is beyond the scope of this training program. As a result, all the content in the AVR curriculum is a subset of the original course curricula for in-class instruction. As such, the intervention did not trigger curricular changes. However, the AVR curriculum involved a shift in the modality with teachers delivering the content of their in-class instruction. Each module involves approximately 90 minutes of instruction. Also, before exploring the learning modules, students receive additional 60 minutes of instruction to become familiar with the technology. As a result, of the original 54 hours of in-class instruction, teachers spend approximately 15 hours using the AVR curriculum (about 28 percent of the total in-class instruction time).

4.2. Program Implementation

The training program rolled out at the Cotopaxi TTI between December 2021 and May 2022. In December 2021, technical institutes in Ecuador began offering face-to-face classes after more than 22 months of total or partial closure due to the COVID-19 pandemic. The TTI implemented the training during the night shift with a group of 24 students.

The team developed a series of data collection tools to track the implementation of each training module (e.g., instruction time) and monitor student learning, the adequate application of the proposed pedagogy, and difficulties encountered in the classroom when using the laboratory. **A knowledge test**, based on the curricular competencies taught in the course, was collected at the beginning and end of the academic year. The questions in both exams were identical. After completing the training, students complete a survey collecting basic demographic information and assessing their training experience. Section 5.3 provides a more detailed description of the data collection instruments.

4.3. Monitoring Protocols

To ensure the adequate implementation of the AVR Virtual Laboratory, the research team established an iterative monitoring and evaluation (M&E) protocol to endure teachers delivered each module according to the designed instruction time and pedagogical approach. The AVR Virtual Laboratory's pedagogical approach was new to teachers, who required training and coaching to implement it as intended in the classroom. The protocol also helped teachers identify and debug implementation challenges and bottlenecks (e.g., a software/hardware malfunction) and collect information for future improvement and adaptation for the eventual scale-up of the program in other TTIs.

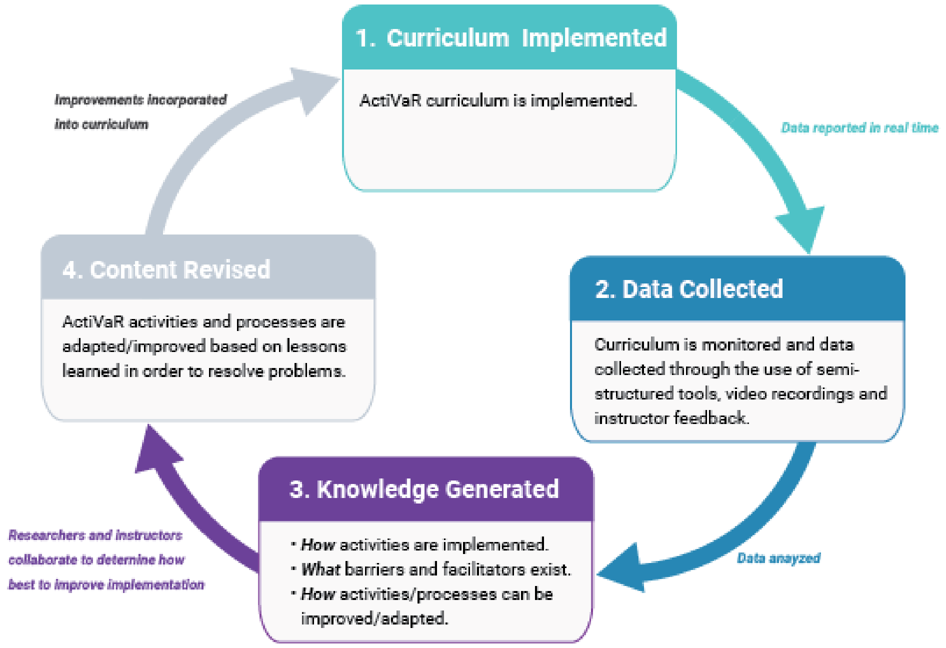
The monitoring protocol consists of a semi-structured questionnaire the teacher would complete and submit to the research team via email after imparting each learning module. The protocol inquires whether teachers experienced problems using the laboratory, if so, to detail the issue and if the teacher managed to resolve it. The protocol also collects information on what type of questions students asked and whether the teacher had enough information to address them. Finally, the protocol monitors the module instruction time, the time students use the AVR Virtual Laboratory, and the teacher's perception of the students' engagement during class.

Complementing the protocol, the research team collected video recordings of each class using the zSpace recording capabilities.[5] The idea of the class observations was to assess if teachers imparted each training module according to the Laboratory's Pedagogical Guide. For each module, the Guide specifies how much time students should interact with each technology devise in the classroom (individually and in groups), the time of teacher's magistral instruction, and the time students should conduct work individually and in groups. [6]

After each session, the research team observed the video and studied the data provided by through the protocol. The video recording allowed the researcher team to virtually observe and validate if teachers in the Cotopaxi TTI implemented each training module according to the implementation manual. The visuals and the semi-structured data were examined during the process of implementation and triggered a dialogue with the teacher. These discussions help enrich the overall learning process, gain deeper understanding of the challenges and barriers of implementation, and search for "just in time" solutions and adaptations as soon as problems were noticed. For example, the examination of one of the video recordings showed that the audio of the zSpace was not turned on and no speakers or headphones were used or available to students. The audio in the zSpace is designed to reinforce the visuals and therefore is key to ensure a good understanding of the content. This problem was corrected as soon as it was noticed by deploying headphones and speakers to the Cotopaxi lab. Section 4.4 presents the implementation results, describing the positive and negative deviations in the implementation of the AVR Virtual Laboratory and the solutions or adaptations incorporated to improve the implementation and therefore, the overall quality of the experience. Figure 5 provides a graphic description of the implementation M&E protocols. Annexes 2 and 3 present the Monitoring and Evaluation Sheet and the links to the monitoring videos generated using the zSpace.

[5] The research team asked students and teachers for their verbal consent to participate in this research project.
[6] The Pedagogical Guide is available upon request (English / Spanish).

Figure 5. Iterative Monitoring and Evaluation System to Track the Implementation of the AVR Virtual Laboratory



Source: Authors' elaboration.

4.4. Implementation

The pilot generated several lessons that allowed the team to improve the implementation of the Virtual Labs and adjust implementation guidelines according to these findings.

First, it was critical to integrate the AVR curriculum into the course curriculum and lesson plans. In Ecuador, based on the class curricula, each course develops a weekly teaching-learning plan that describes the content areas teachers should cover during in-class instruction and the practical exercises to do in laboratory times. The course curriculum also specifies the number of hours for instruction, practice, and independent work, as mentioned before in section 4.1. The team worked with the instructors to embed the AVR curricula in the weekly lesson plans to ensure a cohesive approach to integrating the AVR laboratory within the current course. This exercise involved determining not only in which week of the academic year the AVR laboratory would be used and for how many hours, but also specifying how exactly it complemented the rest of the content areas included in the course. The integration of the AVR modules in the course curriculums also signified that the use of Virtual Lab became a requirement to pass the auto-mechanic course, which proved to be a successful mechanism to increase the take-up of the laboratory. To facilitate the process, the research team developed a

Pedagogical Manual that contains a guide to the use of the technology and the pedagogical approach teachers should follow for the instruction of every module. For each module, the manual includes (i) a description of the module, (i) the main competencies developed by the module, and (ii) a detailed teaching methodology that guides teachers' use of time. The manual explains the objectives and roles of each laboratory device and the content it brings to the lesson.

Second, it was necessary to adequately train teachers and students on how to use the technology prior to beginning imparting its academic content in the classroom. Learning to use the technology of the AVR Laboratory takes time. As such, it was necessary to dedicate enough time to provider students and instructors adequate training to use it. Teacher training was implemented in two parts. Part 1 focuses on the technical use of the Zspace Hardware, including assembly, equipment, and devise calibration, use, and maintenance. The contractor who supplied the equipment delivers this training as part of its contractual arrangements (3-hour workshop). Part 2 focuses on pedagogy and entails (i) the revised course pedagogical approach (i.e., revised roles of teachers), (ii) the use of the AVR software and accessories for adequate instruction, and (iii) class dynamics, including the roles of the teachers and the rotations that take place to expose students to each device (zSpace vs. Tablets). This training was led by a staff member of Namseul’s University, who was involved in the development of the AVR course and with ample experience using AVR technology for instruction – in close coordination with the World Bank research team.

