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Engaging Students in Sustainable Science Education

Edited by
Larry J. Grabau

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Editor

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About the Editor

Larry J. Grabau

Larry J. Grabau is a Professor of Plant and Soil Sciences. Larry's career has revolved around scientific instruction in classrooms, laboratories, in the field, and through studies abroad. He recently earned a second doctorate in educational psychology, and has a new focus on scientific education with emphasis on sustainability for diverse students, instructors and institutions.

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Editorial

Engaging Students in Sustainable Science Education

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Students who find science to be enjoyable are more likely to engage in their science classes [1], and perform at higher levels on science exams [2]. Such students may also have higher levels of interest in science-related careers [3] and become informed citizens on science-related issues [4]. Rather than simply accepting that some students (in primary, secondary, and tertiary education) are naturally intrigued by science, some science practitioners and educators are now devising approaches to science concepts intended to stimulate such enjoyment and engagement [5]. Teaching support, hands-on activities, nature-of-science frameworks, and self-paced (yet mentored) online instruction are just a few of these approaches. In addition, educators are finding that some students feel excluded from science by virtue of their gender, ethnic or racial background, or socio-economic standing [6]; those educators are actively seeking ways to help such students find their identity in science fields (for example, by addressing science issues especially relevant to such possibly excluded students). Science need not be taught as a set of disjointed facts; instead, compelling science narratives can be invoked, drawing students into the story (and study) of science [7].

Six articles (see list of contributions below) comprise this Special Issue. Four articles focus on sustainable, engaging classrooms, emphasizing teachers' development of environments conducive to students' science learning. Meanwhile, the remaining pair of articles present sustainable, engaging classrooms, emphasizing sustainability of materials utilized for teaching and learning—creating a positive feedback loop of both instructional style and practical choices supporting sustainability in the learning context.

Four articles concentrate on teachers' management of science learning environments: Lin and Chang, Petchamé et al., Ali et al., and Grabau et al. Lin and Chang's research considered the possibility that Generation Z students may well have distinct learning preferences, and thus respond to re-considered teaching and learning environments. Their work involved the use of a progressive set of instructional approaches, moving first through a traditional lecture, then to flipped classroom methods, then to well-designed teamwork projects. Student participants were supportive of this novel approach to classroom instruction. Petchamé et al. faced a unique difficulty—engineering students, enrolled in a business management course, faced a reasonable lack of initial engagement in a course that would naturally be outside their skill set and perhaps even outside their interest. These authors developed and tested a series of interactive activities (for example, reciprocal interviews) for the first two days of class, with the goal of enhanced early engagement as well as full-semester learning. Ali et al. invoked a STEM learning model to assist secondary students to grasp concepts in materials science. Their unique approach focused on sports applications of materials; their work included an assessment of students' resultant attitudes toward STEM fields. Grabau et al. considered the relationships between teaching climates in science classroom, finding that disciplinary climate (characterized by a "get-down-to-business" science teaching and learning model) to benefit not only student dispositions toward science but also the students' performance on standardized exams.

Meanwhile, the remaining pair of articles (Kiwfo et al. and Yeerum et al.) helped students contextualize their learning about sustainability in chemistry classrooms by seeking out "green" materials to use, particularly during the season of the COVID-19 pandemic.

While both of these articles' teaching/research practice took place in Thailand, the approaches were somewhat different. Kiwfo et al. used locally available guava leaves to assay for iron in the classroom context—data quality was good, reagent expense was markedly reduced and students were challenged, by this very experience, to learn to think of "doing science" in more sustainable ways. Yeerum et al., faced with stay-at-home orders for many of their students, devised a mail-out kit to help their confined students to learn skills in analytical chemistry. The at-home work of students was complemented by a subsequent synchronous online learning session.

Taken together, the articles comprising this Special Issue support student learning in science-related fields through enhanced and innovative instructional approaches, along with creative techniques to help students learn difficult subjects even when facing resource constraints.

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Article

A Progressive Three-Stage Teaching Method Using Interactive Classroom Activities to Improve Learning Motivation in Computer Networking Courses

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Abstract: Generation Z students have their learning preferences. They like to learn independently, advocate for what they believe in, and work hard to achieve their goals. However, there are significant gaps between Generation Z students' expectations for learning and prior experiences, especially for three domains of motivation in online learning environments: relatability, affirmation, and opportunity. This study aims at exploring the effectiveness of a progressive teaching method designed for Generation Z students in computer networking courses. This study proposes a progressive three-stage teaching method that gradually implements traditional lecture, individual flipped learning, and cooperative flipped learning methods over a semester. The design principle of this study differs from most existing studies that focus on the effectiveness of specific teaching methods. This study encourages each student to learn sequentially through three teaching stages. The purpose of this study is to investigate the changes in students' learning experiences, particularly in terms of learning comprehension and learning motivation. The research results show that the proposed progressive teaching method can improve students' understanding of computer networking courses and enhance their learning motivation. Participants agreed that the proposed progressive pedagogy can improve their teamwork skills and provide a different learning experience in the computer networking courses.

Keywords: progressive pedagogy; three teaching stages; individual learning; cooperative learning; mixed-method study

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1. Introduction

The current generation of college students, born between 1995 and 2010, is known as Generation Z (Gen-Z) [1]. They enjoy consuming information from a variety of digital sources to develop their learning plans [2]. Being tech-savvy also helps Gen-Z students become comfortable with learning independently, where they can set their own pace and practice what they are learning in a personal environment [3]. That does not mean that Gen-Z students give up on collaborative group work with classmates. Instead, they are most motivated by relationships. Gen-Z students enjoy using video sharing, texting, and engaging with social media platforms to build relationships. They cherish the opportunity to interact with their peers and teachers and prefer to collaborate with others after their individual learning [3]. As a result, Gen-Z students are not only self-learners, they also prefer self-paced learning, which means that flipped learning (FL) would work well for them [4].

The traditional lecture (TL) teaching method is a form of teacher-centered pedagogy, which only provides a limited learning environment for students to practice textbook examples. Just as Gen-Z students are motivated by engaging with their identified passions, failure to engage and be recognized in the learning process can also be a lack of motivation for this generation [5]. They like to complete self-study before being asked to do it in class or work with a team, so Gen-Z students can be motivated through experiential learning and teamwork [6].

This study proposes a progressive three-stage teaching approach that guides students to participate in a process ranging from (1) traditional lecture (TL) to (2) individual flipped learning (IFL) to (3) cooperative flipped learning (CFL) methods within a semester. According to the surface, shallow, and deep knowledge levels of teaching content, the proposed progressive three-stage teaching method contains the following: (1) the TL stage serves as the basis for knowledge memory, (2) the IFL stage is used to create a self-learning environment, and (3) the CFL stage is adopted to carry out collaborative group work with peers.

The design principle of this study differs from those of most studies that use groups of students to compare the effectiveness of a particular teaching method with traditional ones. The progressive pedagogy encourages each student to learn through the three teaching stages in sequence and collect his/her subjective feelings about the differences in the learning experience of each stage. This research is based on the belief that knowledge is constructed in an ongoing manner by learners as they engage and give meaning to an activity, experience, or interaction. This research focuses on the acquisition of meaning through students' subjective experiences and perspectives in the progressive teaching environment. The purpose of this study is to investigate the changes in students' learning experiences, especially in terms of learning comprehension and learning motivation, after they sequentially participate in three different teaching stages. This research wants to find a teaching process that allows students to explore their own learning characteristics and find a learning style that is suitable for their lifelong learning.

The remaining parts are organized as follows. Section 2 presents the learning characteristics of Generation Z and the background of different learning methods. Section 3 describes the research questions, participants, research methods, instructional design, progressive teaching approach, and research procedure. Section 4 analyzes the questionnaire data, presents the results of student feedback, and summarizes findings on student engagement. Section 5 concludes the work and summarizes the research contributions.

2. Literature Review

In 2014, the marketing firm Sparks & Honey released a report promoting the name Generation Z [1]. Although many studies have slightly different ranges of birth years for Gen-Z, to make the findings of this study consistent with most studies, the birth years of Gen-Z participants fell within the range of 1995 to 2010. Exposed to digital devices from an early age, Gen-Z has access to more information than any other generation, resulting in different learning preferences such as instant inquiry, video learning, and learning by doing [3]. To match the tech-savvy characteristics of Gen-Z students, information and communication technologies (ICT) should be widely incorporated into learning environments to provide Gen-Z students with modular learning content and diversified knowledge presentations [7].

2.1. Motivation of Generation Z Learners

Research findings by Dusseau [8] show that participants have significant gaps between desired connections and previous experiences for three domains of motivation in online learning environments: relatability, affirmation, and opportunity. That is, while Gen-Z is accustomed to individual online learning, the isolation of online learning can hinder the motivation of Gen-Z students. Therefore, the way teachers establish face-to-face interaction and communication with Gen-Z learners will initiate this motivational improvement process.

First, face-to-face settings are great as a motivator to increase the motivation of relatability. Gen-Z students find it easier to engage with teachers through small talk in FL-based teaching methods. Students typically adopt formal and structured behaviors during online learning, and more casual and immediate behaviors in face-to-face interactions [8]. Therefore, well-defined interactive classroom activities will motivate students to learn.

Lo and Hew [9] recommended that teachers should establish an online learning platform to provide an individual learning environment with self-evaluation mechanisms and learning-by-doing activities. FL is a means to create an interactive teaching environment under time constraints [10]. Classroom time was reserved for students to engage in experiential learning activities in teams [11]. Therefore, this study establishes an FL environment by creating an online learning platform, including instructional videos and learning materials, to help students preview the teaching content by themselves.

Second, affirmation of ability, whether of internal or external origin, acts as a major motivator. It is used to increase their motivation to learn by affirming their own potential [8]. Such motivation is a visualization of the goals in front of them, so experiential learning in FL must allow students to see what is coming next and affirm who they will become. Through peer review, professional production, and academic achievement, Gen-Z can gain the voice and feedback of their peers.

According to Foldnes [12], one of the main variables affecting FL success is the way classroom activities are organized. Teachers take advantage of online learning platforms to provide students with the means to learn by themselves or remotely before classes. Then, teachers can use classroom time to carry out experiential learning and problem-solving activities [9,13]. Compared to TL, FL is more flexible, allowing for the creation of more diverse learning environments and a wider range of teaching materials [14].

Third, the most interesting part of the opportunistic motivation is when the participants discuss the stories of group cooperation. While group projects tend to bring a lot of frustration, it is often the most valuable memory after the class. This cooperative learning opportunity usually makes what is taught in the class relevant, receives affirmation from peers, and organizes a team to share ideas. This opportunity motivation for teamwork cannot be replaced by any other assessment [8].

Therefore, this study constructs an FL environment with different types of interactive classroom activities to explore the learning preferences of Gen-Z students.

2.2. Individual Flipped Learning

The research findings of Seemiller and Grace [3] indicate that Gen-Z students are more inclined to learn individually than interpersonally. Students enjoy exploring their own values first and then sharing the results with their peers [3]. This research carried out the following tasks for implementing an individual flipped learning (IFL) environment: (1) Conduct classroom activities that encourage students to solve problems with the support of teacher guidance, online information search, and critical thinking; and (2) Collect feedback from students to understand their learning progress and experience.

Findings from the Northeastern University's Innovation Survey indicated that Gen-Z students prefer a hands-on learning environment [6]. Gen-Z students value the practicality of what they learn in everyday life and are eager to apply it in a variety of settings [3]. In particular, problem-solving discussions can increase students' interest in learning [15]. In the IFL of this study, the online platform is used as a means of computer-mediated communication between teachers and classmates. Each student independently completes classroom assignments, watches instructional videos, searches for relevant information online, thinks about answers, and reports to the platform individually.

2.3. Cooperative Flipped Learning

Hashim [15] suggested that teachers create a cooperative learning environment where students can realize their creations through teamwork. The theoretical background of cooperative learning is based on Vygotsky's sociocultural constructivism and the zone of proximal development theory [16]. It encourages students to work with their peers and cooperatively apply their knowledge to solve problems. During cooperative learning, team members learn a certain subject through continuous interactions to gain professional knowledge [17]. It can help students consolidate personal experiences and interact with team members to achieve shared learning goals, thereby improving learning effectiveness [18]. Kettunen, Kairisto-Mertanen, and Penttilä [19] also recommended that group-based learning can promote the social constructivist theory more than self-learning.

Many previous studies adopted the notion of cooperative flipped learning (CFL) [20–22]. They reported that CFL increased students' academic achievement and learning satisfaction compared to TL. Furthermore, research results from Lee, Jeon, and Hong [23] demonstrated that CFL positively affected motivation, but it negatively affected achievement. On the other hand, IFL showed the opposite results. Therefore, this study followed the suggestions of Lai [24] and created a CFL environment that encourages peer interaction and teamwork projects. Classroom activities at CFL divide students into small groups to perform problem-solving tasks by using online platforms as a means of communication between group members. The purpose of CFL is to enhance students' learning motivation and improve their problem-solving ability. Students are required to apply the theories of computer networks to real-life applications and complete their narrative work in creative projects.

2.4. Progressive Interactive Learning Experience

The case study results reported by Ng and Nicholas [25] show that students who follow a progressive instructional learning model can consistently complete all the required tasks of an online learning program. Although the effects of cooperative learning on classroom interactions have been studied [23,26,27], few studies have focused on students' perspectives, specifically after they sequentially engage in several different learning methods [25]. Therefore, this study divides the one-semester course into three parts and adopts three different learning methods, from TL to IFL and then CFL, to increase the diversity of learning styles.

3. Methodology

3.1. Research Questions

The overarching research questions to guide the investigation of this progressive teaching method are:

(1) How do IFL and CFL affect Gen-Z students' understanding of learning?
(2) How do IFL and CFL affect the learning motivation of Gen-Z students?
(3) After students participate in different learning styles in sequence, how are their learning experiences different?

3.2. Setting and Participants

This research was conducted in computer networking courses offered by the College of Business at Chung Yuan Christian University (CYCU). The participants in this study were 100 freshmen in the Department of Information Management. The investigation lasted for eighteen weeks. Students who participated in this study used the same book, *Computer Networking: A Top-Down Approach*, by James F. Kurose and Keith W. Ross (2017, 7th edition).

The computer networking courses introduce the functions of the Internet protocol stack and the networking mechanism required for data transmission. The teaching goals were to guide students to (1) understand the basic concepts of data communications and develop their protocol design reasoning; (2) identify necessary networking properties and select an appropriate network; and (3) create a problem-solving network model.

The CYCU developed an online learning platform called i-learning to improve management efficiency for learning and teaching. This study used the i-learning platform to maximize the effect of computer-supported collaborative learning for students. The functions of the i-learning online platform include (1) online examination, discussion, homework, and survey; (2) cloud storage for uploading teaching materials, such as instructional videos, PowerPoint slides, or other teaching materials; and (3) a cooperative learning platform as an e-learning facilitator allowing students to interact online with the teacher and classmates anywhere and anytime.

3.3. Methods of the Research

This study explores the effects of individual and cooperative flipped learning on learning comprehension and learning motivation with those of traditional lectures using a mixed-methods design. This study adopted a mixed research method design. The first goal was to obtain quantitative data through questionnaires to understand students' learning experiences. The second goal was to obtain students' perspectives on the progressive teaching method through student feedback. Through meticulous research design and requirements analysis, a progressive teaching method has been proposed. In the flipped learning method, this study allows students to experience the changes in learning comprehension and learning motivation caused by gradually increasing the degree of interaction. The purpose of this research is to allow students to experience different learning methods, so that students can find suitable learning methods that can improve their overall learning efficiency. During the study, the teaching methods were gradually adopted to take different levels of interactive classroom activities. The TL method takes a lecture teaching, and the class time is simply unidirectional interaction from the teacher to the students. When using IFL, students must complete online learning before class, and then the classroom time is used to guide students to complete homework. Through the chance of two-way interaction between the teacher and students, the teacher can understand the individual learning conditions of students. During the execution of CFL, class time is used to conduct group projects and encourage cooperative learning between students. Students jointly complete the group projects through cooperative learning and classroom interaction.

3.4. Instructional Design of the Program

To maximize the effectiveness of this research, this study used the ADDIE (analysis, design, development, implementation, and evaluation) model of instructional design [28] as a framework for designing this program. We firstly analyze the learning preferences of the students, design teaching goals, and propose teaching strategies. Then, we develop the flipped learning environment on the i-learning platform and implement the proposed three-stage teaching method sequentially. Finally, we evaluate the effectiveness of the teaching methods and conclude the research results. The design process of this teaching program is shown in Figure 1, which is divided into three main steps: (1) research design, (2) teaching practice, and (3) performance evaluation.

- Step 1. Analyze learning preferences
  - Step 1-1. Identify teaching vision: Explore the trend of interactive pedagogy and analyze the knowledge characteristics of computer networking courses.
  - Step 1-2. Set teaching goals: According to the learning preferences of Gen-Z students, define the research goals and evaluation methods.
- Step 2. Design and develop teaching environment
  - Step 2-1. Design teaching methods: Decide to use flipped learning method with progressive interactions to enhance students' comprehension and learning motivation.
  - Step 2-2. Develop an online learning platform: Design instructional video and digital teaching materials for each teaching stage.
- Step 3. (Teaching Stage I) Implement the TL method
  - Step 3-1. Carry out traditional lecture: Deliver core content through conventional classroom teaching.
  - Step 3-2. Assess learning situation: Observe students' notes and find that they could not understand and apply knowledge.
- Step 4. (Teaching Stage II) Introduce the IFL method
  - Step 4-1. Implement flipped teaching: guide students to self-study online, summarize the key points of the course, and encourage students to share their experiences in online forums.

Step 4-2. Conduce classroom activities: Ask questions in class and prompt students to recall learning and solve problems individually.

- Step 5. (Teaching Stage III) Execute the CFL method

  Step 5-1. Arrange teamwork projects: Initiate digital storytelling projects in the classroom to encourage cooperative learning in groups.

  Step 5-2. Organize computer–support interaction: Introduce cooperative learning by placing students in teams to solve problems, thereby enhancing learning motivation.

- Step 6. Evaluate research results

  Step 6-1. Analyze learning feedback: Collect student feedback and questionnaire results to understand student preferences for different interactive learning methods.

  Step 6-2. Conclude continuous improvement plans: Design improvement plans and summarize research findings to continuously improve learning outcomes

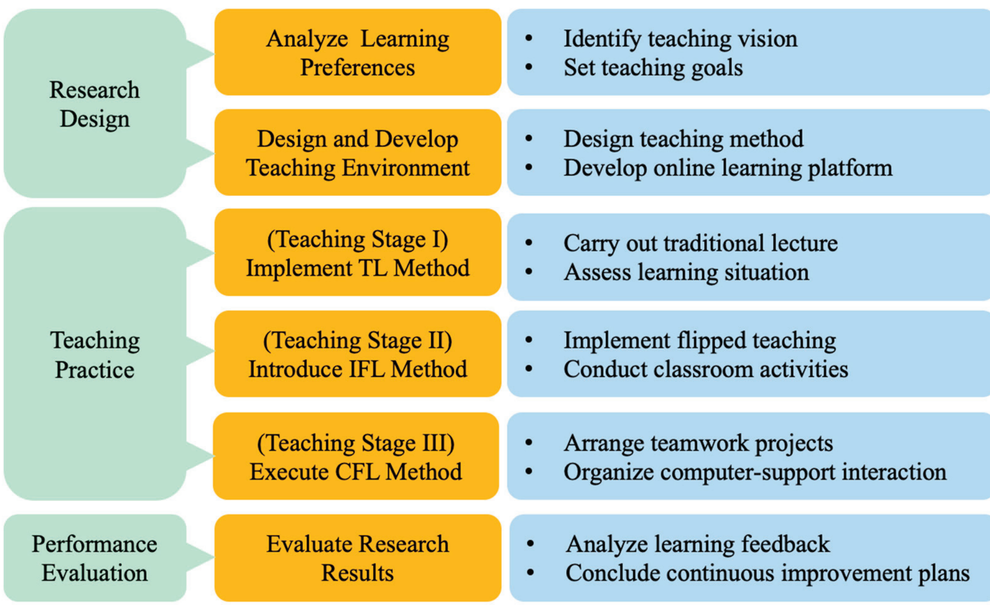

Figure 1. The instructional design process of this study.

3.5. Progressive Teaching Approach

In this study, we followed the three-level learning pyramid of the pedagogy proposed by Bennet and Bennet [29] to categorize the content of computer networks into three levels: (1) surface-level—memorized knowledge, such as facts, data, concepts, and messages; (2) shallow level—social interactions, such as debates and group exchanges; and (3) deep level—practical experiences acquired through learning. This study investigates whether the proposed progressive teaching method affects students' subjective experience of learning comprehension and learning motivation. The characteristics of the three-stage teaching method are shown in Table 1.

Table 1. Characteristics of the three teaching stages of this study.

Characteristics	Teaching Stage I	Teaching Stage II	Teaching Stage III
Knowledge Level	Surface	Shallow	Deep
Learning (internal reflection and comprehension)	Awareness, Memorizing, Understanding	Causality, Coherence, Meaning-making	Effortful practice, Insights, Lived experience
Learned Knowledge	Information, Conscious	Conscious, Causality	Mostly unconscious, Pattern detection
Exhibited Behavior	Remembering, Communicating, Acting	Explaining, Anticipating, Problem-solving	Creating, Intuiting, Predicting
Solving Problems	Simple Problems	Structured Problems	Unstructured Problems

The three-stage teaching method proposed in this study is matched to three teaching activities at different knowledge levels. In Teaching Stage I, surface-level knowledge was presented to students. In this stage, the students acquired knowledge from the lecturer, memorized surface-level content, and solved simple problems. In Teaching Stage II, shallow-level knowledge was presented to the students. Students in Teaching Stage II learned about the causality and logic behind the knowledge content to solve structured problems. In Teaching Stage III, students organized groups to review deep-level knowledge, participated in problem-solving projects, and jointly integrated learning experiences into the learning-by-doing processes.

The learning styles and objectives for the proposed three-stage pedagogy are tabulated in Table 2. This research adopts different teaching methods at each stage. The purpose is to enable the same group of students to gradually experience different learning methods to truly experience the different learning effects. The proposed pedagogy expands individual learning to interactive networked learning and then to collaborative group-based learning.

Table 2. Learning styles of the three teaching stages of this study.

Characteristics	Teaching Stage I	Teaching Stage II	Teaching Stage III
Pedagogy	Traditional lecture	Individual flipped learning	Cooperative flipped learning
Learning Style	Traditional learning	Individual learning	Cooperative learning
Learning Objectives	Describe concepts related to computer networking and solve problems in textbooks	Analyze data communication problems and propose networking mechanisms	Team up to study computer networking problems and cultivate problem-solving skills
Activities	Independently learn knowledge and do homework.	Watch instructional videos before class and solve protocol-related problems in class	Collaborate as a team on digital storytelling projects on computer networking issues
Teaching Purpose	Learn professional knowledge	Enhance learning comprehension	Enhance learning motivation

In Teaching Stage I, the traditional lecture (TL) focuses on content internalization and personal practice. Students attend classroom lectures, review textbooks, complete homework, and take quizzes to effectively strengthen content memorization and foster theoretical reasoning skills. The purpose of teaching is to recite professional knowledge and answer textbook questions.

Teaching Stage II adopted individual flipped learning (IFL), focusing on combining FL with individual classroom activities. IFL takes advantage of the spontaneity of online platforms to facilitate student learning [29]. The digital materials used in IFL included instructional videos and slides [30]. Students analyzed problems specific to data transmission and learned to apply suitable networking technologies to solve communication problems during in-class learning-by-doing activities The course also encouraged students to convert computer networking issues into mind maps and association diagrams, thereby enhancing students' comprehension

Teaching Stage III focused on group discussions and topical activities to encourage debate, reflection, and negotiation. Students applied their computer networking knowledge and participated in grouped problem-solving activities to realize cooperative flipped learning (CFL). These activities brought students from different fields together to collectively solve problems both in the classroom and online. Students can gain a better understanding of the course content by working in a team and learning from their teammates, thereby improving learning motivation.

3.6. Research Procedure

3.6.1. Teaching Stage I: Traditional Lecture

As shown in Table 3, the teacher provided traditional face-to-face teaching in Teaching Stage I. The students took notes during the lesson, and the teacher assigned homework as practice and scheduled tests to measure students' learning effectiveness. As shown in Figure 2, a student note records the processes of establishing and closing a TCP (transmission control protocol) connection. Observing the students' class notes can find that students just copied the content written by the teacher on the whiteboard. Students only recorded the surface of the teaching content and lacked the design meaning that can deepen their understanding. Students exhibited only a preliminary understanding of the course content. The student feedback also supported this inference.

Table 3. Implementation of Teaching Stage I.

Environment	Activities and Tasks	Time
In class (Classroom Instruction)	The teacher provides lectures in class	30–40 min
	Students take notes in class	5–10 min
	The teacher explains learning goals in class	1–3 min
	Q&A in class	Flexible
Out of class (After class)	Students do homework/taking online quizzes	2 h
	Students share learning feedback online	10 min

3.6.2. Teaching Stage II: Individual Flipped Learning

As tabulated in Table 4, the pedagogy used in Teaching Stage II is the IFL method. Students first engaged in self-learning on an online platform before class. The content of the instructional videos included knowledge delivery and case studies. The online teaching materials help students understand how to realize the service quality of different data communication through the cooperation of communication protocols. In class, students participated in problem-solving activities in the classroom. They were allowed to search for relevant information online to help them solve problems. Following the findings of Cevikbas and Kaiser [13], this study observes student notes as a means of understanding student learning. Figure 3 shows one example of student notes in this stage. Figure 3a shows that students annotated airline systems with airline functional layers to help understand the function of each protocol layer. Furthermore, Figure 3b shows that students can not only describe what they have learned, but also internalize the course content into a mind map, which can help them improve their learning comprehension. That is, the pedagogy of Teaching Stage II improved students' understanding of the course content.

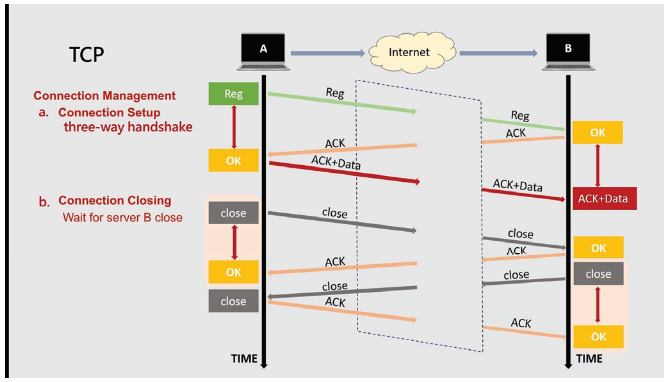

Figure 2. An example of student notes in Teaching Stage I.

Table 4. Implementation of Teaching Stage II.

Environment	Activities and Tasks	Time
Out of class (FL before class)	Students watch instructional videos online	15–20 min
	Students taking notes after studying online	5–10 min
	Students share learning feedback online	10 min
In class (Individual classroom activities)	The teacher summarizes the teaching content in class	10–20 min
	Q&A in class	Flexible
	Students do homework/taking quizzes/classroom activities under the guidance of the teacher	15–20 min
	Students actively search for additional learning resources online to solve the classroom problems	Flexible
	The teacher preview the progress of the course next lesson	3–5 min

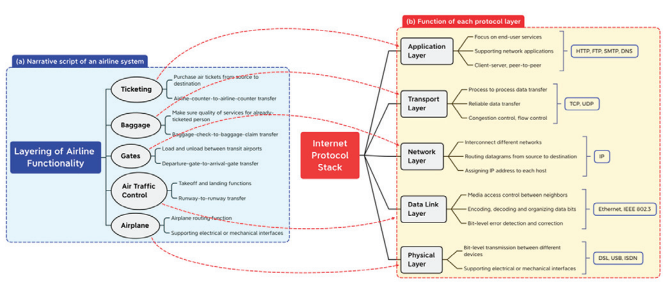

Figure 3. An example of student notes in Teaching Stage II: Using (**a**) a narrative script for an airline system to illustrate (**b**) the function of each layer of the Internet protocol stack.

Lo and Hew [9] asserted that the underlying risk of implementing a flipped-classroom course design is that students could lack a sense of responsibility for independent learning, resulting in students skipping online lectures and extracurricular activities and attending classroom lectures and activities instead. Therefore, we introduced a third teaching stage to encourage team interaction and enhance learning motivation.

3.6.3. Teaching Stage III: Cooperative Flipped Learning

To help students understand the course content from different perspectives while participating in team activities and engaging in discussions, we combined the FL with cooperative classroom activities in Teaching Stage III. Table 5 shows the implementation of this stage. First, students watched instructional videos before class. Then, the teacher raised real-world data communication problems during class and asked students to form teams to study the problems. After the class, students continued to work on assignments in teams. Workloads were allocated based on the different expertise of team members. The process allowed students to gain a deeper understanding of the course content while producing the final results.

The roles of the teacher are crucial in this stage. The teacher serves as a promotor, role model, evaluator, informer, and planner, promoting students to draw on what they have learned to solve problems [31]. In this study, the teacher guided students to create digital narrative works on computer networking issues. Through cooperative learning and storytelling skills, students can deepen their understanding of teaching content [32]. The effectiveness of this stage was measured based on group performance, learning logs, and survey results.

An example of student teamwork results is illustrated in Figure 4. The presentations were based on the transport layer of Internet protocol suite. The students adopted an anthropomorphic approach in transforming the TCP and user datagram protocol (UDP) into virtual characters and attempted to distinguish TCP and UDP from the perspective of reliable data transfer. Students used a comic style to represent TCP and UDP through the characteristics of two courier companies. Then, they used these two courier characters to make a comic strip. They compared the processing mechanisms of the two courier companies in connection establishment, network congestion, packet loss, and reliable data transmission to connect the comics with the course content. Students were very proud of their collaborative model, with some members analyzing course content, some scripting, and others creating comics. Feedback from students on group work indicated that they were very immersed in teamwork and found the activity had the effect of increasing interest and motivation in learning.

Table 5. Implementation of Teaching Stage III.