After a series of class observations, it became evident that students needed more time than originally planned to learn how to use the technology and the software, and to get familiar and feel comfortable operating the system. To accommodate this need, the team decided to add a full extra lesson for this purpose during the first week of instruction. Teachers also extend the instruction time by 20 to 30 minutes during the first 3 weeks to review key operational features of the technology with students.

Instructors also needed time to master using the laboratory and learn how to address and answer questions from students. Teacher training should focus on how to use the technology and the Pedagogical Guide and include hands-on activities with practical exercises and permanent coaching during the semester to allow instructors to receive feedback and guidance on how to resolve specific emerging issues during the AVR laboratory implementation

Third, it was important for teachers to give special attention to students who were less technology savvy and used to collaborative peer-to-peer learning. Class observations revealed that older and female students were less prone to use technology and participate in group discussions. As mentioned before, the pedagogical approach of the laboratory includes group work. While one student operates the zSpace technology, others observe, listen, use tablets, and answer questions. Class observations revealed that, during group sessions, female and older students were less prone to use the primary technology device (zSpace), limiting their opportunities to take advantage of the laboratory. This observation triggered discussions with the instructors to find ways to incentivize and monitor that all students take equal benefit of the laboratory. The instructor began to monitor the use of the technology more closely by gender and age groups and encouraged and enforced rotations so that each student would use the zSpace and other available technology devices. The instructor began to reinforce the importance of practicing to master the content and highlight that making mistakes represent an opportunity to learn and improve. Teachers reminded students regularly about the rotation methodology for using the different devices (zSpace, tablets), especially in the first few weeks of the course. The novelty of the technology and the curiosity of students interested in exploring other modules or features of the zSpace contributed to delays in the rotation among devices. Extending the time to practice with the technology during the first few weeks also helped students get more familiar with it and help them get used to the routine of the class.

Finally, the research team identified areas for improvement for subsequent laboratory implementation and scale-up. For instance, as students went over modules 8 and 9, the research team realized they needed more time to use zSpace than initially planned to cover all the content. On the contrary, modules 1 and 2 took less time to complete than expected, requiring the teacher to add instruction time to reinforce the topics covered. Also, in some modules, instructors found it helpful to use AR tablets and markers to analyse and discuss content (e.g., possible causes of breakdowns in the motor) before exposing students to the zSpace, where they would experience closely the contents learned. During implementation, the research team also learned of some technical areas requiring improvement. For instance, students reported difficulties listening to the instructions provided by the zSpace because headphones were not available as part of the equipment supplied for the Virtual Labs. Once the research team identified the problem, it added speakers to the zSpace. The instructor reported that adding speakers allowed students to focus better on the content (and avoid distractions) and improve their understanding of the content. During implementation, students and instructors reported other software bugs, mistranslation, and typos in the text, which were subsequently corrected and addressed.

5. Research Methodology

5.1. Research Questions

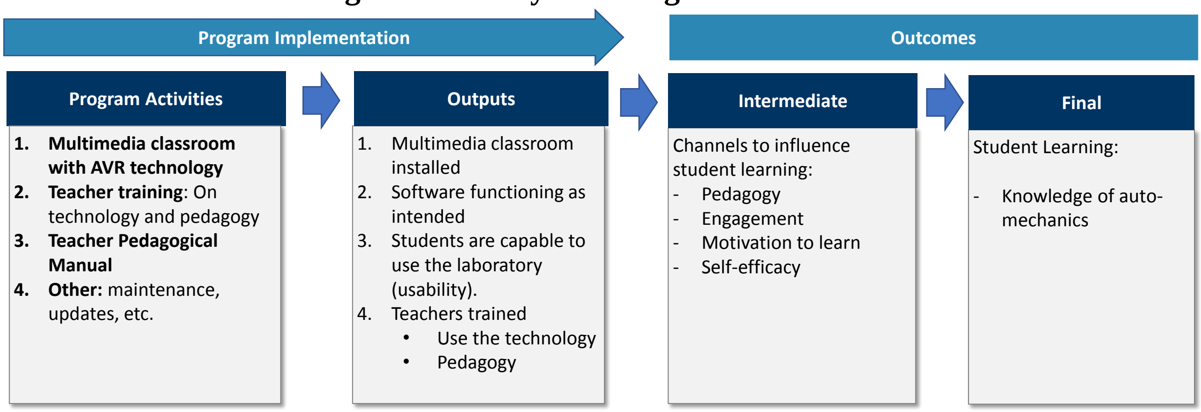
The value-added evaluation's main research questions are the following:

- Can proficiency-based training using an AVR Virtual Laboratory improve students' learning in Auto-mechanics?
- To what extent does student learning correlate with their perceptions of how the AVR Virtual Laboratory influences their engagement and motivation to learn?

5.2. Theory of Change

Theoretical and empirical evidence supports the use of immersive training to improve student learning (Angel-Urdinola, Castillo-Castro, & Hoyos, 2019). Based on the literature, we identify two main channels through which the use of the auto-mechanics Virtual Laboratory could affect student learning: (i) the pedagogical approach, and (ii) the extent to which the immersive features of the laboratory generate student engagement, self-efficacy, and motivation (Mikropoulos, & Natsis, 2011; Kavanagh, Luxton-Reilly, Wuensche, & Plimmer, 2017; Madathil et al., 2017) (Figure 6).

Figure 6. Theory of Change of ACTIVAR



Source: Authors' elaboration.

Using a classic academic achievement production function (see Glewwe and Kremer 2006), let's denote stent learning (*L*) to be a function of years of schooling attained (*YS*), students' characteristics (*X*), school and teachers' characteristics (*Y*), and household characteristics and access to education inputs (*Z*).

$$L = f[YS, X, Y, Z] \quad (1)$$

The AVR Virtual Laboratory is expected to have an effect in student's characteristics (X) through higher motivation, engagement, and self-efficacy (M) as well as in teachers' characteristics (Y) through the pedagogical approach (P) and type of media used for instruction (AVR), so that:

$$L = f[YS, g(M, P, AVR), Z] \quad (2)$$

5.2. Empirical Strategy

Student learning in the domain of auto-mechanics was assessed using tests prior and after the completion of the training (details on the instruments used are provided in section 5.3). A first exercise will be to determine if the difference in the average scores of the test prior and after the training are statistically different using distributional and ANOVA analysis.

Learning for each participating student (L_i) was estimated as:

$$L_i = Posttest_i - Pretest_i \quad (3)$$

After the training was completed, students responded to a set of questions (see Section 5.3) assessing the extent to which (i) they felt engaged with the training (E); (ii) the technology used was well designed and easy to use (U), and (iii) the course had positive effects on their motivation to learn (M).