Environment	Activities and Tasks	Time
Out of class (FL before class)	Students watch instructional videos online	15–20 min
	Students taking notes after studying online	5–10 min
	Students share learning feedback online	10 min
In class (Cooperative classroom activities)	The teacher summarizes the main points of the instructional videos	10–15 min
	Q&A in class	Flexible
	The teacher introduces challenge problems and assigns them to students	5 min
	Students team up to study the assigned problems	10–15 min
	Students share what they have learned and discuss it with teammates to identify gaps in achieving targets	20–30 min
	Students brainstorm and determine group works	10–15 min
Out of class (Online discussion after class)	Students actively search for additional learning resources online to solve assigned tasks	Flexible
	Students share learning experiences and discuss with each other	Flexible
	Students propose their solutions to the ill-defined problems	Flexible

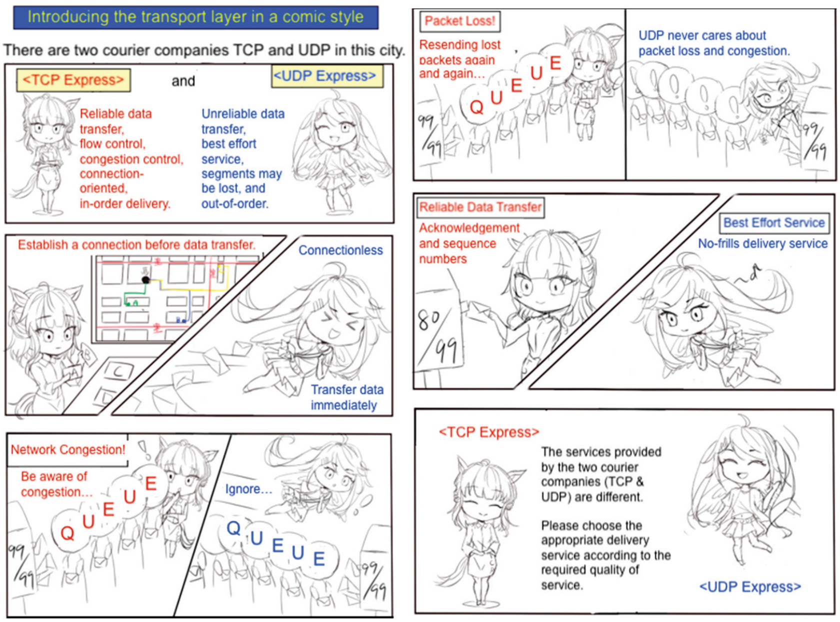

Figure 4. An example of student creation in Teaching Stage III: Introducing the two protocols of the transport layer in comic style.

4. Results

4.1. Questionnaire Survey

A questionnaire survey was administered after each teaching stage to collect quantitative data. All participants were similar in that they did not differ significantly by age and year of college. All students are taught by the same teacher. The items of the three questionnaires are tabulated in Table 6. The researcher used a five-point Likert-type response format (1 for the lowest impact and 5 for the most positive impact), where each student could choose to agree or disagree. Questionnaire A focused on Teaching Stage I. It aimed to measure the effects of TL on the students' learning effectiveness. Questionnaire B focused on Teaching Stage II. It aimed to compare the effects of TL and IFL on students' learning effectiveness. Questionnaire C focused on Teaching Stage III. It aimed to compare the effects of IFL and CFL on students' learning effectiveness.

Table 7 presents the results of three questionnaires (A, B, C), each with three items labeled (e.g., a1, a2, a3, etc.). A total of 100 students participated in the survey on the improvement of their learning experience. The table presents the frequency of student approval for each item. We can discuss the survey results separately in terms of learning comprehension, learning interest, and learning motivation, as follows.

- For learning comprehension shown in Table 8, the mode was 3 (39%) in Teaching Stage I, 3 (46%) in the second stage, and 4 (43%) in the third stage. This result shows that as the teaching mode changes from TL to IFL to CFL, the learning comprehension of most students gradually improves through individual and cooperative interaction. The variance of these three stages is reduced from 0.7011, 0.6236, to 0.51, and the number of students who scored 2 also dropped from 6%, 5%, to 1%. This shows that differences in students' comprehension levels can also be mitigated through different types of interactive activities.
- From the learning interest shown in Table 9, the modes of the three teaching stages were 4, and the number of people who scored 4 points had an increasing trend, from 38% to 45% and 42%, although the number of students who scored 5 points

gradually decreased in the three stages, mainly because the difficulty of the content gradually increased from surface level, shallow level, to deep level. However, the standard deviation of the overall learning interest in these three stages dropped from 0.8185, 0.7263, to 0.7228. This result shows that students are still able to maintain their interest in learning as the teaching mode changes from TL to IFL to CFL, although the difficulty of teaching content gradually increases. That is, the learning challenges posed by the difficulty of professional courses can be compensated by well-designed interactive activities.

- For the learning motivation shown in Table 10, the mean was 4.15 in Teaching Stage I, 4.22 in Teaching Stage II, and 4.24 in Teaching Stage III. The percentage of students who scored 5 points gradually increased from 33%, 39%, to 40% in the three stages. These results show that the average value of students' learning motivation increases gradually. Moreover, the number of students scoring full marks gradually increased in the three-stage teaching method.

Table 6. Questionnaire survey items.

Questionnaire A: (Be Conducted after Teaching Stage I)
a1. In your opinion, how effective is attending classroom lectures on improving learning comprehension?
a2. In your opinion, how effective is attending classroom lectures in increasing interest in learning?
a3. In your opinion, how effective is attending classroom lectures in improving learning motivation?
Questionnaire B: (Be Conducted after Teaching Stage II)
b1. In your opinion, how effective is previewing instructional videos and participating in classroom activities in improving learning comprehension?
b2. In your opinion, how effective is previewing instructional videos and participating in classroom activities in increasing interest in learning?
b3. In your opinion, how effective is previewing instructional videos and participating in classroom activities in improving learning motivation?
Questionnaire C: (Be Conducted after Teaching Stage III)
c1. In your opinion, how effective is engaging in group discussions in improving learning comprehension?
c2. In your opinion, how effective is engaging in group discussions in increasing interest in learning?
c3. In your opinion, how effective is engaging in group discussions in improving learning motivation?

Table 7. Results of the three questionnaires.

Questionnaire	**Item**	**Frequency**					
		1	**2**	**3**	**4**	**5**	**Total**
A (Teaching Stage I)	a1	0	6	39	37	18	100
	a2	0	2	33	38	27	100
	a3	0	0	18	49	33	100
B (Teaching Stage II)	b1	0	5	46	35	14	100
	b2	0	0	35	45	20	100
	b3	0	0	17	44	39	100
C (Teaching Stage III)	c1	0	1	42	43	14	100
	c2	0	0	41	42	17	100
	c3	0	0	16	44	40	100

Table 8. Results of the questionnaires on the degree of improvement in learning comprehension.

Item	Frequency						Mode	Mean	Variance	Std. Deviation
	1	2	3	4	5	Total				
a1	0	6	39	37	18	100	3	3.67	0.7011	0.8373
b1	0	5	46	35	14	100	3	3.58	0.6236	0.7897
c1	0	1	42	43	14	100	4	3.7	0.51	0.7141

Table 9. Results of the questionnaires on the degree of increased interest in learning.

Item	Frequency						Mode	Mean	Variance	Std. Deviation
	1	2	3	4	5	Total				
a2	0	2	33	38	27	100	4	3.9	0.67	0.8185
b2	0	0	35	45	20	100	4	3.85	0.5275	0.7263
c2	0	0	41	42	17	100	4	3.76	0.5224	0.7228

Table 10. Results of the questionnaires on the degree of improvement in learning motivation.

Item	Frequency						Mode	Mean	Variance	Std. Deviation
	1	2	3	4	5	Total				
a3	0	0	18	49	33	100	4	4.15	0.4875	0.6982
b3	0	0	17	44	39	100	4	4.22	0.5116	0.7153
c3	0	0	16	44	40	100	4	4.24	0.5024	0.7088

Overall, students expressed that the proposed progressive pedagogy was better at enhancing learning effectiveness than TL. Based on the aforementioned points, we inferred that the three-stage pedagogy effectively improved students' learning comprehension and motivation.

4.2. Student Feedback and Perspectives

This study believes that motivation to learn is the meaning constructed by learners as they continue to engage in activities, experiences, or interactions. Therefore, the subjective experience and cognitive feelings of students in this progressive teaching environment are the focus of this study on the collection of student feedback and perspectives. It is particularly suitable for exploratory research to uncover the teaching experiences, course design, student feedback, and achievements of the proposed innovative pedagogy. This study collected the students' learning feedback and online discussions to illustrate the students' thoughts on participating in the course. These feedbacks are first-person descriptions of subjective experiences and corresponding feelings that students actively share. The learning motivation strategies described by these experiences can be integrated into lesson-planning strategies and will contribute to improving the effectiveness of the progressive teaching method.

The learning experiences of two students in Teaching Stage II are illustrated in Figure 5. In Figure 5a, the student expressed that the learning-by-doing activities helped him connect theory with everyday life. The assignments encouraged deeper contemplation, allowing him to find practical examples for the application of theories taught in the course. Another student compared the learning-by-doing activities with traditional assignments and expressed his learning experience in Figure 5b. He agreed that the graphical representation of theoretical transformations helped him better understand the course content. He said that the classroom activities required students to understand the content and communicate the content to others. This process helped him understand the content more deeply than TL.

The learning experiences of students in Teaching Stage III are illustrated in Figure 6. A student shared that, as shown in Figure 6a, in TL mode, he only concentrated on the completeness of his notes instead of understanding the content of the class. However, after participating in the group work, he can review the content in more detail and listen to the opinions of other classmates. He said that group activities improved his academic performance. Another student shared, as shown in Figure 6b, saying that in traditional face-to-face lectures, he did not completely understand the concepts taught in class. After participating in the group work and discussing the content with his teammates, he was able to better understand the content of the course. He also expressed that giving examples helped him understand the content better and that teamwork is helpful for learning.

(**a**)	*After the mid-term assignment, I realized that many protocols were similar to parts of everyday life. This made me think that maybe these protocols were designed by referring to lifestyles. Initially, I only focused on packet loss. However, the assignment forced me to continue searching for similarities. After finishing the homework, I found that there was more than one similarity. This was an interesting discovery. Associating protocols with everyday life makes studying significantly easier and more fun.*
(**b**)	*This assignment was very interesting. I was able to convert textbook content into a format that both creators and viewers alike. Although textbooks are still required to get a complete description, presenting textbook content as pictures or a story makes learning fundamental concepts much easier!*

Figure 5. (**a**,**b**) Two examples of student feedback on the IFL in Teaching Stage II.

(**a**)	*I was worried that I would not have enough time during class to take notes. I only focused on copying the content on the board without taking the time to understand the meaning. Later, I realized that I did not understand what I had taken down. Fortunately, the group assignment allowed me to review the content in my mind and listen to the views of my teammates. It helped me gain a better understanding of the content.*
(**b**)	*The group assignment helped me better understand the course content. The concepts introduced in class were confusing at first. However, through group discussion, I was able to hear different conceptual explanations, which clarified most of the initial confusion. Using analogies is a bit like concluding. This is not as simple as it seems. You must fully understand the content to clearly describe the content. When I integrated the content for my team, I reviewed the content to identify problems, which gave me a better understanding of the content.*

Figure 6. (**a**,**b**) Two examples of student feedback on the CFL in Teaching Stage III.

4.3. Student Engagement

Gen-Z students in Taiwan are familiar with online social networking interactions but are cautious about face-to-face peer interactions. When using the IFL method in this study, we observed that most students are used to learning independently and completing tasks on their own. In the beginning, students only interacted with the teacher in class, and had less face-to-face interaction with their peers. Even with the encouragement of the teacher, most of the interaction between classmates is only on the online platform. They do not engage in course-related discussions until they watch other students' learning experiences posted online.

When implementing the CFL method, the teacher required students to join groups and encouraged them to collaborate. Because students' face-to-face interaction in class increased their interest in learning, students not only actively engaged in face-to-face discussions in their spare time but also interacted through online social networks. These opportunities for peer interaction deepen students' engagement with the coursework and increase their interest in cooperative learning. As shown in Figure 7, students participated in face-to-face meetings after class to discuss solutions to complex problems.

Figure 7. Two photos show students creating a face-to-face learning atmosphere after class and actively participating in collaborative learning projects.

5. Conclusions

The learning characteristics of Gen-Z students are different from previous generations. Their learning preferences are self-learning, achievement-driven, a desire to be affirmed by their peers, and enjoyment of peer interaction. Research on motivation to learn online shows that Gen-Z wants support for relatability, affirmation, and opportunity. This study aims to explore a teaching method suitable for Gen-Z students to study computer networking courses in a college of business. The research process uses the ADDIE instructional design model to analyze learning preferences, design teaching methods, develop online instructional platforms, implement a progressive teaching method, evaluate teaching effectiveness, and collect student learning experiences.

This study proposes a progressive three-stage teaching method in which students are gradually guided to participate in traditional lectures, individual flipped learning, and cooperative flipped learning over a semester. This study places particular emphasis on making each student aware of the differences between the three learning styles and providing feedback on their learning experience. The purpose of this study is to investigate changes in students' learning experiences, focusing on changes in learning comprehension and learning motivation.

5.1. Research Findings

The progressive three-stage teaching method proposed in this study focuses on gradually improving the learning motivation of Gen-Z students, ranging from the face-to-face flipped learning that increases the motivation of relatability to the classroom interactive activities of individual flipped learning that can improve the motivation of affirmation, and finally the teamwork project of cooperative flipped learning that can improve the motivation of opportunity. The results of the learning experience questionnaire showed that the proposed progressive teaching method improved students' understanding of computer networking courses and enhanced their motivation to learn. Furthermore, student feedback on their subjective learning experiences showed that the proposed progressive classroom interaction activities not only recognized individual learning outcomes, but also promoted opportunities for teamwork.

5.2. Theoretical Contributions

The contribution of this research provides educators with a wealth of instructional planning details. This study developed a progressive three-stage teaching method based on learner motivation, and thus collected the subjective experiences of Gen-Z learners who participate in this pedagogy. The research design proposed in this study is similar to the within-subject study design, allowing each student to experience multiple learning approaches. Students' self-reports of subjective learning experiences during the learning process can be used to explore teaching methods that are suitable for students.

5.3. Practical Implications

For educators, different generations of students have different learning preferences. How to choose the most suitable teaching method for contemporary students is often the most important task for educators. Teachers often use a single teaching method with a rigorous assessment mechanism to evaluate the teaching effectiveness. However, when students learn new knowledge for the first time, they do not have enough experience to judge the effectiveness of teaching methods. Students will simply assume that particular courses tend to use the designated pedagogy. They cannot choose a learning style that is suitable for a particular course. Therefore, the progressive pedagogy proposed in this study allows students to experience the advantages and disadvantages of different learning methods, to be able to decide the learning method that is suitable for them.

5.4. Limitations and Further Research

In terms of recommendations for further research, this study proposes a progressive pedagogy targeting the motivations of Gen-Z students currently enrolled in higher education, but the type of courses and the sample size of students are limited. Further development of within-subject study design should be undertaken in the future to better understand whether the proposed progressive teaching method is applicable to various courses and to explore the degree of overall impact on students' learning experience.

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Engaging ICT Engineering Undergraduates in a Management Subject through First Day of Class Activities: An Empirical Study

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Abstract: The expectations, attitudes, engagement, and motivation of students are key elements when designing learning activities. Several studies have been implemented and different strategies and activities have been analyzed to improve the aforesaid aspects of learning content. In the context of the New Learning Context (NLC), this paper presents the findings of two first day of class activities aimed at engaging engineering students in a business and management subject from the very first moment: an empirical study conducted by means of a survey answered by engineering students in Information and Communication Technologies (ICT), followed by an interactive activity between students and instructors carried out through a reciprocal interview activity. The survey was performed with the objective of identifying what they 'liked' and 'disliked' on their first day of class of a business subject. The findings are presented and compared with previous studies and have proven to be mostly consistent with previous academic work. Finally, a reciprocal interview activity was chosen to potentially enhance the students' engagement and motivation. According to the feedback received, this activity was positively valued by the students.

Keywords: engagement; engineering students; first day of class; ICT; management; motivation; reciprocal interview activity

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1. Introduction

All first encounters that human beings have with someone or with something generate initial impressions or perceptions that tend to remain in their minds for some time. Just by looking at someone's face, even for less than a second, people make judgments about that person [1–3], although accuracy is not granted [4,5]. In fact, short behavioral observations, from half a minute to five minutes, seem to be enough [6,7]. First impressions about people may be shaped by clothing [8], body language [9], and so on. Shaping first impressions also applies even when thinking about products, such as website aesthetics [10]. Furthermore, first impressions can condition beliefs and behaviors [11]. In terms of education, the first day of class may have a multisided impact on students [12–14].

Several researchers have studied whether students' first impressions have a long-lasting impact on their perceptions of subjects and instructors. Buchert et al. [15] concluded that students formed lasting impressions about academic staff within the period of the first two weeks of class. Laws et al. [16] found that the impressions students had formed during the first week persisted until the end of the semester.

Most ICT engineering syllabi include, in addition to specific engineering knowledge, other topics that provide an all-round formation. In fact, both specific technical knowledge and nontechnical competencies are required [17,18], including teamwork, communication, problem solving, or leadership skills [19–23]. Along these lines, basic knowledge in business and management was introduced in engineering programs, since these topics are necessary to complete the training of students and improve their employability [24]. However, some engineering students have shown a degree of reluctance when they were first presented with subjects that they perceived to be quite far from their area of personal interest [25,26], for example, business or management subjects taught in ICT engineering programs. Therefore, all the efforts made by instructors in the first session of a subject to enhance engagement and motivation should be carefully planned because of the positive (or negative) impact that they could have on the students [12,13,27,28].

The general aim of this research was to explore two activities carried out on the first day of class of a management subject, in order to increase the students' expectations, engagement, and motivation. Specifically, the first purpose of this this paper is to describe an empirical study on what undergraduate ICT engineering students liked and disliked on the first session of class, contextualized in a management subject. The second objective of this study is to show the students' assessment of a reciprocal interview activity carried out during the second part of the session. Both activities were designed to enhance the appeal of the management subject and allow students to meet their peers and instructors.

The article contributes to the literature by analyzing the outcomes of two different first day of class activities hypothesized to enhance the appeal of a management subject. Given that all the participants in this research were second-year ICT undergraduates, all the findings about the efforts oriented to increase expectations, attitudes, and engagement can shed light in designing good practices to be included in subjects that are not included as core topics according to the perceptions of some students.

2. State of the Art

All the efforts and activities that instructors may implement to increase expectations, attitudes, engagement, and motivation on the first day of class of a subject can be crucial to their success in teaching the entire subject. The relevance of this topic is reinforced by the fact that most books dealing with teaching have a chapter dedicated to the first day of class, e.g., [29–33]. Therefore, the findings of previous research works are synthesized as follows.

2.1. Enhancing Engagement and Motivation the First Day of Class

Motivation to learn is a construct that has been defined by different authors, i.e., [34,35], and can be defined as identifying chosen individual behaviors to reach a specific goal [36]. The motivation to learn has been formalized by means of different theories as shown in [37], the contemporary ones being summarized in [38] as follows: expectancy-value, attribution, social cognitive, goal orientation, and self-determination.

The engagement construct has been conceptualized through different definitions that may include different components [39,40]. Engagement is an observable action, as it can be defined as 'energy and effort in action' [40], and some tips to enhance engagement have been identified in research works [41].

On the one hand, according to several research works, students' motivation is correlated with academic success [42,43] or with an impact on their engagement [44]. In fact, motivation may improve different academic outcomes [45–47]. On the other hand, engagement is related, among other issues, to improved achievement [48,49], decreased dropout rates [50], or to the creation of a positive class climate [51].

The very first day of class can be seen as an exceptional opportunity to implement activities that may help develop students' expectations [12,52,53], attitudes [13,54], engagement [12,55–58], or motivation [13,14], while also determining the learning environment and class atmosphere for the remaining sessions of the subject [59,60]. Although such actions are obviously designed to improve class dynamics, some may have negative effects on students' perceptions.

2.2. Studies about 'What Likes' and 'What Dislikes' to Students the First Day of Class

Several studies have been performed with the aim of identifying both the 'likes' and 'dislikes' that students preferred on their first day of class. The main works and findings include the following.

In an empirical study, Perlman & McCann [53] identified what they labelled as 'works well' and 'peeves' on the first day of class by means of two open-ended questions. They identified and taxonomized seventeen different categories and added the number of occurrences for each one of the normalized options that they identified from a survey of 570 undergraduate students. It should be noted that in some cases an item that 'worked well' for a student could be a 'peeve' for another student. The general trends of students' preferences were the following: general information about the subject (syllabus, overview of the subject, etc.); grading system and information about the instructor (background, teaching style). Among the peeves, homework assignments and beginning the subject content the first day of class were ranked at the top of the list.

Henslee, Burgess & Buskist [61] asked 146 undergraduate students by means of a twenty-nine item survey (twenty-two items to be ranked and seven open-ended questions) about the first day activities, with the aim of identifying student preferences. Results detected that student's favorites were 'information about the class structure' and 'coursework'.

Basset [62] surveyed 249 university students, identifying the following as valued preferences: information about the subject difficulty, professional information about the instructor, structure and content of the classes, procedures followed in class, and also personal information about instructors and peers.

In an empirical study, Eskine & Hamer [63] asked 230 undergraduate students to replicate the aforementioned Perlman & McCann empirical study [53]. The authors asked the identical open-ended questions and classified the answers according the same seventeen categories that were formerly identified in the study performed by Perlman & McCann. In terms of 'likes', the top findings were the same, whereas when talking about 'dislikes', the two top topics were 'poor use of class time' and 'beginning subject content'.

2.3. Activities Carried out the First Day of Class

During the first day of class, a variety of different actions and activities can be performed to achieve different goals [27,55,64]. Iannarelli, Bardsley & Foote [64] highlighted four basic actions that can be performed on the first day of class: explaining subject expectations, where the content of the syllabus plays a key role; learning about students; introducing the instructor; and establishing the right tone.

Some of the actions that have been experienced during the first day of class are listed as follows:

- The most basic activity could be to introduce the academic staff and present the syllabus. Sometimes the instructors start giving contents after the presentation or choose to end the first session of class. Along this line, several activities are described in [65] as examples of 'what not to do' during the first session of class session.
- Creating positive and/or negative 'experiences' on purpose during the first session of class. For instance, Wilson & Wilson [13] showed two different videos explaining the syllabus to different groups of students. In one of the videos, the instructor gave the presentation in a friendly way, whereas in the other one the instructor presented the syllabus while avoiding emotional tone and followed the syllabus presentation by another video that generated a homework assignment to be performed. Another experience, related to a psychology subject, is described in LoSchiavo, Buckingham & Yurak [66], where an instructor showed up at the classroom and after asking the students to fill out some information, he told them to stand up and face the back of the room; later, after some minutes and once the real instructor appeared, they discussed the topic of obedience.
- Introducing topics to create students' interest in the subject. Within this category, icebreakers could be included. Different activities were performed in different fields

to create interest. Different academic experiences can be mentioned as an example, as follows: regarding economics, Helmy [67] played a lottery to assign a country to students in order to discuss their development problems; as for statistics, Bartsch [54] asked their students to generate anonymous questions to be answered during class on the first day, and Bennet [68] also analyzed probability by means of matching students' dates of birth; in the context of physics, Gaffney & Whitaker [69] asked students to answer Fermi's questions, in other words, to quantify questions to which it was quite difficult to obtain the exact solution in terms of their quantification, an experiential learning activity to introduce topics about 'operations management' [70]; using a Readers' Theatre technique [71]; or just whipping [72], a teaching activity to promote students' participation.

- Reciprocal interview activity. As described in different papers [12,73], a reciprocal interview activity consists of following these steps: (1) create groups of students; (2) offer a potential list of questions, as examples, to ask the instructor during the interview phase; (3) each group of students discusses the set of predefined questions that will then be asked to the instructor during the interview activity once the speaker of the group has been selected; (4) carry out the reciprocal interview activity in class, or the instructor asks the different groups what is the same, and finally; (5) students ask the instructor.

According to the academic literature, several objectives may be achieved by means of a reciprocal interview activity, as shown in different research works: building an awareness of students' and the instructor's goals and expectations [12,58,73]; gathering information about peers, the instructor, etc. [55,58]; encouraging class discussions and generating more comfortable interactions students-instructor [12,55,58,73]; creating a lasting effect on students' attitudes [52]; influencing students' motivation by increasing their perception of the interest and usefulness of the subject and also by transmitting attention to them [14] and; establishing a positive climate at class [28].

2.4. NLC at La Salle URL or Leveraging the First Class Session

Due to the new reality and possibilities of the educational sphere (digital natives, new technologies, etc.) the way of teaching may change and evolve [74,75]. In December 2018, La Salle Educational Mission Assembly (AMEL 2018) agreed to design and implement a new educational model in all its educational centers for all the different educational stages, from children's education to universities. This new model was named the 'New Learning Context' (NLC) and is currently being deployed in Spain after two years of design and implementation [76]. This deployment involved 104 centers, including two university colleges, such as La Salle Campus Barcelona (Universitat Ramon Llull) and La Salle Campus Madrid (Universidad Complutense de Madrid).

The NLC model [76,77] is based on five pedagogical principles that constitute a nonvisible substrate of the educational model. These principles are implemented through five learning environments, as shown in Figure 1. In short, the five pedagogical principles are as follows:

- Interiority: The educational model transcends the academic field, considering personal growth as an inseparable part of education.
- Mind (body and movement): This principle tries to convey the idea that learning takes place beyond the classroom. The NLC considers the use of space and its organization as the third educational agent, with students and instructors being the other agents.
- Thought Construction: The NLC should generate cognitive skills and abilities, structures, procedures, and strategies that develop different thinking processes and their use.
- Self-Regulated Behavior: The NLC creates spaces and experiences in which autonomous learning habits are encouraged, where each student learns to self-regulate his/her own pace, intensity, effort, commitment, and time required to reach the learning goals, which can be achieved through different paths.

- Social Dimension of Learning, which is structured on three fundamental levels: (1) the educational spaces, as a pedagogical element which favors social learning; (2) the organizational proposal, which specifies the pedagogical framework of coexistence; (3) the community, as a learning structure.

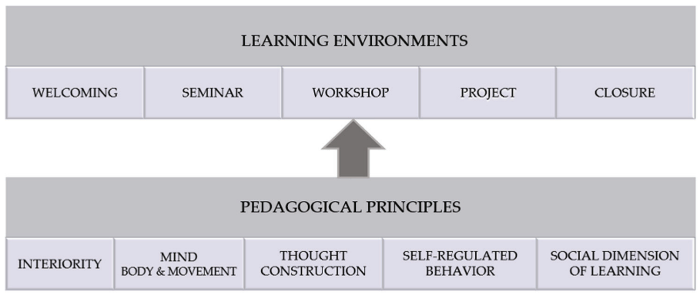

Figure 1. Schema of the New Learning Context (NLC) structure: Five pedagogical principles and five learning environments.

The concept learning environment was widely studied and analyzed from different academic viewpoints, e.g., [78,79]. The learning environment constitutes an essential part of the NLC pedagogical model. In terms of methodology and teaching, the environment can be considered as a separate space with its own educational purpose. The NLC learning environments are as follows:

- Seminar (i.e., focusing on 'knowing'): seminars are organized as teaching areas to allow the student's acquisition of the concepts. In other words, seminars are knowledge areas in which different learning methodologies (such as, lectures, flipped classrooms, peer-to-peer learning, etc.) can be implemented to achieve the learning outcomes.
- Workshop (i.e., focusing on 'knowing how to be'): workshops are pedagogical environments in which the students use their own strengths to construct their own learning process. In the global context of the NLC Methodological Framework, workshops represent the integration of knowledge, allowing students to fully connect with multifaceted elements of their life. Workshops are orientated to build and develop the students' competences which in turn help them develop their own personality.
- Project (i.e., focusing on 'knowing what to do'): this interdisciplinary learning area enables students to learn competences through complex tasks. Those tasks are characterized by their transversal integration of knowledge, being developed in an interdisciplinary way by means of several different sources (scientific, social, historical, artistic, etc.). Projects are usually focused on a specific source, which is then complemented by the other ones, thus creating a learning environment in which students can truly grow, develop, and construct knowledge.
- Welcoming: this is an area of experience that can help students develop healthy study habits by means of different tools. It ranges from internal elements of the human being (such as reflexional, interiority, consciences, motivation) to organizational needs (planning, to-do lists, and objectives, etc.). Not all the welcome activities are mandatorily programmed at the beginning of the session. In fact, some activities may be scheduled just at the beginning of a specific activity or project.
- Closure: this implies the completion of the task. At this point, students assess the work done, make insights for the future, celebrate their achievements, and finish their session. This activity enables students to truly appreciate what they have learnt: conclusions about what they can make, or simply how they can take advantage of these conclusions, as well as being aware of the mistakes they have made and how to learn from them. In the same way as the welcoming sessions, closure sessions are

not necessarily programmed at the end of the day, nor do they always last the same length of time.

During the design period of the NLC, the focus was on substantiating and validating the pedagogical model, while different lines of research were created to assess the impact on the deployment of the model. Along this line, academic research has been performed on several NLC topics (e.g., about redesigning a subject [36], assessment issues [26,80], etc.). Three of the previously aforementioned areas (seminars, workshops, and projects) are well-established elements, which have been widely used and studied in a great amount of academic research. Nevertheless, similar efforts in terms of research have not been made for the other two elements (welcoming and closure, in NLC terminology). Therefore, all the efforts in researching items related to the first day of class will positively affect the effective implementation of the NLC.

3. Methods

The research was focused on obtaining data that helped to adjust both the activities and the content of the first day of class in a management subject taught to ICT engineering undergraduates. In this case, the research objectives related to the first day of class were: (1) to obtain information from the students about which activities they preferred to do, (2) to assess students' reactions to a reciprocal class-interview activity carried out in the first session.

Figure 2 shows a methodology to continue finetuning a subject taught in the context of an official undergraduate program once feedback from the students is collected. The initial design of a subject is clearly marked by the requirements established in the official program of the studies, according to the 'VSMA Framework' [81] (in Spanish, VSMA is the acronym that stands for Ex-Ante Assessment, Monitoring, Modification, and Accreditation). The main inputs of this design of each subject are the definition of content and methodologies along with the needs of academic staff and infrastructures. At this level should also be included the Smart Classroom (SC) [82,83], a technology that offers new teaching and learning possibilities and that was deployed in most of classrooms and laboratories in September 2020 at La Salle URL. Once classes begin, a review and update mechanism must be established. Usually, the main elements to analyze the operation of the subject are the surveys completed by students as well as the opinions of the academic staff. The text written in blue refers to the new elements that the present research work incorporates. On the one hand, the NLC establishes a general framework for the use of new teaching methodologies that the subjects should incorporate. On the other hand, two first-class instruments are proposed to complement the usual mechanisms to refine the subject.

The research related to both activities that were carried out on the first day of class was conducted in the context of the second-year management subject 'Value Chain and Financial Economics'. This is a core subject of all the ICT engineering programs taught at La Salle URL, where seven undergraduate ICT engineering programs are taught: Audiovisual Engineering, Computer Engineering, Electronic Engineering, Engineering in ICT Management, Multimedia Engineering, Telecommunications Systems Engineering, and Telematics Engineering. The activities took place during the first session of class in the first term of the 2020–2021 academic year, and surveys linked to both research activities were handed out to all students that attended the first two-hour class session.