Finally, the following linear equation is used to assess students' main learning correlates based on the available information at the end of the training:

$$L_i = \beta_1 Age_i + \beta_2 X_i + \beta_3 E_i + \beta_4 U_i + \beta_5 M_i + \varepsilon_i \quad (4)$$

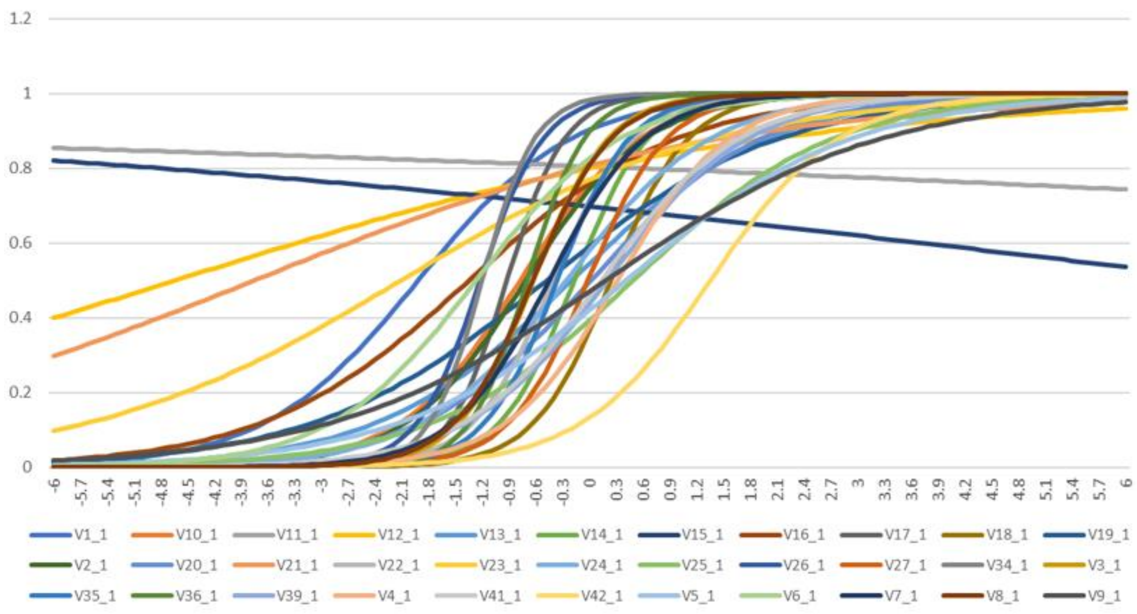
Where ε_i represent independent and identically distributed errors. Since the training was implemented in only one technical institute and by the same instructor, covariates Y and Z are invariant.

5.3. Instruments and scales

The study uses a series of instruments to answer the main research questions. The instrument to assess student learning consists of an academic test designed to evaluate student knowledge in the domain of auto-mechanics (ANNEX 4). The test evaluates a series of content items imparted by the training and included in the course curriculum. A variety of questions were developed to target three areas of Bloom's Taxonomy: "remember", "understand" and "apply". The test included 46 items: a combination of multiple choice (n=25), open-ended questions (n=20), and a small essay that measures knowledge of basic facts and concepts and deeper levels of comprehension and understanding. The first 25 multiple choice questions measure learning at a "remember" level. The 20 short answer questions measure both "remember" and "understand". The last section uses an essay question to measure how well students can "apply" the learning. To assign grades, teachers reviewing the tests used a grading rubric prepared by two content experts in the field of motor mechanics. The test was proctored to students using an online platform.

Figure 7 presents a simple psychometric assessment of all dichotomous questions included in the knowledge assessment. The Figure shows that capacity of the different questions to discriminate between "novices" and "experts" (the steeper the slope, the higher discriminatory power of the item). Results indicate that, apart from questions 11 and 15, most items in the assessment have positive discriminative power. Results from this analysis will also guide further revisions / updates to the knowledge assessment in anticipation of the planned impact evaluation of intervention.

Figure 7. Psychometric Assessment of Dichotomous Questions [Knowledge Test]



Source: Authors' elaboration.

A student survey was collected at the end of the semester. The survey includes basic demographic information of the student (e.g., gender, age), along with some information about their academic status (e.g., semester in which they are enrolled), some easy-to-collect proxies of the socioeconomic status of the student (e.g., whether the student works part time, full time, or only studies, and the student's mother education). [7]Furthermore, the survey included battery of questions from different scales described below.

The study also uses an adapted version of the Web-Based Learning Tool (WBLT) to assess student's overall engagement with the choice of technology used (see Kay, 2011). The WBLT has been widely used in the literature to evaluate the efficacy of digital learning tools for education. The tool consists of 13 self-reported questions asking participants to rate their perceptions (Likert scale 1-5) of how digital tools help their learning process, how well designed these tools are, and how engaging they are (ANNEX 5). Furthermore, Motivation was measured with a modified version of the Science Motivation Questionnaire (ANNEX 6) from Glynn, Brickman, Armstrong & Taasoobshirazi (2011). This has been modified to encompass auto-mechanics, rather than science. It measures three main components of motivation: intrinsic motivation, self-efficacy, and self-determination. Each of these are measured on a five-point Likert scale. The System Usability Scale (Brooke, 1996) is a 10-item questionnaire on a scale of 1-5 which measures the usability of a variety of products, including hardware (ANNEX 7). All scales in the study were constructed by adding the values of the items, reversing negative statements, and generating a total score.

Since the knowledge test was developed for the purpose of this study, and the different surveys and scales were tested for the first time in Ecuador, it was important to assess the internal consistency and reliability of the instruments. The internal consistency reliability measures the degree of interrelationship or homogeneity among the items on the different assessments, and whether they are consistent with one another and measuring the same thing. Specifically, we used the "Internal consistency reliability – Cronbach's alpha" which generates a value that ranges from 0 to 1 with values close to 1 indicating the items within the construct are more related to each other. The general rule of thumb is that a Cronbach's alpha of .65 and above is consider good. [8] The internal consistency results are presented in Table 1. Overall, the results reveal that most assessments tools have good internal consistency reliability except for the "intrinsic motivation" sub-scale, which will need to be reviewed and improved. Most

[7] Students' employment status can positively affect learning if the work they are engaged in pertains to auto-mechanics. However, it could also affect learning negatively if students who work have time constraints for independent study.

[8] In the Cronbach's alpha formula $\propto = N\bar{c}/\bar{v} + (N-1)\bar{c}$, N is equal to the number of items, c is the average inter-item covariance among the items and v equals the average variance. Thus, alpha improves when N of items increase, and the average inter-item covariance increase.

instruments, except for the student survey, were translated from English into Spanish. Native Spanish-speaking professors at the Cotopaxi institute validated the translations. The research team then piloted the instruments with a group of students before the rollout of the evaluation and made necessary adjustments based on the feedback obtained.

Table 1: Internal Consistency Results of the Different Scales Used in the Survey

Scale	Items	Number of Items	Internal Consistency: Cronbach's Alpha
Knowledge Test – Auto-mechanics	Multiple choice & open ended	45	0.90
Scale 1: Web-based Learning Tool (WBLT)	q14a-q14l	12	0.92
Learning	q14a-q14e	5	0.83
Design	q14f-q14i	4	0.85
Engagement	q14j-q14l	3	0.72
Scale 2: Usability	q15a-q15i	9	0.78
Scale 3: Motivation	q16a-q16o	15	0.90
Intrinsic motivation	q16a-q16e	5	0.54
Self-efficacy	q16f-q16j	5	0.91
Self-determination	q16k-q16o	5	0.81

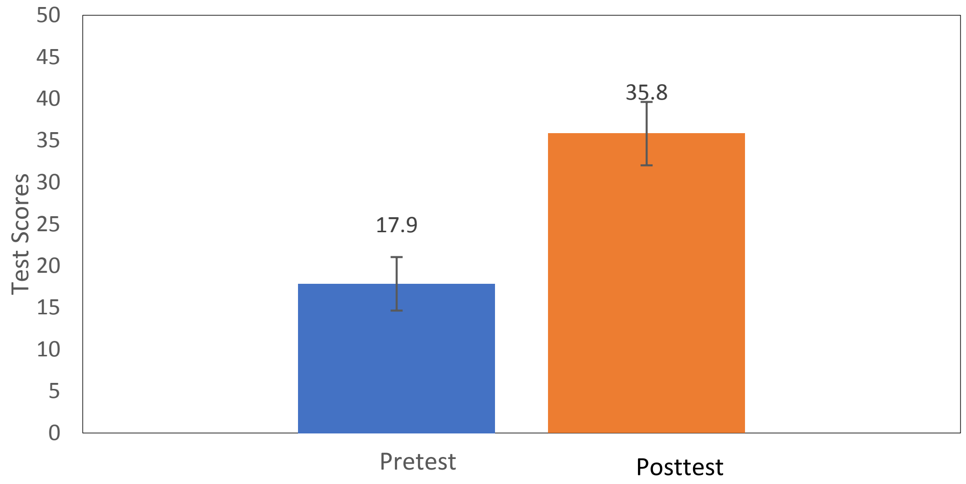
Source: Author's estimates.

6. Main Results

Results in Figures 8 and 9 indicate that, on average, post-test scores were higher than pre-test scores (almost twice as large). Differences are statistically significant using the sample's confidence intervals (Figure 8). These results are confirmed by the repeat measure ANOVA estimates, which indicate that the difference between the pre and post-tests is statistically significant a closed to 17 points in favour of the post-test. Furthermore, the distribution is post-tests stochastically dominates that of pre-tests, suggesting that all students who took the course displayed positive learning (Figure 9).[9]

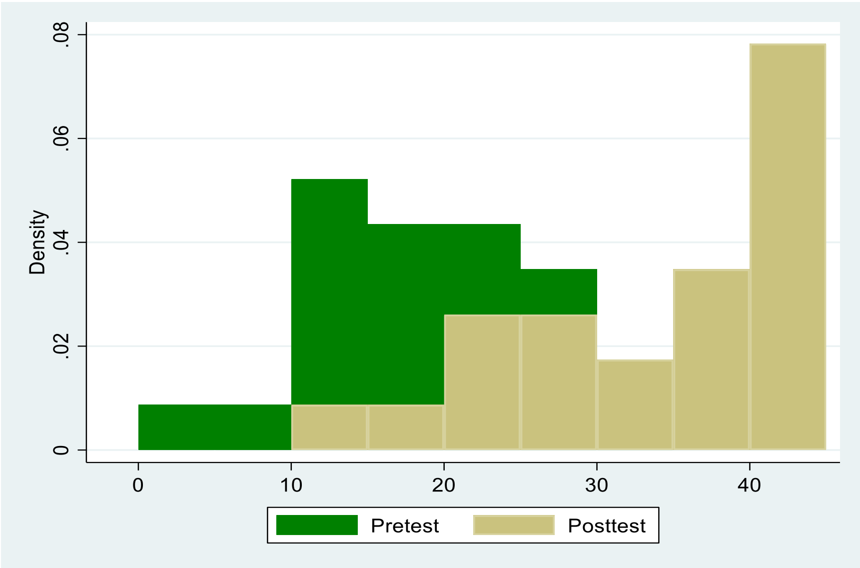
[9] We also estimated the Wilcoxon matched-pairs signed-rank test for the pretest and posttest. The null hypothesis, which assumes that both distributions are the same, was rejected: z = -3.897, z = -3.897, Prob > |z| = 0.0001.

Figure 8: Distribution Histograms [Pre and Posttest]



Source: Author's estimates.

Figure 9: Distribution Histograms: Pre and Post tests



Source: Author's estimates.

Students in the sample come mainly from low socioeconomic families. Most students (72 percent) indicates that the highest level of maternal education is "complete primary or below". All students in the sample reported to work and study at the same time, of which half report to work full time. Most students in the sample are male (91%). The students' age ranges from 19 to 38 years old (the average age is 24). Table 2 provides an average pre-test and post-test results according to a series of observable characteristics of the students. Results indicate that, for all groups, results in the post-test were higher than in the pre-test. Differences between post-test and pre-test were slightly larger students who were younger, from more educated households (proxied by the level of education of the student's mother) and work part-time. Of course, due to the limited sample size, these results should be interpreted with care and are sensitive to "outlier effects."

Table 2: Descriptive Statistics [Pre and Posttest]

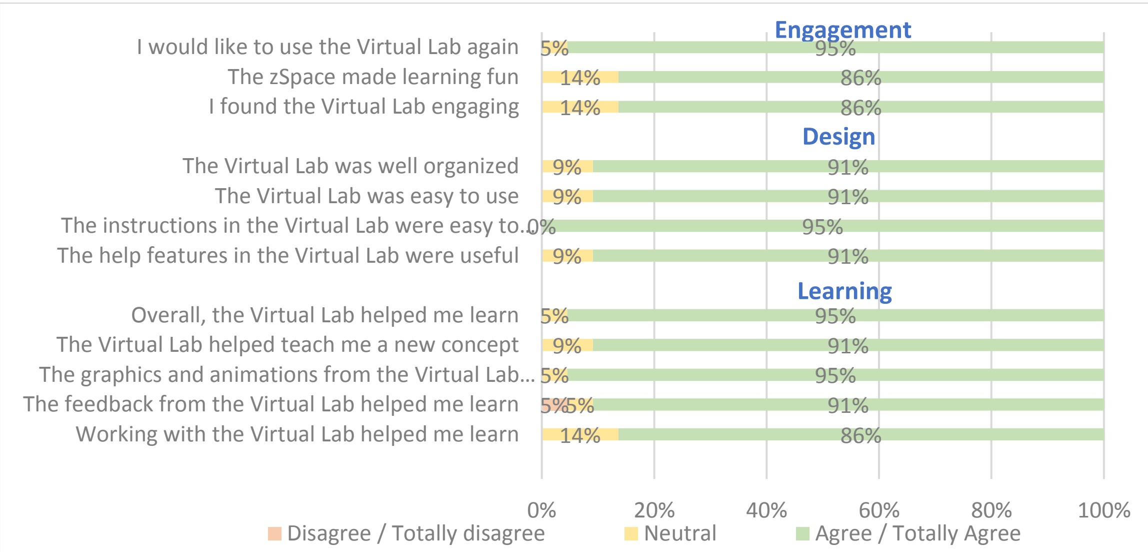
Group	Pretest			Posttest		
	Mean	*SD*	N	Mean	*SD*	N
All	18.1	7.66	22	34.8	9.08	22
Age						
19-23	15.0	7.01	10	32.6	7.36	10
24-38	20.5	7.74	11	38.77	7.09	11
Mothers' education						
None or incomplete primary	18.1	6.33	8	34.5	7.46	8
Complete primary	19.9	7.43	7	37.3	8.08	7
Secondary	15.2	10.17	6	35.9	8.71	6
Work condition of the student						
Studies and works part time	16.1	4.08	10	34.6	7.53	10
Studies and works full time	19.5	9.95	11	37.0	8.06	11

Source: Author's estimates.

6.1. *WBLT Survey Results*

Students' responses indicate high levels of student engagement with the Virtual Lab's technology. A great majority of students would like to use this technology again, and they found it fun and engaging. Most students found the Virtual Lab easy to use and follow in terms of technological design. Finally, most students also indicated that the technology used in the virtual laboratory was conducive to learning, helpful to understanding new concepts, and provided valuable feedback and graphic features which were useful to learn (Figure 10).

Figure 10: WBLT Student Responses (N=21)



Source: Author's elaboration.

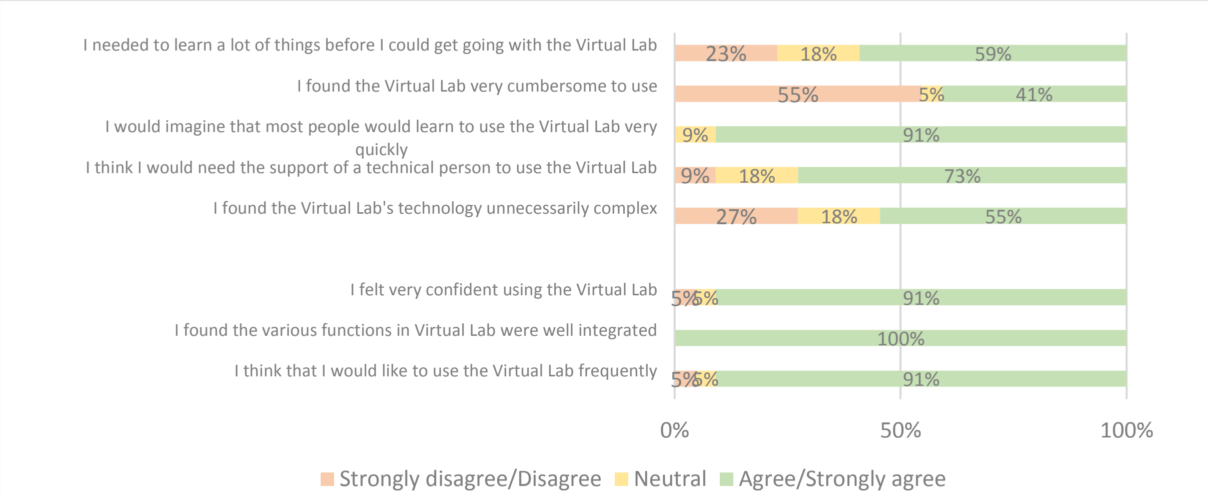
The survey also included open-ended questions asking students what they liked most about the training they received in the Virtual Laboratory. Below are some of their answers:

- *"The ease of knowing the parts that make up an engine"*
- *"The ease of learning and doing practice and theory at the same time"*
- *"That it is easy to use and that it is very good for learning motors"*
- *"Its programming and how easy it was to Navigate the ACTIVAR"*
- *"The explanation of each part of the engine"*
- *"The way to be able to know the different parts of an internal combustion engine, in addition to the way and the correct order to assemble an engine"*

6.2. Usability

Results from the usability survey indicate that a significant share of students (about 60 percent) found the Virtual Laboratory cumbersome to use, while about one-third found it unnecessary complex (Figure 11). About 23 percent of all students felt they needed training before using the laboratory, and about 10 percent indicated that users need a technical support person to assist them in using the technology. Nonetheless, after completing the training, most students felt confident using the virtual laboratory and expressed that they could use it frequently. These results highlight the importance of providing students with training and exposing them to the technology before using the laboratory for instruction.

Figure 11: Usability Survey Responses (N=21)



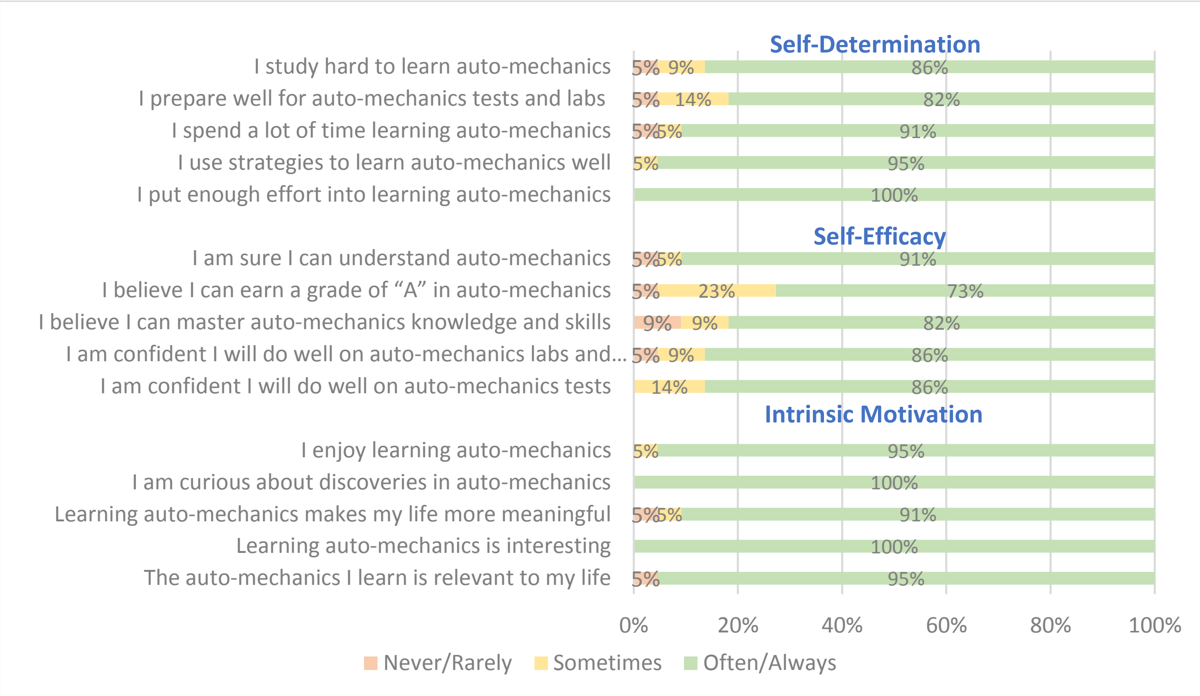
Source: Author's elaboration.

In the open-ended questions, students reported difficulties operating the virtual laboratory. Some students reported not liking the hand position required to handle the optical pen and that it takes time to use it properly. Students who wore glasses indicated that using the z-space 3D glasses was uncomfortable on top of their own. The team plans to address some of these problems during scale-up and evaluation. For instance, students need to know the importance of sitting close to the z-space and keeping a 90-degree angle for the optical pen to work efficiently. The team will also inform instructors that the lab equipment includes clip-on z-space lenses for students already wearing glasses.

6.3. Motivation

Students' responses indicate high levels of student motivation to continue to learn auto-mechanics. Most students reported being willing to make necessary efforts to learn auto-mechanics, felt proficient and confident they could do well in their auto-mechanic coursework and reported high levels of intrinsic motivation to continue to learn about the subject (Figure 12).

Figure 12: Motivation Survey Responses (N=21)



Source: Author's elaboration.

Students also provided additional qualitative information about their motivation in relation to the training they received in the Virtual Laboratory. Below are some of their comments:

- *"It is striking and interesting"*
- *"It was very interesting, and you learn in a better way since it attracts much more attention"*
- *"Quite interesting and innovative"*

6.4. Learning correlates

This section provides the results of a series of linear regressions assessing students' main learning correlates using available data collected by the research team on students' socioeconomic characteristics and through the different surveys and instruments described above. Due to the limited sample size, including all indexes and socioeconomic data in a single regression was problematic as it would generate high collinearity, especially with subindices that proxy similar aspects using different instruments, such as engagement and motivation. Thus, the study includes three different regressions models. Model 1 assesses the relationships between student learning and their observable socio-economic characteristics. Model 2 assesses the effects of the WBLT sub-indexes in student learning. Model 3 assesses the effects of usability and motivation on student learning. As described in the methodology sections, all sub-indexes included in the analysis were constructed so that a higher level of the index is indicative of a desired outcome. Results are summarized as follows.

Model 1 results indicate that observable socio-economic characteristics did not appear to be significant correlates of learning. In particular, the age of students (older or younger than 23 years old), mothers' higher level of education attainment (versus no education), and the student's work status (full-time vs. part-time worker) do not appear to have a statistically significant relationship with student learning (Table 3). The low R-square indicates that the variables used are not good predictors overall of the observed learning variance.

Table 3: Exploratory relation between learning and some student and family characteristics

	(1) Learning	(2) Learning	(3) Learning
Older than 23 years old dummy	0.623		
	(3.964)		
Mothers' education: Primary (vs. no education)		4.000	
		(5.430)	
Mothers' education: Secondary (vs. no education)		6.550	
		(6.068)	
Study and work full time (vs. work part time)			-1.000
			(4.010)
Constant	17.650***	14.200***	18.500***
	(2.672)	(4.803)	(3.066)
R-square	0.001	0.074	0.003
N	21	21	21

Source: Author's elaboration.

Note. Standard errors included in parenthesis. Coefficients with *, **, *** indicate they are statistically significant with 10, 5, and 1 percent confidence interval.

Model 2 results indicate that two of the three WBLT sub-scales have a statistically significant association with student learning. Students who self-reported higher levels of perceived learning are associated with higher learning gains. Moreover, students who self-reported higher levels of engagement with the virtual laboratory are also associated with higher learning scores. Results, however, do not show any association between students' self-reported "design index" (a proxy for the usability of the laboratory) and student learning (Table 4). Although these results cannot explain causality, they are consistent with the theoretical idea that immersive training, such as that provided by the AVR virtual laboratory, contribute to increase meta-cognition and learning engagement of students, which are essential factors that can influence their academic performance. Model 2 displays a higher (albeit still low) R-square indicating that WBLT sub-scores are better predictors of the observed learning variance than the observed socio-economic characteristics included in Model 1.