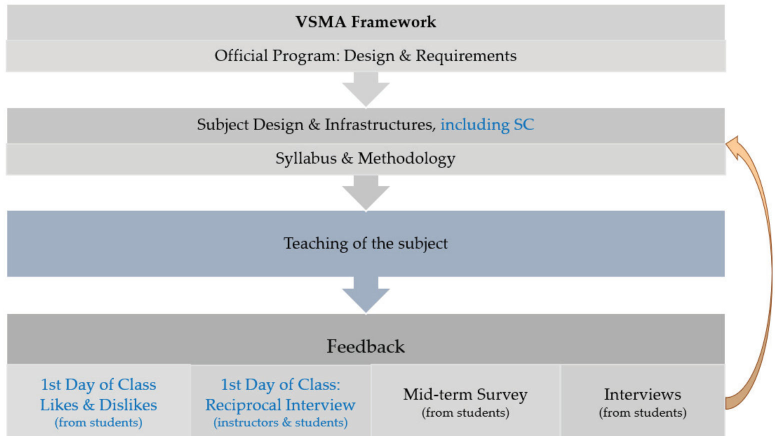

Figure 2. Proposed design and continuous finetuning of a subject in an official undergraduate program once feedback from the students is collected.

3.1. An Empirical Study: First Day of Class, 'What Likes' and 'What Dislikes'

The empirical study to determine the 'likes' and 'dislikes' of ICT engineering students the first day of class was performed during the first session of a second-year management subject. The questionnaire was handed out to the students in class just before a brief presentation of the instructors, after saying 'Hello, good morning' and giving the instructors their first name. At the top of the first page of the survey, data about participants were collected to allow segmentation of the data: 'university degree that you are studying', 'entrance' or access to engineering studies, 'age', and 'gender'. However, no identification in terms of names or any other data that could identify the student was required, resulting in an anonymous form. Each side of the paper contained one of the two open-ended questions: 'Which things would you like an instructor to do on the first day of class of a subject?' on the front side of the paper and 'Which things would you not like an instructor to do on the first day of class of a subject?' on the back side of the paper. Students were invited to answer the questions with a short sentence per idea (ideally, from one to five words, despite not being a specific restriction) to force students first to think and then write a synthesized idea.

Once all the questionnaires had been collected, the answers given by the students were reclassified in homogeneous categories independent of the literal wording of the answers. The methodology that was followed was the same performed by Perlman & McCann [53] and Eskine & Hammer [63]. However, homogenization was not initially restrained to the former taxonomy resulting from the Perlman & McCann's empirical study [53] in order to allow new items to be identified, resulting in the items listed in Table 1. Once the classification was completed, eventual matches in terms of different wording were identified to compare findings, despite keeping some topics disaggregated that were linked to motivation and utility of the subject once the data was analyzed.

Table 1. First day of class (all ICT engineering students): 'likes' & 'dislikes'.

Items [1]	'Likes'		'Dislikes'	
	n	%	n	%
General overview, syllabus, content, & expectations	107	78.10	16	11.68
Describing assessment & grading	75	54.74	12	8.76
Utility & objectives of the subject	44	32.12		
Instructor: introducing background & experience	42	30.66	7	5.11
Icebreaker: doing activities	38	27.74	5	3.65
Getting to know classmates	31	22.63		
Positive attitude of instructor towards students	25	18.25		
Doing a 'nonconventional' class session	22	16.06		
Motivating students	22	16.06		
Beginning subject content	15	10.95	95	69.34
Instructor's advice to pass the subject	15	10.95		
Class takes up full session (2 h)	8	5.84	6	4.38
Explaining instrumental elements (software, etc.)	4	2.92		
Reviewing content (that should be known)	3	2.19		
Doing a test to check initial knowledge	1	0.73	24	17.52
Poor use of class time			20	14.60
Homework assignments			9	6.57
Instructor: poor teaching			8	5.84
Instructor: uncaring, intimidating			7	5.11
Instructor: not being empathetic			6	4.38
Beginning subject content without prior introduction			4	2.92
Instructor: bad attitude			2	1.46
Instructor: not being enthusiastic about the subject			2	1.46

[1] Items have been inferred from findings of two open-ended questions.

3.2. Instructors' and Students' Interactions: A Reciprocal Interview Activity

The reciprocal interview activity was designed to allow the interaction of the whole class with the instructors and vice versa. The mechanics of the reciprocal interview were described briefly in Section 2.3 of this paper. Groups of four students were created and the activity was carried out. One of the instructors sat at the instructor's table writing all the answers given by the different groups of students to the questions raised by the instructors (fifteen minutes were left to prepare the interview, while the interview lasted around fifteen minutes). The final stage of the activity was the instructors answering the different questions asked by the students (eight minutes were left to prepare the interview, while the interview activity lasted twenty minutes).

Once the reciprocal interview was completed, a survey to assess the activity was handed out to all the students to be answered individually to assess students' perceptions of the activity. Again, data about participants were collected to segment the data, in fact the same that was collected in the previous survey: 'university degree that you are studying', 'entrance', 'age', and 'gender'. Yet again, no identification in terms of names was required, resulting in an anonymous form. The survey was structured in four blocs: (1) comfort with approaching the instructor (four items); (2) student comfort with class participation (three items); (3) evaluation of the activity, a reciprocal interview (two items); and (4) ' . . . the activity helped me:' (four items). A space under the tittle 'Any comments?' was left to include students' commentaries. The content handed out to the students was an evolution of the questions surveyed in the Hermann & Foster questionnaire [12].

4. Findings and Results

This section presents the findings obtained once students carried out two activities specifically designed to improve their expectations, engagement, and motivation.

4.1. First Day of Class, 'Likes' and 'Dislikes'

The main findings of the first survey were obtained from the answers to two open-ended questions. Students were asked what they liked and what they disliked, in terms of the class content of the first day and the activities to be carried out during the first session of the subject 'Value Chain and Financial Economics'.

The number of students enrolled in the subject was 164, of which 7 did not participate in any class activity throughout the course. The survey was completed by 137 of them (*M* = 19.42 years old, *SD* = 1.32), who answered the open-ended questions. In terms of gender, there were 33 females (24.09%; *M* = 19.09 years old, *SD* = 1.08) and 104 males (75.91%, *M* = 19.52 years old, *SD* = 1.38). Once the data were collected, responses were normalized without trying to match all of them with the previous taxonomy presented in [53], in order to avoid being conditioned by previous findings. Once the collected data had been classified and reworded, resulting in the items listed in Table 1, the contents were compared with the aforementioned research and then further reworded in a second stage to be able to compare findings. Table 1 shows what students 'liked' and 'disliked' in terms of actions and percentages on the first day of class for the surveyed students. The students' answers shown in Table 1 were standardized to allow adding students' assessments under the identical concepts.

Table 2 shows the actions taken and the percentages of 'likes' and 'dislikes' expressed by the ICT Management engineering students on the first day of class. In all seven engineering programs, the same core subjects are taught in the first academic year. In second year, students take different subjects according to their specific engineering degree program. The distinctiveness of the ICT Management engineering program is that the weight that management subjects have in terms of ECTS (acronym that stands for European Credit Transfer and Accumulation Systems) is much bigger in comparison with the other six ICT engineering programs. The total number of ICT Management engineering students that answered the survey was 15 (*M* = 18.93 years old, *SD* = 0.45), with 3 females (20.00%, *M* = 19 years old, *SD* = 0) and 12 males (80.00%; *M* = 18.83 years old; *SD* = 0.57).

Table 2. First day of class (ICT Management engineering students): 'likes' & 'dislikes'.

Items [1]	'Likes'		'Dislikes'	
	n	%	n	%
General overview, syllabus, content, & expectations	13	86.67		
Describing assessment & grading	10	66.67		
Instructor: introducing background & experience	8	53.33	1	6.67
Getting to know classmates	6	40.00		
Icebreaker: doing activities	5	33.33		
Motivating students	4	26.67		
Utility & objectives of the subject	3	20.00		
Instructor's advice to pass the subject	2	13.33		
Good instructor's attitude towards students	1	6.67		
Doing a 'nonconventional' class session	1	6.67		
Beginning subject content	1	6.67	9	60.00
Reviewing previously acquired content	1	6.67		
Doing a test to check initial knowledge			4	26.67
Poor use of class time			1	6.67
Instructor: uncaring, intimidating			1	6.67
Instructor: bad attitude			1	6.67

[1] Items have been inferred from findings of two open-ended questions.

Table 3 shows the actions and percentages of all ICT engineering students in terms of 'likes' and 'dislikes' on the first day of class, excluding ICT Management engineering students. The total number of students matching this criterion was 122 (M = 19.48 years old, SD = 1.39), with 30 females (24.59%; M = 19.10 years old, SD = 1.14) and 92 males (75.41%; M = 19.60 years old, SD = 1.44).

A Chi-squared analysis compared listed and unlisted frequencies of the ICT Management engineering students to all the other ICT engineering students. No significant differences emerged in the list of 'likes' and 'dislikes' except for the one of the 'likes' items. Chi-squared analysis identified that a greater percentage of the ICT Management engineering students (53.3%) listed 'Instructor: introducing background & experience' as a 'like' than all the other ICT engineering students (27.9%), resulting in an $X^2(1, n = 137) = 4.807$, $p = 0.04$.

Table 3. First day of class (all ICT engineering students, excluding ICT Management engineering students): 'likes' & 'dislikes'.

Items [1]	'Likes'		'Dislikes'	
	n	%	n	%
General overview, syllabus, content, & expectations	94	77.06	16	13.11
Describing assessment & grading	65	53.28	12	9.84
Utility & objectives of the subject	41	33.61		
Instructor: introducing background & experience	34	27.87	6	4.92
Icebreaker: doing activities	33	27.05	5	4.10
Getting to know classmates	25	20.49		
Positive attitude of instructor towards students	24	19.67		
Doing a 'nonconventional' class session	21	17.21		
Motivating students	18	14.75		
Beginning subject content	14	11.48	86	70.49
Instructor's advice to pass the subject	13	10.66		
Class takes up full session (2 h)	8	6.56	6	4.92
Explaining instrumental elements (software, etc.)	4	3.28		
Reviewing content (that should be known)	2	1.64		
Doing a test to check initial knowledge	1	0.82	20	16.39
Poor use of class time			19	15.57
Homework assignments			9	7.38
Instructor: poor teaching			8	6.56
Instructor: uncaring, intimidating			6	4.92
Instructor: not being empathetic			6	4.92
Beginning subject content without introduction			4	3.28
Instructor: not being enthusiastic about the subject			2	1.64
Instructor: bad attitude			1	0.82

[1] Items have been inferred from findings of two open-ended questions.

This qualitative research was planned according to the guidelines presented in previous works [84–89]. As presented in [84], the steps followed were: (1) define the objectives of the research; (2) identify potential respondents; and (3) decide on the methods for collecting the data and the analysis methodology.. The tool chosen to collect students' preferences about activities to be done during the first day of class followed the same methodology used in [53,63], while questions about the activity were collected and analyzed in line with the study of [12]. The data from the first day of class were collected from students by means of an open-ended questionnaire, a tool that enables students to answer while minimizing possible biases [90]. It should be noted that the sample of surveyed respondents was homogeneous since all of them were students of a second year ICT engineering undergraduate program who took a management subject. Once data about the first day of class were collected from students by means of open-ended questionnaire, the items were analyzed separately by three different researchers to increase the validity of the obtained findings [84].

4.2. Reciprocal Interview Activity

The reciprocal interview activity took place at the final part of the class session once a synthetic presentation of the syllabus was given. A summary of the main results obtained from the interviews when activity was completed is presented in this subsection.

After completing the reciprocal interview activity, a second survey was performed to evaluate the students' assessment of the interview activity. It was the last activity before finishing the first-class session of the mandatory management subject 'Value Chain and Financial Economics' in all ICT engineering programs. Information was extracted from a survey in which students' statements were rated by means of a 5-point Likert scale (ranging from 1—*not at all*—to 5—*a very great extent*—). The results, in terms of mean, median, and standard deviation, are presented in Table 4.

The total number of students that filled the survey with valid results was 131 (*M* = 19.33 years, *SD* = 1.56), and six forms were discarded because data were not completed. In terms of gender, the form was answered by 30 females (22.90%; *M* = 19.10 years, *SD* = 1.10) and 101 males (77.10%; *M* = 19.30 years, *SD* = 1.56).

To assess reliability, the internal consistency of the different sections of the questionnaire was measured by means of the Cronbach's alpha [91,92]. 'Comfort with instructor interaction' had a Cronbach's alpha of 0.72, and removing sequentially each one of the items of the section, the measures were 0.64, 0.74, 0.57 and 0.68, respectively. Further, removing C2 increased the analyzed value, moving from 0.72 to 0.74. Therefore, there was no need to remove any of the items since the whole former section obtained a value greater than 0.7 [92]. 'Student comfort with class participation' had a Cronbach's alpha of 0.69, and removing sequentially the items results were 0.47, 0.62 and 0.76, respectively. Again, by removing an item, S3, the value increased. As in the other case, the result of the second section was nearly 0.7, so consistency was achieved. All the other items, despite been grouped in different sections, were linked to individual concepts. The questionnaire had content validity according to the view of the researchers since it covered the different aspects to be measured once compared with other studies, e.g., [12].

Answers to the questions asked by instructors were compiled carefully. Two instructors asked questions, while another instructor noted down students' responses in front of the whole class. In the same way, students' questions were answered by instructors. All the opinions and statements given by students were analyzed in depth by the instructors once the session was completed. For illustrative purposes, some of the answers to the questions asked by the instructors were about the grading system, continuous assessment activities, key dates, instructors' experience, instructor motivation to teach the subject, and utility of the subject, among others. In addition, some of the students' answers to the instructors' questions were about their expectations for the subject, what they thought they were to be taught, their previous knowledge in management and business, etc.

Table 4. First day of class (ICT engineering students). Reciprocal interview: Data and statistics.

Reciprocal Interview Questionnaire	*M*	*Mdn*	*SD*
Comfort with instructor interaction			
C1. 'Talking to the instructor about assignments'	3.93	4	0.70
C2. 'Asking the instructor questions during class sessions'	3.93	4	0.70
C3. 'Talking to the instructor during office hours'	3.71	4	0.91
C4. 'Emailing the instructor with questions'	3.87	4	1.19
Student comfort with class participation			
S1. 'Participating in group activities during class'	4.20	5	1.01
S2. 'Sharing ideas and opinions during class'	4.00	4	0.76
S3. 'Working group activities outside class hours'	3.67	4	1.23
Evaluation of the activity			
E1. 'Would you recommend other instructors do this activity at the beginning of the term?'	3.80	4	0.86
E2. 'Did this activity seem to be a waste of time?'	1.47	1	0.64
. . . the activity helped me:			
H1. 'To understand what was expected in class'	4.13	4	0.74
H2. 'To work hard to do well in the class'	4.00	4	0.88
H3. 'To become more comfortable participating in class'	4.13	4	0.74
H4. 'To share concerns with the instructor'	4.00	4	1.07

5. Discussion

This section presents the analysis of the results shown in Section 4 regarding two activities that were carried out on the first day of class of a management subject taught in seven engineering programs.

5.1. What Students 'Like' and What They 'Dislike'

The first part of this research deals with ICT engineering students' opinions on what they prefer to do on the first day of class. The collected data were classified and quantified in terms of percentage of mentioning. All the items sourced from the answers of the whole pack of ICT engineering students are shown in Table 1. Hence, on the top of the 'likes' rank appears, 'General overview, syllabus, content, and expectations', followed by 'Describing assessment & grading', as shown in Table 5. Equally, when thinking about 'dislikes', 'Beginning subject content' is the most common dislike, as shown in Table 6. In addition, both tables include data segmented consistently with Section 4.1.

Table 5. Top ranked 'Likes' clustered by engineering programs.

	AICTep [1]	ICTMep [2]	ICTeMep [3]
General overview, syllabus, content, & expectations	78.10%	86.67%	77.06%
Describing assessment & grading	54.74%	66.67%	53.28%
Utility & objectives of the subject	32.12%	20.00%	33.61%
Instructor: introducing background & experience	30.66%	53.33%	27.87%
Icebreaker: doing activities	27.74%	33.33%	27.05%
Getting to know classmates	22.63%	40.00%	20.49%
Good instructor's attitude towards students	18.25%	6.67%	19.67%
Doing a 'nonconventional' class session	16.06%	6.67%	17.21%
Motivating students	16.06%	26.67%	14.75%

[1] AICTep (All ICT engineering programs); [2] ICTMep (ICT Management engineering program); [3] ICTeMep (ICT excluding Management engineering program).

Table 6. Top ranked 'Dislikes' clustered by engineering programs.

	AICTep [1]	ICTMep [2]	ICTeMep [3]
Beginning subject content	69.34%	60.00%	70.49%
Doing a test to check initial knowledge	17.52%	26.67%	16.39%
Poor use of class time	14.60%	6.67%	15.57%
General overview, syllabus, content, & expectations	11.68%	-	13.11%
Describing assessment & grading	8.76%	-	9.84%

[1] AICTep (All ICT engineering programs); [2] ICTMep (ICT Management engineering program); [3] ICTeMep (ICT excluding Management engineering program).

As in the previously mentioned research works [53,63], the most common 'dislike' is 'Beginning subject content', as seen in Table 6. 'Doing a test to check initial knowledge' was considered an unpopular activity, according to students' perceptions.

Most of the results found in the research (first column of Tables 5 and 6) are consistent with other previous studies [53,63]. Most of the answers to the ranked items are the same, despite changing the numeric value in terms of percentages associated with citing each one of the items by the students. However, some findings included in Table 5 that differ from the aforementioned previous research studies should be highlighted, as follows: (1) 'Utility and objectives of the subject' are highly ranked (32.12%) on the list compared to previous studies, as they were not found in [63] and only reached 7% in [53]. The fact that this element was in the third position and that it did not appear as a 'Dislike' reveals that it was an action highly appreciated by students, and therefore its inclusion in it on the first day of class could be useful to increase the intrinsic motivation of the students. Intrinsic motivation deals with behaving or doing something in a specific way because the individual (i.e., the student) believes that it is inherently pleasant or interesting [93]. (2) 'Motivating students' was selected by 22 students (16.06%) as a positive action to be done by instructors while this item did not appear in previous referenced research works [53,63].

Analyzing the segmented data subsets, some ideas can be highlighted about the previously mentioned items: (1) 'Utility & objectives of the subject' was cited more often by ICT engineering students (33.61%) than by ICT Management engineering students (20%). This difference could be explained by the fact that undergraduates that are enrolled in the latter program are likely to know more about business topics than students that have chosen a purely ICT engineering program. (2) Quite surprisingly, 'Asking for motivation from the instructor' was cited by more ICT Management students (26.67%) than ICT engineering students (14.75%).

5.2. Analizing the Students' Evaluation of the Reciprocal Interview Activity

Data obtained from the reciprocal interview activity were collected from a second survey articulated to assess pronouncements by means of a Likert scale [94], specifically a 5-point Likert scale. Results of the form were grouped in four categories, two related to students' comfort (with approaching the instructor and with class participation), one evaluating the reciprocal interview activity, and the last one evaluating four statements related to potential benefits of the first day activity that the student actually performed.

All the items related to the label 'comfort with instructor interaction' received a high score value. Within this tag, the statement that received a lower mean value (3.71) was 'talking with the instructor during office hours'. All the other items received values quite close to four. In fact, students asked a lot of questions about the continuous assessment of the subject. When analyzing the elements associated with 'student comfort with class participation', two of the statements were also highly assessed. Again, the item with lower values (and again with the higher variance) was the one related with an action to be done outside class hours, in other words, 'working with their peers outside class hours'. Both low values may suggest that students are initially more oriented to perform their learning activities within class hours. Further research should be done in these specific items to shed light on both statements.

The third section of the form was focused on the assessment of the reciprocal interview activity. Two sentences were provided to check how students assessed the activity, one in positive while the other one is formulated in negative. Both results were consistent, giving good feedback about the activity. Here again, further research to compare the results generated by different first day activities should be carried out. In the framework of the NLC [76,77], a list of available activities to be done in the specific context of engineering and management subjects during the welcoming should be made. This list can be completed after an analysis of the evaluation and effectivity of the potential activities by means of student surveys. It seems that the reciprocal interview activity, according to the results obtained in the survey, worked very well considering the students' opinions, in line with other research works [12].

The last section of the questionnaire was designed to check what specific issues had emerged from the reciprocal interview activity. Understanding expectations, sharing concerns with instructors, and becoming comfortable with their participation in class were very well valuated (all equal to or greater than four).

5.3. Practical Implications of the Findings

Once the main findings of the research are presented, different practical implications emerge. The mere fact that students realize that their opinions are heard and considered increases their engagement [41]. Hence, both activities performed on the first day of class that give voice to the students can enhance their engagement. In addition, the information collected through the answers of both activities is very valuable feedback for the instructors. Moreover, in the case of implementing some students' opinions, engagement can increase since they perceive that their ideas have been valued and applied [41]. Another option that may enhance engagement is to promote the use of new technologies by students [95], and once again, asking students about how they perceive their experience using technology [82] may be crucial. Finally, promoting peer-to-peer interaction also may increase engagement [96]. In fact, most of these actions took place in the context of this research through both activities that were carried out the first day of class.

5.4. Limitations, Restrictions and Future Research Directions

A first limitation of both studies, the empirical survey and the assessment questionnaire about the reciprocal interview activity, was that surveyed students were restricted to those taking a second-year ICT engineering subject. Consequently, even though students from seven different ICT specialties were asked, which facilitates the comparison of student's perceptions across all the diverse ICT engineering programs, the sample was limited to second-year students. However, and to cope with this limitation, replicating this research work in other subjects has already been already scheduled. A second limitation related to the first day of class activity was that only one option was chosen, a reciprocal interview. Some of the other activities listed in this paper could be implemented in other subjects and in different academic courses to verify and compare results between the different first day activities. A third limitation was that students were invited to answer the survey with short sentences. This option was chosen to force students to first think and then write synthesized ideas. However, this option could lead to limiting the depth of their opinions. In fact, we are going to repeat these activities in the next academic year in different subjects, and we are planning to set a new limit (around twenty words).

Future research works should aim at properly developing the 'New Learning Concept' that is currently being implemented at La Salle URL [76,77]. Firstly, it would be wise to replicate the study of the 'likes and dislikes' of the first day of class in different subjects. Hence, third and fourth-year ICT engineering students should be surveyed in the context of subjects taken for all ICT engineering students to check if findings are similar in terms of items and its percentages. The study should be carried out in the context of engineering subjects and in the framework of business subjects. Secondly, and along the same line, preferences about 'what likes and what dislikes' could be done in the context of ICT master students to analyze eventual differences in students' preferences that may exist between undergraduate and master programs. Finally, besides the reciprocal interview, some other first day activities could be implemented to check its potential success in a technological context.

6. Conclusions

The main contribution of the empirical studies presented in this paper was to shed light about the preferred actions to be done on the first day of class in the specific framework of ICT engineering programs through collecting students' opinions. In fact, asking students preferences and carrying out an activity that promotes their participation is a powerful way to establish the tone of a subject, which impacts engagement and motivation. Findings were quite consistent with previous research in terms of the list of preferences, despite some differences in ranking and percentages. An item related to requiring 'motivating students' by instructors appears recurrently as one of the students' requests. Further, once a specific first day activity was implemented, by means of a reciprocal interview between students and instructors, students' perception about the activity were surveyed. According to the results of the survey based on those interviews, the activity was very positively assessed by students. These findings, results and experiences are very valuable in the framework of the NLC, specifically in the Welcoming stage, because the outcomes obtained from this research will help to develop in a tangible way the new learning strategy that is being implemented at this moment.

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A STEM Model to Engage Students in Sustainable Science Education through Sports: A Case Study in Qatar

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Abstract: Sports has the potential to integrate with different scientific subjects, including materials science and engineering, making it an ideal approach to enhance the students' affinity toward sustainable education in science, technology, engineering, and mathematics (STEM). Amid gradual educational reformations in the state of Qatar, a distinctive STEM program titled, "Science in Sports" (SIS) was launched to investigate STEM integrated learning in secondary school students. The participant students, 248 students (112 females and 136 males) from 15 different government-operated (public) secondary schools, from rural and urban areas, were given STEM workshops on one of the sports materials, during this pilot study, resultantly challenging them to engineer a sports product. The study employed a mixed-method study in which quantitative approaches were applied to analyze the program effectiveness, with a *t*-test statistical analysis performed over data collected from a period of five continuous years from 2012 to 2017 in five different cycles. A more dominant data collection included pre and post surveys, substantiating observations of the program facilitator and their schoolteachers were included in this research and development (R&D) study to review the student learning behavior for a qualitative approach. Moreover, the results of the strength, weakness, opportunities, and threats (SWOT) analysis provided an overview of the program's effectiveness in implicating the engagement of the students in exhibiting their prototypical skills in engineering sports products along with STEM literacy. Apart from understanding the scientific concepts/principles applied in simple sports applications, student attitudes toward STEM fields augmented, as witnessed by the student productivity.

Keywords: sustainable science education; science implementation; youth empowerment; high school students; STEM; sports science

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1. Introduction

Sports can promote social integration, economic development, develop teamwork capabilities, and improve physical and mental health. The state of Qatar has been recently brought to the limelight of the sports industry because it has grabbed the opportunity to host the most sought-after sports event—the FIFA world cup 2022. The coverage and discussions on the event and the wide-spread enthusiasm for the sports is a well-timed opportunity for the educational community to emphasize the positive impact of sports on students of all ages. In this context, trends show a growing inclination in youth toward sports and its related disciplines [1]. A significant percentage of high school students actively participate in sports and enjoy the competitive spirit, recreation, or personal development. Educators believe sports as paramount while providing a wholesome educational experience [2]. They are inspired by successful programs that use sports to empower the youth and educate them. There are studies on successful programs launched in Latin America and the Caribbean that achieved profound results. Additionally, several case studies have been performed on working with youth who were hooked to formal education through sports, changing their lives for the better and paving the way to better employment opportunities [2]. Their study describes the success of programs such as "A Ganar," which implemented team-based sports to help at-risk youth learn self-employment skills and enhance their physical, cognitive, and intellectual growth. In light of these studies, a rich background literature was collated by the research team on similar programs to understand the outcomes of implementing sports or sports-based techniques in learning. They were trying to overcome the shortcomings in students' learning goals in Qatar.

Our research program aims to couple science, technology, engineering, and mathematics (STEM) learning with sports in an advanced and different way than the previous reports, taking into account various influential factors in generating considerable interest in science education. We developed different concepts to create an innovative and thoughtful sports-based program capable of enhancing students' attitudes to STEM curriculum and STEM-driven careers. The program requirements needed to consider the factors of an out-of-school environment and supported the construction of a workshop for high school students, providing STEM activities. Apart from improving STEM literacy, this research was also capable of observing multiple competencies in students that could alleviate their cognitive behavior.

1.1. Relevant Literature Background

An uphill challenge faced by educators in Qatar in the recent past was the lack of sufficient development of STEM skills in students. Despite massive effort and investment made toward enriching the STEM program by authorities in the past two decades, the field is still unable to completely meet the great demand of a highly educated workforce that can support a knowledge-based economy. Countries that focused on STEM early on have embarked on a journey of innovations that has started steering the wheel of the global economy to their benefit [3,4]. Hence, the significance of STEM and increasing reliance on the STEM workforce cannot be downplayed for innovation-driven countries trying to maintain leadership in the world's economy [5–7]. Unfavorably for Qatar, various reports cite concerns regarding the lack of qualified Qatari STEM professionals and an obvious deficit in the level of learned skills itself [8–11]. This means strengthening the STEM discipline—its courses, content, or faculties—in itself is not enough; instead, educators should delve deeper into understanding the attitudes or underlying approach of Qatari youth toward STEM education. Identifying what quickly generates interest in sports and applying the same principles to education might be a pioneering but straightforward step in creating a positive impact in young minds to instill interest in STEM learning.

Many educational researchers provided direct insights into improving students' STEM interests with the help of activities instead of traditional instruction [12]. Citing numerous examples of integrating STEM, Wendell et al. [13] incorporated engineering design into the science curriculum with LEGO Mindstorm Kits. Subsequent results were profound, and it proved that students learn scientific concepts faster and better than an instruction-only curriculum. Having students participate in STEM activities is considered an assuring way to increase interest in STEM subjects and foster STEM literacy [6].

Role of Self-Motivation and Motivational Factors

Personal interest is another crucial factor in a student choosing to learn any discipline aiming to establish a career path [14]. Students across all socio-economic backgrounds find school education and learning disconnected from the real world, which makes schoolwork uninspiring or boring, gradually leading to underperformance in school. One of the key traits here that sets some students apart is self-motivation or personal interest. Evidence from previous studies suggests that students set their dispositions toward disciplines such as mathematics and science early in life much before higher education [12,15], indicating the crucial role of various motivation enhancing tools or techniques in modeling student interest at the right stage of growth. It was hypothesized by the Texas Academy of Mathematics and Science (TAMS) that students of different age groups might possess the competencies and skills required to become STEM professionals at varying degrees.

It could be an area of importance and interest for educational researchers to identify the key influential factors such as individual interests, teachers, curriculum, and out-of-school activities that can cultivate motivation in children of all ages. They believe that certain instigating factors can lead many students to favor STEM disciplines, target STEM careers, and promote broader participation in the future STEM workforce. Kilpatrick [16] recommended sports participation as an effective intrinsic motivator, which is also closely related to being a recommended youth development driver in Qatar and can inspire involvement without external incentives. Sports-based activities also act as drivers as in one of the dimensions of motivation, "Motivation to accomplish" [17]. It is also well supported by Choi and Song [18] study in which they discuss the effectiveness of sports in developing life skills and its potential to contribute to a wide range of subjects to make them palatable for students. Hence, we focused on an approach that could apply the students' interest in sports in encouraging them to participate in STEM activities that "speak" science through sports.

1.2. Conceptual Framework

Our method of projecting science through sports-driven activities was based on many analytical findings reported in different previous studies [19–21]. A detailed systematic study was performed on diverse research evidence determining factors for a student's STEM-driven "interest" in secondary education, focusing on both personal and social aspects (both parental and cultural). While introducing the concept of motivational factors, Hanrahan [20] implicated in her study that implementing more activities to reinforce positive attitudes for self-direction is preferential in active learning. Sports-driven activities creating situations similar to that in real-life problems were proven to enhance positive attitudes with their contribution to cognitive skills such as peer collaboration, problem solving, curiosity. These activities implemented to promote student-centered learning are a realistic approach [19,21,22] because they stimulate curiosity through problem-based situations [21]. These activities also enhance logical reasoning, helping the children attain better emotional, social, and physical well-being [23].

Taking into account sports-driven activities, it was crucial for us to construct a well-coursed framework of activities that can cultivate curiosity, STEM interest and consequently motivate participants to consider careers in similar fields, etc. The Material World Module (MWM) program, which aimed at instilling collaborative scientific research and engineering skills in high school students [24], provided adequate research backings to follow an inquiry and design methodology in our study. This Methodology introduces students to familiarize themselves through technological design, urging them to engage in hands-on activities to demonstrate how science is applied in our daily life routine. We developed the workshops, keeping the study evidence related to the importance of inquiry [25], problem solving, technical experience, and engineering projects to influence students' attitudes toward learning and enhance their science process skills. The first set of workshop activities was developed initially to aim to design sports products such as golf balls and baseballs. These two products were chosen randomly, inspired by the study conducted by [24]. Later, another set of workshop activities were constructed to consider designing sports products such as "concrete bowling ball" and "concrete boat" inspired from the competitions held by the American Concrete Institute (ACI) [26] and American Society of Civil Engineers (ASCE) National Concrete Canoe Competition (NCCC) [27]. However, both workshop activities (details in Figure 1 and Methodology Section, page 13) helped the students understand the structure and physical behavior of diverse composites such as concrete and other multi-layered sports materials and realize the science and correlating their application in daily life. In both sets of sports products (from workshops 1 and 2), we intended to develop the correlation between the underlying scientific concepts in each workshop offering the scientific principles in sports product development. The structure of implementing activities was similar in both the workshops, and the activities complement each other and lead the students to their respective design challenges.