Table 4: Exploratory relation between the WBLT sub-scales and student learning

WBTL	(1) Learning	(2) Learning	(3) Learning
Learning sub-scale	1.451**		
	(0.674)		
Design sub-scale		1.211	
		(0.797)	
Engagement sub-scale			3.016***
			(1.052)
Constant	-15.117	-3.585	-21.369
	(15.530)	(14.229)	(13.681)
R-square	0.174	0.097	0.246
N	21	21	21

Source: Author's elaboration.

Note. Standard errors included in parenthesis. Coefficients with *, **, *** indicate they are statistically significant with 10, 5, and 1 percent confidence interval.

Finally, model 3 results indicate students who self-reported higher levels of perceived intrinsic motivation and self-efficacy are associated with higher learning gains. However, there is no significant association between the usability index of the self-determination index and student learning. These results of Model 3 are consistent with those of Model 2.

Table 5: Exploratory relation between Usability and Motivation sub-scales and student learning

	(1) Learning	(2) Learning	(3) Learning	(4) Learning
Usability Scale	-0.363			
	(0.426)			
Intrinsic Motivation		1.138*		
		(0.609)		
Self-Efficacy			0.840*	
			(0.471)	
Self-Determination				0.460
				(0.928)
Constant	27.992	-9.178	-0.496	7.733
	(12.441)	(13.599)	(10.153)	(21.195)
R-square	0.028	0.064	0.129	0.018
N	21	21	21	21

Source: Author's elaboration.

Note. Standard errors included in parenthesis. Coefficients with *, **, *** indicate they are statistically significant with 10, 5, and 1 percent confidence interval.

7. Conclusions

Educators are starting to rely on Augmented and Virtual Reality (AVR), to develop learning experiences that would otherwise not be easily accessible to students. Virtual laboratories can provide students with opportunities for practical training without pressure or danger and allow for repeated interventions.

In this context, this study provides an in-depth assessment of using Augmented and Virtual Reality (AVR) to deliver training in auto-mechanics to a cohort of second-semester students enrolled in the Technology in Automotive Mechanics program at the Cotopaxi Technical Institute in Ecuador. This auto-mechanic virtual laboratory is the first of its kind in Ecuador's State Technical and Technological Institutes network. The training program seeks to improve students' learning in the domain of auto-mechanics after being exposed to the basic principles of the operation of internal combustion engines. The curricula consist of nine competency-based learning modules imparted within one academic semester. A multidisciplinary group of professors developed the curriculum and software for this virtual lab, education and multimedia experts, and programmers from the Cotopaxi TTI, the World Bank, and Namseoul University, a leader in VR development, research, and education in South Korea.

The study reveals that using Augmented and Virtual Reality (AVR) to deliver training in auto-mechanics is not an easy task. Access to a virtual laboratory does not ensure that teachers and students will use it properly, as changing teaching practices requires training, implementation support, and coaching. One of the main lessons of the study is that any new content provided through new technologies requires careful integration of the content into the existing curriculum and teaching plans. To do so, it is necessary to adequately train teachers on how to use the technology before imparting its academic content in the classroom. Before any instruction, it is also essential to dedicate enough time to help students become familiar with and comfortable operating new technologies. New technologies trigger new pedagogical approaches. In this case, the virtual laboratory promoted collaborative work and discussion and prompted students to use different technology devices. Female and older students displayed difficulties adapting to this new pedagogical approach. As such, instructors must find ways to incentivize student participation and monitor that all students benefit equally from the laboratory.

To assess the effects of the training on learning outcomes, students completed a pre-test and a post-test to quantify the training's value added to student learning. Results indicate that students who participated in the course had statistically significant learning gains measured by the percentage increase in the post-test relative to the pre-test. Results also suggest that students exposed to the training reported high levels of engagement and motivation with the AVR training and reported favorably on the design and usability of the technology. Most students in the study would like to use this technology again, and they found it fun and engaging. Students' responses also indicate high levels of student motivation to continue to learn auto-mechanics.

Results indicate that Virtual Laboratories constitute a promising pedagogical and technological tool to help teachers develop students' learning in the field of auto-mechanics. To quantify the impact of the virtual laboratory on student learning, the government of Ecuador may consider scaling up the intervention and conducting a randomized control trial, whereby some students selected randomly would use the virtual laboratory (treatment group) while others (the control group) traditional instruction. Finally, it is worth mentioning that the results of this evaluation seek to inform the ongoing higher education policy in Ecuador about investments in infrastructure, laboratories, and equipment and accelerating access to digital learning, as well as the World Bank's overall engagement in EdTech for education.

References

Angel-Urdinola, D., Castillo-Castro, C., & Hoyos, A. (2021). Meta-Analysis Assessing the Effects of Virtual Reality Training on Student Learning and Skills Development. Policy Research Working Paper; No. 9587. World Bank, Washington, DC.

Bloom, B. S., & Krathwohl, D. R. (1956). Taxonomy of educational objectives; the classification of educational goals by a committee of college and university examiners. Handbook I: Cognitive Domain. New York, NY; Longmans, Green.

Brooke, J. (1986) SUS—A Quick and Dirty Usability Scale. Usability Evaluation in Industry, 189-194.

Buiu, C., & Gânsari, M. (2014). Designing robotic avatars in Second Life - A tool to complement robotics education. In IEEE Global Engineering Education Conference, EDUCON, 1016–1018. IEEE Computer Society.

Dafli, A., Arfaras, G., Bamidis, P.D. (2016). Versatile Mixed Reality Educational Spaces - A Medical Education Implementation Case, 15th International Conference on Ubiquitous Computing and Communications and 2016 International Symposium on Cyberspace and Security (IUCC-CSS),132-137.

De la Cruz, D. R., & Mendoza, D. M. (2018). Design and development of virtual laboratory: A solution to the problem of laboratory setup and management of pneumatic courses in bulacan state university college of engineering. In 2018 IEEE games, entertainment, media conference (pp. 1–23). IEEE.

Dill, D. D., & van Vught, F. A. (2010). National Innovation and the Academic Research Enterprise: Public Policy in Global Perspective. Johns Hopkins University Press.

Ferreyra, M.M., Avitabile, C., Botero, J., Haimovich, F., & Urzúa, S. (2017). At a Crossroads: Higher Education in Latin America and the Caribbean. Directions in Development—Human Development. World Bank, Washington, DC.

Glewwe, P., and M. Kremer. (2006). "Schools, Teachers, and Education Outcomes in Developing Countries," in E. Hanushek and F. Welch, eds., Handbook of the Economics of Education: Vol 1. North Holland

Glynn, S. M., Brickman, P., Armstrong, N., & Taasoobshirazi, G. (2011). Science motivation questionnaire II: Validation with science majors and nonscience majors. *Journal of Research in Science Teaching*, *48*(10), 1159–1176.

Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: a systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computers in Education, 8*, 1–32.

Johnson, L., Adams Becker, S., Cummins, M., Estrada, V., Freeman, A., & Hall, C. (2016). NMC Horizon Report: 2016 Higher Education Edition. Austin, Texas: The New Media Consortium.

Kavanagh, S., Luxton-Reilly, A., Wuensche, B., & Plimmer, B. (2017). A systematic review of Virtual Reality in education. *Themes in Science and Technology Education, 10*(2), 85-119.

Kay, R. (2011). Evaluating learning, design, and engagement in web-based learning tools (WBLTs): The WBLT Evaluation Scale. *Computers in Human Behavior*, *27*(5), 1849-1856.

Klopfer, E., & Squire, K. (2008). Environmental detectives-the development of an augmented reality platform for environmental simulations. *Educational Technology Research and*

Development, *56*(2), 203–228.

Krokos, E., Plaisant, C., & Varshney, A. (2019). Virtual memory palaces: immersion aids recall. *Virtual Reality*, *23*(1), 1–15.