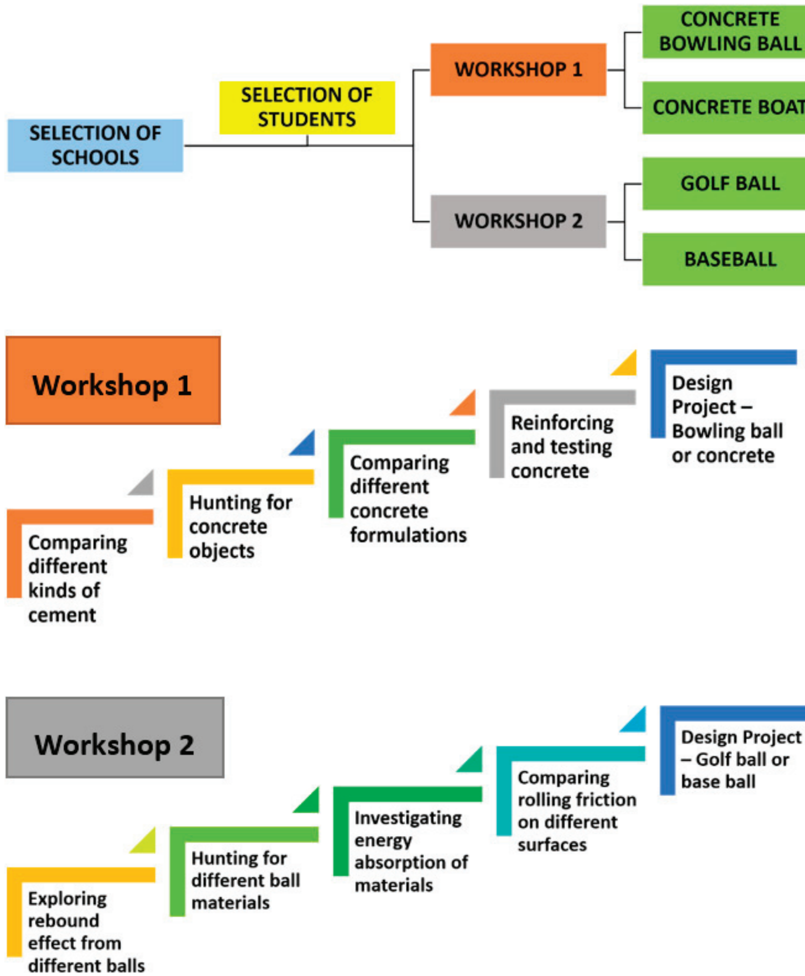

Figure 1. Schematic diagram of "Science in Sports" program methodology. The activity layout is provided for each workshop, demonstrating the daily activities for each day, Workshop 1 and Workshop 2 are directed to learn about concrete materials and sports materials, respectively. Regardless of the layout, the design project does not culminate on day 5 and takes nearly three months to complete after repetitive testing.

1.3. Research Objectives

The study was based on a program, "Science in Sports" (SIS), intended to steer high school students' passion in sports to explore the embedded science and gradually evolve into aspirants in STEM fields. The study emphasizes the program's successful integration of science in sports by solving engineering design challenges that arise while developing a sports product. The research objective was solely focused on acquainting them with STEM and its relevance in daily life by engineering simple sports products. The research questions that need to be addressed during our study are

1. Did the student understand the importance of STEM by experiencing science through sports product engineering?
2. Will the student consider a STEM-driven career resultantly in the future?

3. Were the students able to understand and correlate scientific principles to the applications in daily life?

Apart from the above questions, the research was capable of deriving the exceptional secondary students' dispositions and self-efficacy in carrying out scientific experiments. The learning environment bolstered by sports products-driven challenges is an influencing factor that will be utilized in attracting Qatar's secondary youth to attain the program goals. Integrating sports as a carrier for acquainting scientific knowledge, the study will examine the diverse possibilities in promoting science process skills, reinforcing their attitudes toward science and engineering fields by intriguing them for creative learning.

2. Materials and Methods

The SIS program was designed and evaluated by employing a mixed-method study that implemented both quantitative and a more dominant qualitative analysis. While the former method used statistical tools to assess student attitudes toward STEM importance, relevance in daily life and future careers, the latter involved the observations of facilitators and school teachers who mentored the students during the program. Other qualitative data were retrieved from field notes, media (photos and videos), and student artifacts to derive an outlook on developing reasoning competencies and dispositions of the students as they progressed through the research. The annual program functioned within a three-month tentative period. The students experienced science and engineering through a science workshop directing them to construct a sports product for the engineering design challenge (Figure 1).

2.1. Participants and the Educational Context

The current study was conducted on 248 high school students including 112 girls and 136 boys from grades 10 and 11, who attended the SIS program from 2012 to 2017 in five cycles, over the five continuous years. The three-month time taken by each batch of students in one year for participating in the program was addressed as one cycle, and therefore, the study witnessed five batches of students from 15 schools over five cycles, as in Table 1. The participant students were provided with STEM workshops on different types of composite materials. While some schools were provided with "Workshop 1," for familiarizing themselves with concrete composites, other participating schools engaged in "Workshop 2" on some other sports material used for rebounding balls. The schools were assigned either of the topics on a random choice. For the first two cycles, the schools were from urban areas, whereas the schools involved in the experimental study during the third cycle were from rural areas, hence a smaller number of participants. However, in consequent years, we experimented on students from both urban (fourth cycle) and rural schools (fifth cycle), respectively.

Table 1. Demographic details of participants and Qatari student percentage. The total participant count for all five years is 275. However, there were student withdrawals, and hence the study was conducted on a fewer number of participants (248) according to the questionnaire analysis, for those who have completed both pre and post questionnaires.

Cycle	Total Number of Students				Number of Withdrawals (Nw)		Qatari Students				Schools	
	M	%	F	%	Nw	%	M	%	F	%	M	F
Cycle 1: 2012	24	47.1	27	52.9	0	0	19	79.1	26	96.2	1	1
Cycle 2: 2013	36	60	24	40	4	6.6	36	100	24	100	2	1
Cycle 3: 2014	24	63.5	16	36.5	5	12.5	18	75	14	91.3	2	1
Cycle 4: 2015	36	60	24	40	8	13.3	31	86.1	21	87.5	2	1
Cycle 5: 2016	29	45.3	35	54.6	10	15.6	27	93.1	35	100	1	2
Total	149	54.1	126	45.8	27	9	131	87.9	120	95.2	8	6

The number of schools participating per cycle was then limited to three due to the restricted working time that could be engaged by the facilitator for the workshop hours and the product development phase that took place during their after-school period. The engineering of sports products consumed most of the program schedule because it was carried out within two months. Even though the program tenure was three months, a certain amount of time (as mentioned in the next section) was taken off for their regular school activities, including examinations scheduled according to the academic calendar.

The schools with maximum national student enrollment were chosen for the program during the initial screening process because the study primarily targeted Qatari students and their development. The schools were also requested to strictly maintain at least 75% of national students for the program (due to the aim of the national capacity building). The final filtrate of students was selected according to the first-come, first-served basis, regardless of their intellectual capacity, and was grouped into students of three or four, maintaining a demographic ratio of non-national students and national students as 1:2 or 1:3, respectively, as in the case of participation of non-national students. (refer to Table 1).

The program was organized and delivered by the program facilitator, who is also the first author of this article. She holds a degree in engineering and has seven years of experience in STEM education. She is skilled in identifying the key areas of interest in a student and helps in applying them to overcome their learning deficits. She has experience designing and delivering around 90 engineering workshops for school students ranging from primary and secondary stages. The findings stated in this article corresponds to her observations noted in the daily report for each session and interaction with the students. For this study, with the assistance of other STEM professionals (PhD/Masters/bachelor's degree holders) of the Al-Bairaq team at the Qatar University Young Scientists Center (YSC), field notes, observations, and various resources were employed for the detailed analysis. Here, it is essential to mention that the YSC team has an extensive 10 years of experience in constructing workshops and educational activities. Table 1 details the number of participants and the percentage of Qatari student participation during each cycle.

2.2. Methods

The facilitator offered extensive two-hour daily workshops for a week with diverse hands-on activities (refer to Figure 1) to engage the students in experiential learning. The main goal of providing workshops to the students was to acquaint them with enough scientific information to design and construct the sports products—concrete boat, bowling ball, golf ball, and baseball. Each school was either provided with STEM workshops—"Workshop 1" and "Workshop 2" (refer to Figure 1)—leading to the respective sports products. The workshops were followed by informal sessions for designing and constructing the product. During these sessions, the students had free choice to carry out the procedure; however, they would have to adhere to the facilitator's evaluation criteria, as in Table 2. These sessions were also allocated to repeated testing and designing of the product prototypes. In case of failure in creating the product according to the desired criteria, they would have to start over again or fix the products for positive results. The facilitators recorded student responses and learning behavior during the activities from attending workshops until they accomplished the final products. The facilitator observations were later analyzed to understand the student response or learning behavior exhibited during their project course.

The method exercised on the students through each of the following workshops is briefed below.

2.2.1. Workshop 1

Students' groups provided with "Workshop 1" were monitored by their respective schools for successful completion of a concrete boat or a concrete bowling ball as a final product. Workshop 1 taught students about concrete materials, the making of concrete, the different properties of concrete composites, and their diverse applications through a set of diverse activities developed by integrating all STEM subjects. The activities that were carried out to satisfy the workshop objectives are detailed hereafter (Figure 1):

- Activity 1: Comparing different kinds of cement—The workshop started with an ice-breaking experiment, wherein the students studied the different types of cement, one of the key ingredients in the concrete composite. They explored their hardening rates by measuring in different weights and analyzing the consequent results. They plotted graphs and interpreted them, thereby understanding the necessary science behind the process;
- Activity 2: Hunting for concrete objects—They researched different concrete applications, thereby increasing students' awareness of the most common infrastructure material. This activity was crucial in enhancing students' inquiry and research skills as they observe, question, learn, and deduce reasons behind using concrete materials;
- Activity 3: Comparing different concrete formulations—They familiarized themselves with the different ratios of ingredients/aggregates, i.e., sand, gravel, and cement, by experimenting with them to understand the properties of concrete, mainly density, hardness, and strength, according to the difference in ratios. They compared cement with concrete blocks and studied the packing of different aggregates to understand how each aggregate ratio affects concrete density;
- Activity 4: Reinforcing and testing concrete—The students grasped the effect of reinforcing materials on concrete properties, understanding their effect on strength and hardness. Moreover, they also tested the reinforced concrete blocks and compared them with non-reinforced concrete using strength-test apparatus, confirming the superior quality over the other.

Design project—All the above activities led the students to acquire the necessary knowledge in creating one of the sports products, i.e., a concrete bowling ball or a concrete floating boat, as a part of the design project. The workshop put forth design challenges for the students to choose the sports product for the design project and construct according to the preset criteria (refer to Table 2). The students interpreted the correct mixing-proportions for adequate sports product results through trial-and-error methods. The students also made careful decisions to meet the criteria, thereby choosing or preparing the correct casting mold, which will hold the concrete mixture.

The design criteria to create the respective sports products are elaborated hereafter:

1. Bowling ball—The group of students who chose to design a bowling ball considered certain conditions (refer to Table 2) to meet parameters such as surface smoothness, the ball's weight, and the distance traveled by it when rolled on a solid surface. The evaluators observed balls' surface smoothness by touching the balls and comparing them between that of each group to score the maximum. The entire construction of the bowling ball was wholly administered and carried out by the participants based on their judgment. They chose spherical mold and prepared concrete mixtures as per their choice of shape and ingredient proportions, although the facilitator pronounced the optimum ratio. They also performed casting, i.e., filled the molds with the fresh concrete mixtures and left them to dry for 1–2 weeks. Based on their judgment, they removed molds to carry out the curing process. The curing process is by which the concrete samples are hydrated to improve their strength. The students were solely responsible for deciding the curing time for concrete structures, which is an essential step in the construction because it affects the strength of the product. The students were also provided permission to smoothen the surface using any external tools such as a metal file rather than depending on the mold's texture, which naturally gives a smooth surface. This whole process was repeated if the end product broke or failed in meeting the diameter due to shrinkage. The ball was also dropped from a height multiple times to test its strength or success of the product. Once the ball met the required smoothness and weight, the test bowling ball was assessed by rolling through a V-shaped ramp to strike the bowling pins set across the lane. The wooden ramp was 1220 mm long and raised 400 mm on one end to achieve a reasonable ball

speed (refer to Figure 2a). The ball had to "strike" between two edges spaced 600 mm apart at the end of the 3000 mm long lane. The test product, positioned at the top of a V-shaped ramp with no dust, was propelled down by gravity's force at room temperature onto a flat-surfaced lane. The ramp was made from two rectangular slabs of plywood, 440 mm wide, placed at an angle of 40 degrees from the flat surface (refer to Figure 2a). The product ball was rolled in two orientations as arbitrarily marked "mostly perpendicular" on the ball. For each orientation, the ball was tried twice to pass through the strike zone successfully;

2. Concrete boat—The design product alternative to the student's choice of "concrete bowling ball" was the concrete boat. The concrete boat was expected to meet certain assessment conditions (refer to Table 2) in parameters such as buoyancy, load-carrying capacity, and float time. Similar to the bowling ball design, the participants either made a mold out of raw materials such as foam, cardboard, wood, etc. or chose a mold with an appropriate size that could be immersed in a rectangular box of 40 × 70 × 40 cm^3 filled three-quarter with water as a part of testing (refer to Figure 2f). The students went under similar conditions in choosing the correct amount of concrete aggregates, casting, and curing identical to that of the bowling ball. The testing of the boat, however, was conducted in the water-filled tank as mentioned earlier and was carried out in three phases as follows:
    - Assessment phase 1—The empty boat was placed in the water to examine its behavior under external factors; for example, the boat was tested to analyze its stability in the water and float freely for a minimum of 5 s. The students also ensured that the boat was self-balanced while floating on the water (without touching the sides of the water-filled tank/box) (refer to Figure 2c);
    - Assessment phase 2—It was assessed for another 60 s to monitor the internal parameters such as the concrete boat's quality in terms of leakage, water displacement, water absorption by the concrete walls, etc. While water leakage was observed visually, looking for traces of wetness in the interior of the boat, water displacement was monitored by examining the volume of the boat and the height by which the water rises in the tank. The interior of the boat was observed for wetness or moisture to test the absorption of concrete;
    - Assessment condition 3—The boat would be lastly tested for its load-carrying capacity. The initial cargo added to the boat was 5 g. Students incremented the weights only if the boat was in a stable condition without rocking to and fro in the tank. Cargo of 5 g was usually added in increments until the point when the vessel began to take on water. However, in some cases, students also used 10 g weights, depending upon the availability of weights. There was no minimum requirement for the cargo weight, and hence, the boat carrying maximum cargo without taking in water was considered for scoring the most in the score sheet. The leakages and similar defects observed in a few cases were fixed before the final trial for marking scores.