Lampi, E. (2013). The effectiveness of using virtual laboratories to teach computer networking skills in Zambia (Doctoral dissertation, Virginia Tech).

Madathil, K. C., Frady, K., Hartley, R., Bertrand, J., Alfred, M., & Gramopadhye, A. (2017). An empirical study investigating the effectiveness of integrating virtual reality-based case studies into an online asynchronous learning environment. *Computers in Education Journal*, *8*(3), 1-10.

Makransky, G., Petersen, G.B. (2021). The Cognitive Affective Model of Immersive Learning (CAMIL): a Theoretical Research-Based Model of Learning in Immersive Virtual Reality. *Educational Psychology Review 33* (3), 937–958.

Mayer, R. (2009). Multimedia Learning. Cambridge University Press.

Mayer, R. (2014). Cognitive Theory of Multimedia Learning. In R. Mayer (Ed.), The Cambridge Handbook of Multimedia Learning (Cambridge Handbooks in Psychology, pp. 43-71). Cambridge: Cambridge University Press.

McLaurin, E. J., & Stone, R. T. (2012, September). Comparison of virtual reality training vs. integrated training in the development of physical skills. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 56, No. 1, pp. 2532-2536). Sage CA: Los Angeles, CA: SAGE Publications

McMahan, A. (2003). Immersion, Engagement, and Presence. In Wolf and Paren (Ed.). The Video Game Theory Reader. New York: Routledge. 67-86.

Mikropoulos, T. A., & Natsis, A. (2011). Educational virtual environments: A ten-year review of empirical research (1999–2009). Computers & Education, 56(3), 769-780.

Mount, N. J., Chambers, C., Weaver, D., & Priestnall, G. (2009). Learner immersion engagement in the 3D virtual world: principles emerging from the DELVE project. Innovation in Teaching and Learning in Information and Computer Sciences.

Román-Ibáñez, V., Pujol-López, A. F., Mora-Mora, H., Pertegal-Felices, L. M., & Jimeno-Morenilla, A. (2018). A low-cost immersive virtual reality system for teaching robotic manipulators programming. *Sustainability*, 10(4)

Rupasinghe, T. D., Kurz, M. E., Washburn, C., & Gramopadhye, A. K. (2011). Virtual reality training integrated curriculum: An aircraft maintenance technology (AMT) education perspective. International Journal of Engineering Education, 27(4), 778.

Schubert, T., Friedmann, F. & Regenbrecht, H. (2001). The experience of presence: Factor analytic insights. *Presence: Teleoperators and virtual environments*, *10*(3), 266-281.

Stone, R. T., Watts, K. P., & Zhong, P. (2011). Virtual reality integrated welder training. Welding Journal, 90(7), 136s

Wei, W., Dongsheng, L., & Chun, L. (2013, September). Fixed-wing aircraft interactive flight simulation and training system based on XNA. In 2013 International Conference on Virtual Reality and Visualization (pp. 191-198). IEEE.

Zhou, Y., Ji, S., Xu, T., & Wang, Z. (2018) Promoting knowledge construction: a model for using virtual reality interaction to enhance learning. *Procedia computer science, 130* (2018), 239-246

ANNEX 1: Cost Associated to the Intervention

Curricula Design		**50,000**
Software Development		**150,000**
Technical support and laboratory deployment	Remote technical support services (4 years)	42,000
	Equipment import / transport	26,000
	Teacher training and implementation support	15,000
	Sub-Total	**83,000**
Laboratory hardware and licenses (for 30 students)	Laboratory hardware	70,000
	Accessories (eyewear, clips, pointers, etc..)	2,000
	Licenses and warranties	10,000
	Sub-Total	**82,000**
Furniture and lab adaptation		**10,000**
COVID-19 Sanitary protocols	PCR test (X115)	7,500
	Cleaning Supplies for Lab (for one year)	750
	Thermometer	250
	Sub-Total	**8,500**
TOTAL COST		**383,500**

ANNEX 2: Monitoring and Evaluation Sheet

Indications: Please fill out the form after completing each ACTIVATE module. **Remember:** There are not right or wrong answers. Honest responses will allow us to better understand how ACTIVAR works in the classroom and improve program implementation and efficiency over time.

1 **Name of the Technological Institute:**

2 **Date:**

Day	Month	Year

3 **Teacher:**

4 **Number of students enrolled in the class to date:**

4.1 **Number of students present in the last class you taught with ACTIVAR:**

About the Technology, zSPACE:

5 **Did (teacher/students) experience any problems using zSPACE technology?**

a No

b Yes

5.1 **If the answer was yes to the previous question, please describe the problem:**

5.2 **Please describe how you solved the problem or if you needed technical help to solve it**

6 **What kinds of questions did students ask about zSPACE or its contents?**

6.1

6.2

6.3

7 **Did you feel ready to answer them?**

a No

b Yes

7.1 Why not?

About Tablets:

8 **Did (the teacher/students) experience any problems using the TABLETS?**

a No

b Yes

8.1 **If the answer was yes to the previous question, please describe the problem:**

8.2 **Please describe how you solved the problem or if you need technical help to solve it**

About the Pedagogical Content:

9 **Which ACTIVAR module have you recently implemented?**

Module #:	

10 **How long did it take to teach module X of ACTIVAR?**

total days	all minutes

11 Approximately how many <u>minutes</u> were dedicated to the use of technology (z-space, tablets)?

12 Approximately how many <u>minutes</u> were dedicated to the closing of the class?

11	
12	

13 **How did the students receive the technology of the course with ACTIVAR?**

14 **Do you have any other comments about the implementation of the course with ACTIVAR that you want to share?**

Thank you very much!

ANNEX 3: Class Observations

	Class Observation
1	https://drive.google.com/file/d/1TVq8jobr97ODIUugUvhLLCMwEb0SWuOF/view?usp=sharing
2	https://drive.google.com/file/d/1_Hlu2La1b9wEL_y0BS5TWUqrvgkpbyPx/view?usp=sharing https://drive.google.com/file/d/1DzdyGVSuvm3MxlybBXQUqF4B2oVLbjfD/view?usp=sharing
3	https://drive.google.com/file/d/1FIBWuEC2ilTrxh8TyXJxXB5OBHdz2y1q/view
4	https://drive.google.com/drive/u/1/folders/0B1IiDCbhkVVGfjNTTndRMnBHMC15dEpTeXNZV2E3bjZRTF9pYl9YVHdsY3BqemIxTVlTWjQ?resourcekey=0-MiytYxIcVu0L7TjmxDW18A
6	https://drive.google.com/file/d/1YA0TFCznf8wFNlbBOZTfE6bTuwFKafwW/view?usp=sharing

ANNEX 4: Knowledge Assessment

Internal Combustion Engines

Section 1: Multiple Choice (25 Questions)

*Each question in this section is a multiple-choice question with 4 answer choices. Read each question carefully and choose the **ONE** best answer.*

---

1. The function of a car's engine is to:

    a. Convert fuel into heat
    b. Convert fuel into exhaust
    c. Convert fuel into motion
    d. None of the above

2. As part of the main rotating component of an engine, its significant weight helps to maintain torque and control rotational speed.

    a. Flywheel
    b. Counterweights
    c. Vibration damper
    d. Crankshaft deflections

3. Which of the following is NOT an advantage of an inline four cylinder engine?

    a. It is small and compact.
    b. It is lightweight.
    c. Primary forces are balanced.
    d. Secondary forces are balanced.

4. What is the space called between the inner bearing surface and the main journal of the crankshaft?

    a. Bearing clearance
    b. Crankpin clearance
    c. Crankshaft clearance
    d. Journal clearance

5. The typical journal-to-bearing clearance is:

    a. .004 to .005 mm
    b. .006 to .012 mm
    c. .05 to .12 mm
    d. .5 to .9 mm

6. Energy is stored in the flywheel in the form of:

    a. Potential Energy
    b. Kinetic Energy
    c. Heat Energy
    d. Electrical Energy

7. With reference to pistons, which of the following statements is NOT true?

    a. Pistons convert energy from expanding gases into mechanical energy.

b. Pistons move linearly within the cylinder liner.
c. Pistons are commonly made of cast-iron alloy.
d. To prevent gases bypassing the piston, each piston has rings wrapped around it.

8. Concerning connecting rods, which of the following statements is NOT true?

a. The connecting rod connects the piston to the crankshaft.
b. They are made from drop-forged, heat-treated steal to provide the required strength.
c. The smaller diameter top bore of the connecting rod connects to the wrist pin.
d. The smaller diameter top bore of the connecting rod connects to the crankshaft.

9. A misaligned connecting rod causes what type of engine wear?

a. Cylinder taper
b. Barrell-shaped cylinders
c. Ridge wear
d. Angle wear on the piston skirt

10. Two technicians are discussing timing the camshaft to the crankshaft. Technician A says that marks are often provided on the cam and crank gears or pulley so that the engine can be properly timed. Technician B says that some engines use a camshaft sprocket or gear that is not keyed to the camshaft. Which technician is correct?

a. A only
b. B only
c. Both A and B
d. Neither A nor B

11. What do the valves do?

a. Allow the spark to enter the engine
b. Open to allow the explosion to be forced onto the crankshaft
c. Open to allow gas/air to enter and for exhaust to exit
d. Allow coolant to enter engine

12. What do camshafts do?

a. Open the valves
b. Push out engine exhaust
c. Drive the crankshaft
d. Inject fuel/air into the engine

13. In typical engine lubrication systems, what components are last to receive oil?

a. Main bearings
b. Rod bearings
c. Valve trains
d. Oil filters

14. Which component returns the coolant from the expansion tank to the cooling system after the engine has cooled down?

a. Radiator bleed hose
b. Lower radiator hose
c. Upper radiator hose
d. Steam hose

15. Blue exhaust smoke indicates which of the following problems?

a. Oil leak
b. Coolant leak
c. Fuel leak
d. Excessive water condensation

16. What is engine component that supplies the fuel/air mixture to the cylinders?

    a. Radiator
    b. Catalytic converter
    c. Exhaust manifold
    d. Intake manifold

17. For an engine to make the best use of the fuel, the spark should occur before the piston reaches the top of which stroke?

    a. Compression
    b. Power
    c. Intake
    d. Exhaust

18. Two technicians are discussing spark plugs. Technician A says that ignition coils are essentially transformers. Technician B says that the primary side of the coil delivers the high voltage spark that is necessary to jump the plug gap. Who is correct?

    a. Technician A
    b. Technician B
    c. Both technician A and B
    d. Neither technician A nor B

19. What is the function of the carburetor?

    a. To atomize and vaporize fuel
    b. To mix petrol and air in correct proportion
    c. To supply fuel air mixture to the engine
    d. All of the above

20. Before the timing chain can be removed, which of the following components must be removed?

    a. Valve cover
    b. Vibration damper
    c. Cylinder heads
    d. Intake manifold

21. The ends of this two-in-one device come in “open” and “box” variations.

    a. Combination wrench
    b. Drill
    c. Screwdriver
    d. Pliers

22. This is a specialized tool used to safely grip and turn the boots on an engine’s ignition devices.

    a. Scribing tool
    b. Spark plug pliers
    c. Needle scaler
    d. Ratchet extender

23. What is torque?

a. Another measurement of horsepower
b. Force that causes an object to rotate
c. The electrical output of an engine
d. How quickly the pistons go up and down

24. When installing camshafts, in what general sequence should the bearing cap bolts be tightened?

a. The four outside bolts first, then from the center out
b. From the outside bolts to the inside bolts
c. From the inside bolts to the outside bolts
d. From the front of the engine to rear

25. When installing the cylinder head, what tools would be used to check for straightness.

a. A feeler gauge and straight edge
b. A dial caliper and head stand
c. A dial indicator and head stand
d. Measuring tape

Section 2: Short Answer (15 Questions)

Answer each question in this section with brief, concise response. Read each question carefully.

1. Name the four strokes of a four-stroke engine in the proper order.

____
____
____
____

2. What causes the piston in a four-stroke engine to move downward in the power stroke?

____

3. Name 3 common causes of crankshaft failure.

____
____
____

4. What material are crankshafts usually made from?

____

5. When piston rings are installed, they are staggered so that they do not align. Why?

6. Name the two basic types of piston rings used in an engine.

7. Which component in the valve system is in direct contact with the cam lobe?

8. What is the primary symptom of failure of camshaft followers?

9. When changing a car's engine oil, what component should always be changed at the same time?

10. Name the component that is used to reduce air temperature between stages of compression.

11. What component must be removed before unscrewing the spark plug?

12. When replacing a catalytic converter, if the bolts are too corroded to be removed, what tool may be used to?

13. Before removing the timing belt and components, the engine must be set to a certain position. What is that position?

14. What is the name of the precision measuring device used to measure thickness of materials and small amounts of movement?

15. Often pistons have a notch in the crown. What is its purpose?

16. Discuss how engine emissions are controlled.

17. Explain why there is more cylinder liner wear at the top.

18. Vibrations can cause accelerated wear and damage to engine components. Which is more damaging: linear or torsional vibration? Explain.

19. Discuss the advantages of overhead camshafts.

20. Explain how spark ignition works.

Section 3: Essay

Look at the picture of the damaged piston below. Write a brief statement in which you:

1) *Describe the damage*
2) *Assess the extent of damage*
3) *Offer explanations for possible causes of the damage.*

ANNEX 5: WBLT Evaluation Scale

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
Learning					
Working with the Virtual Lab helped me learn					
The feedback from the Virtual Lab helped me learn					
The graphics and animations from the Virtual Lab helped me learn					
The Virtual Lab helped teach me a new concept					
Overall, the Virtual Lab helped me learn					
Design					
The help features in the Virtual Lab were useful					
The instructions in the Virtual Lab were easy to follow					
The Virtual Lab was easy to use					
The Virtual Lab was well organized					
Engagement					
I found the Virtual Lab engaging					
The Virtual Lab made learning fun					
I would like to use the Virtual Lab again					

ANNEX 6: Motivation Questionnaire

To better understand what you think and how you feel about this auto-mechanics course, please respond to each of the following statements from the perspective of "When I am in an auto-mechanics course…"

Components (Scales) and Statements (Items)	Never (0)	Rarely (1)	Sometimes (2)	Often (3)	Always (4)
Intrinsic Motivation					
The auto-mechanics I learn is relevant to my life					
Learning auto-mechanics is interesting					
Learning auto-mechanics makes my life more meaningful					
I am curious about discoveries in auto-mechanics					
I enjoy learning auto-mechanics					
Self-Efficacy					
I am confident I will do well on auto-mechanics tests					
I am confident I will do well on auto-mechanics labs and projects					
I believe I can master auto-mechanics knowledge and skills					
I believe I can earn a grade of "A" in auto-mechanics					
I am sure I can understand auto-mechanics					
Self-Determination					
I put enough effort into learning auto-mechanics					
I use strategies to learn auto-mechanics well					
I spend a lot of time learning auto-mechanics					
I prepare well for auto-mechanics tests and labs					
I study hard to learn auto-mechanics					

ANNEX 7: System Usability Scale

Variables	**Strongly disagree**				**Strongly agree**
I think that I would like to use the Virtual Lab frequently	1	2	3	4	5
I found the Virtual Lab unnecessarily complex	1	2	3	4	5
I thought the Virtual Lab was easy to use	1	2	3	4	5
I think that I would need the support of a technical person to be able to use Virtual Lab	1	2	3	4	5
I found the various functions in the Virtual Lab were well integrated	1	2	3	4	5
I thought there was too much inconsistency in the Virtual Lab	1	2	3	4	5
I would imagine that most people would learn to use the Virtual Lab very quickly	1	2	3	4	5
I found the Virtual Lab very cumbersome to use	1	2	3	4	5
I felt very confident using the Virtual Lab	1	2	3	4	5
I needed to learn a lot of things before I could get going with the Virtual Lab	1	2	3	4	5