2.2.2. Workshop 2

The groups of students provided with Workshop 2 were monitored by the respective school to design a baseball or golf ball successfully. During the workshop, the students were familiarized with different sports materials and their properties, thereby cultivating their observational skills and analyzing capabilities. As the workshop progressed, the students performed hands-on experiments that provided a visual representation of scientific concepts such as friction, rebound, and energy transformations that are typically conveyed as regular school lectures. They were also acquainted with the different parameters that affected the functioning of the products. The various STEM activities (refer to Figure 1) carried out during the workshop is detailed as follows:

- Activity 1: Exploring rebound effect from different balls—As the workshop started with an ice-breaking activity, the students studied the rebound ability of different sports balls that were identical in shape and size, despite the materials, using a drop test (freely dropping from a specific height and measuring the rebound length);

- Activity 2: Hunting for different ball designs and materials—This activity, bolstering inquiry skills in high school participants, encouraged research on different sports materials such as cowhide, rubber, leather, etc. used in balls. Students studied different balls such as basketball, football, baseball, golf ball, etc. and hypothesized the purpose of each material as applied in a specific sports product. They also examined the design for each sports ball and compared its functionality. They interpreted the results mathematically in the form of graphs because STEM integration was encouraged throughout the activities.
- Activity 3: Investigating energy absorption of materials—During this activity, students familiarized themselves with energy absorption as they calculated the rebound height of a ball when impacted on different materials (floor tile, wooden board, carpet, felt) under freefall, thereby learning about energy absorption of the respective materials. Students also observed surface deformation in the case of different balls' impact. They also determined conclusions based on their acquired knowledge of the relationship between surface deformation and energy absorption;
- Activity 4: Comparing rolling friction on different surfaces—During this activity, students examined the behavior of different materials with respect to generating a frictional force on a rolling ball. Students tested different sports balls on each mat material one by one to draw out conclusions. They familiarized themselves with various frictional forces—kinetic, rolling, and static. They also interpreted results drawn from rolling ball surface and mat surface to be distinct from each other, and rolling action entirely depended on the materials.

Design project—This workshop focused on challenging the students to design sports products such as baseball and golf ball with materials that can provide the optimum results to meet several criteria (refer to Table 2). Since they invested a productive period for researching and understanding different materials during the workshop, they also performed binding and arranging different materials to obtain the desired outcomes, as in golf ball and baseball. The students evaluated their products' strengths and drawbacks, keeping records of every detail during their project work.

1. Baseball—The students who chose to design a baseball needed to overlook the evaluation criteria such as specificity in its diameter, weight, and the maximum ability to rebound on free fall. Since the regularity in the diameter of a handmade ball could not be guaranteed, the test ball diameter was measured using a Vernier scale (refer to Figure 2g). They transferred the knowledge acquired from the workshops to choose varied materials that could satisfy the requisites while testing the product balls. During the testing, the test baseball was freely dropped from a specific height of 1 m to measure the rebound height;
2. Golf ball—The golf ball challenge was staged in two sections, i.e., constructing the golf course pit and designing the golf ball for the students who chose the golf ball design project.

The students initially constructed a golf pit using synthetic materials considering rolling friction, rebound effect, and impact energy (refer to Figure 2f). They employed different materials, such as felt and synthetic grass in the pit area, to restrict a golf ball's rolling within a specific length (refer to Table 2).

While designing the golf ball, the participants considered different materials according to their behavior to accomplish specific scientific concepts that could satisfy the preset conditions (refer to Table 2). They chose the materials that led to building a smaller diameter ball with a specific weight producing lower rebound ability when compared to that of a baseball.

While testing, the ball was rolled down the tube (PVC tube, cut to 30 cm length) and placed fixed at an angle of 30 degrees (as shown in Figure 2e). The students determined the success of the ball, depending upon its ability to bounce once and clear the obstacle, roll across the green area, and stop within the target area (refer to Figure 2e). The test was repeated enough to obtain a 75% success rate for the respective product, i.e., out of four test attempts, the ball should be successful for three tries.

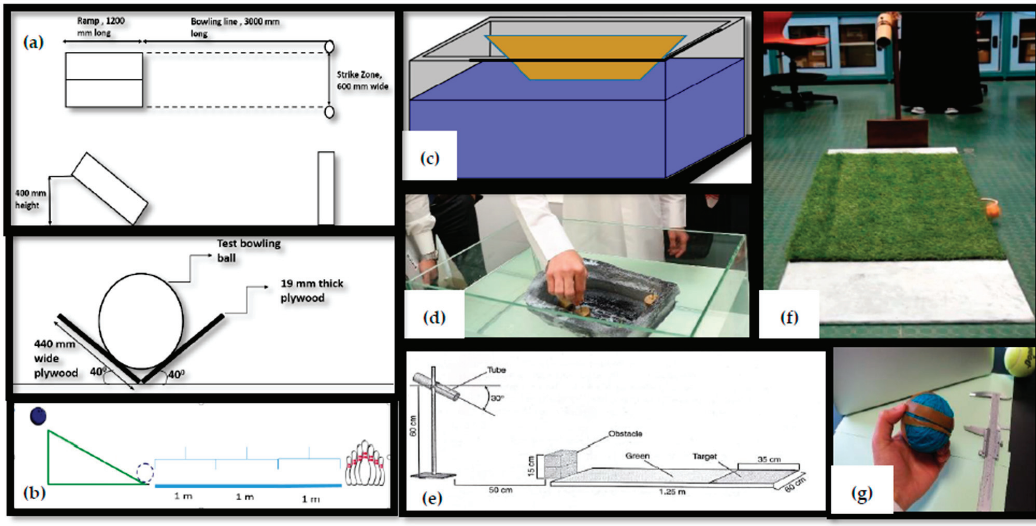

Figure 2. Schematic diagram of testing the different sports products. (**a**) An elevation view of the testing pits for the concrete bowling ball. (**b**) The front view of a schematic representation of the front view of a bowling ball testing kit. (**c**) The schematic representation of testing a concrete boat in a tank, three-quarter filled with water. (**d**) The concrete boat should be able to carry weight without sinking or any leakage. (**e**) The schematic diagram for the testing pit of a golf ball. The students prepare a golf course pit using different materials to test the rolling action of the golf ball. (**f**) A golf course is set up by the students to test their product golf balls considering the different parameters such as friction, rebound effect, etc. (**g**) A baseball diameter is tested using a Vernier scale.

Table 2. The list of parameters that need to be satisfied for excellent results.

Product.	Parameter	Requirement
Concrete Bowling ball	Surface smoothness Weight of the ball Distance traveled	Smooth surface Less than 5.5 Kg 3 m and hit the pins as shown in Figure 2b
Concrete Boat	Buoyancy without weights (External factors) Buoyancy without weights (Internal factors) Loading capacity	Floating < 5 s Floating < 60 s Maximum weights
Baseball	Diameter Weight Ability to rebound	7.3 cm to 7.6 cm 142 g to 149 g Maximum
Golf ball	Diameter Ability to rebound Ability to roll and stop (Friction)	Between 4.5 and 5.5 cm Bounce once and clear the obstacle Stop at target area

2.3. Data Collection Methods

Different forms of qualitative data were collected during the program, including facilitator observations, field notes, media (photos and videos), and student artifacts. The facilitator recorded daily observations immediately after the session that detailed student regular attendance, their learning outcomes, or cognitive skills acquired during each workshop session, and progress in their daily project work. She also recorded progress and obstacles during each workshop day, during which field notes, images, and videos were also taken. Questionnaires, as a quantitative data-collecting tool, were provided to the students before and after the workshop, later analyzed to understand the improvement in their attitudes toward STEM fields, the relevance, and STEM-driven careers. The questionnaires were adapted from previous research studies but were modified according to the study objectives [24]. Student artifacts/work that comprised of project presentations, sports products, and documentation video were also collected and presented as a part of a program-adjourning event, which was later utilized for the study. The two primary program evaluation tools that were implemented in data analysis are detailed below.

2.3.1. Pre and Post Questionnaires

The students were obliged to complete a set of study questionnaires (refer to Table S1 in Supplementary Materials) by pen and paper method to assess their attitude on science, technology, engineering, and mathematics (STEM) and its impact in the real world. The questionnaires consisted of multiple-choice questions that stemmed from the student opinion on STEM education, their career interests in scientific fields, and their skills. The students may recommend from four standards of agreement: "agree", "neutral", "disagree," and "do not know". The questionnaires were assessed using standard monitoring and evaluation (M&E) procedures. The mean percentages of agreement of pre and post questionnaire results were compared in the procedure to analyze the outcome of the program. The questionnaire analysis used the Likert Scale (R. Likert, 1932), a one-dimensional psychometric response scale measuring a single trait implemented in questionnaires to achieve the participants' degree of agreement to a statement or set of statements. We used a 3-point scale ranging from "Agree" on one end to "Disagree" on the other with "Neutral" in the middle.

The questionnaires were pivotal in measuring their agreement on the importance of STEM fields, career aspirations, and their views toward independently performing a scientific experiment. Eventually, both the post and pre questionnaires were analyzed together to obtain the results.

2.3.2. Evaluation of Project Presentation

After completion, the products would be examined by external evaluators from sports facilities, academia, and leading economy driving industries. This evaluation was performed during a conference for two days to felicitate the student work. The evaluation was carried out in two stages—day 1 and day 2. On day 1, all the program participants were evaluated on their STEM competencies acquired through the sports product engineering project. They presented their project experience in a PowerPoint presentation, implementing digitalization in the process, and self-mentoring themselves in preparing for the evaluators' queries. The project presentation provided the students with opportunities to showcase their efforts. The examiners also challenged the students with questions that could assess their critical thinking and future outlook on their products.

Although each product had its respective testing criteria, as shown in Table 2, the evaluators also examined for other criteria, which were common to every design project. They had a separate rubric (refer to Table S2 in Supplementary Materials) for each student group presentation to rate the students' organizational ability, self-confidence, research methods employed for the design project, and critical thinking. The students were also rated for the quality of slides that were displayed as a part of their presentation. They were also scored for the students' creative display for choosing product mold, materials, and the quality of work exhibited in accomplishing each task.

The external examiners were from different backgrounds to perform a fair and overall assessment of the student work. For each design project, each sports product was examined on day 1 of the conference by a set of three judges. While one judge who held PhD qualifications and served as an academic in a university assessed the depth of scientific details and principles applied in the product, the other two, from the industry with backgrounds in engineering, focused on the presentation quality and the scope of the product in the future.

On the other hand, day 2 of the conference witnessed the participation of selected students who scored the maximum on day 1 evaluation. Only one group of participants from each category of sports product presented before the judges, who, this time, were from a wide range of fields that even included sports science specialty. There were five judges, one from academia, one from a sports training facility, and the other three from leading oil and gas industries. The first two judges were focused on science and sports, exploring the scientific knowledge and application of students. The latter three who hailed from the training and development department of heavy industries evaluated students' competency display because they were more focused on the STEM skill development and presentation of the national participants.

3. Results

In this section, we lay out findings that include summaries of the journey of the students with each sports product based on the observation made by the facilitator during each session with the student. The findings drawn below are also based on their PowerPoint presentation from participant artifacts during their course-adjourning event. The students elaborated on their project journey and the number of trials and failures, providing the examiners the opportunity to picture the complete journey in the PowerPoint presentations. We also provided results drawn from statistical analysis of pre and post questionnaires that demonstrate the student attitudes toward STEM-driven careers and the importance of STEM in daily lives. According to conclusions in PowerPoint presentations, the participant students recorded their complete attempts, their reason for failure, and their successful attempts. These records were crucial in analyzing their problem-solving skills that provided adequate backings for facilitator observations.

3.1. Analysis of Sports Products

3.1.1. Design Product 1

Design product 1 chosen by a few participants of the concrete workshop was a concrete bowling ball that could roll on a solid dust-free surface and strike the pins set at the end of the course. The participants successfully constructed and designed bowling balls that met different criteria, such as surface smoothness, specific weight, and distance rolled, for the final evaluation (refer to Figure 3a). Since surface smoothness was one of the three requisites for successful completion as in Table 2, they chose suitable molds for casting concrete mixture that could provide a smooth texture, appropriate size, weight, and shape for the product. The design of the mold also influenced the resulting functioning of the product. The application of the right mold for casting a concrete mixture requires fine techniques and an understanding of texture, physical strength, and measurement. The students were ensured to choose a mold that can hold heavy concrete mixtures and can be easily broken once the concrete is ready. While some students used volleyball as a mold, most of the students used spherical light bulbs made from plastic or glass.

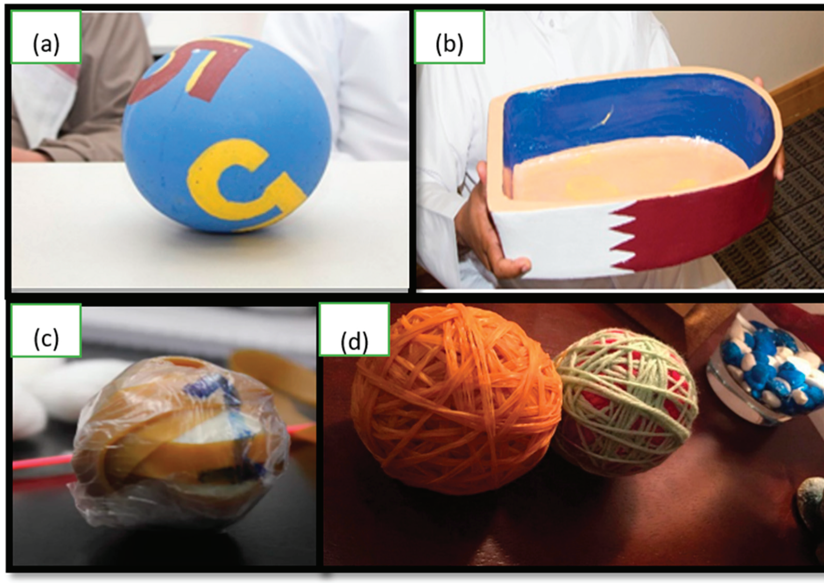

Figure 3. Examples of students' sports products that were displayed during the program- adjourning event. (**a**) A sample concrete boat is made as an engineering design challenge by the students applying knowledge acquired. (**b**) The students applying knowledge acquired during the concrete workshop session make a sample concrete bowling ball as an engineering design challenge. (**c**) A golf ball made by the participant groups is illustrated through the images. The students transfer knowledge acquired during the sports material workshop session by making a sample golf ball as an engineering design challenge. (**d**) Different samples of baseballs as developed by participant students. The latter images also showcase the binding of the materials in different patterns.

Another criterion of specific weight was also met by the students' different measures to accomplish the task. For appropriate weights, students considered different reinforcing materials that could contribute to balancing the weight and strength, and quality of the product (refer to Figure S1 in Supplementary Materials). Moreover, restricting the weight of the ball according to the evaluation criteria was a major challenge as they repeatedly tested various combinations of concrete mixture ingredients to obtain the desired weight within the specific diameter. It was completely students' choice to fix the composition of concrete ingredients, and thus, they had to ensure that they had enough concrete to fill the mold.

Since the students were faced with multiple conditions, i.e., restricting weight as in Table 2 and maintaining a spherical shape simultaneously, the assignment nurtured their thinking capacity and solving capabilities, in turn enhancing their critical thinking and problem-solving skills. The students also familiarized themselves with the impact and different techniques for proper mixing, as in the boat challenge, to obtain the desired texture and consistency without any lumps. The finished product was tested by dropping freely down the ramp, set 3 m away from the bowling pins (refer to Figure 2b). While rolling the ball on the ground, the students identified the possible flaws in the product that might have resulted from improper texture, weight, or shape depending on the rolling action of the balls. The testing of bowling balls fascinated the students as they indulged in "play and learn," thereby engaging actively in the program.

Table 3 implicates the course of two random groups (1a, 1b) who applied the trial-and-error method to create the final successful product, which was obtained from student records in PowerPoint presentations. This table also provides insight into developing their reasoning and problem-solving tactics as they carried different strategies to accomplish the task. They were also challenged while testing their product, concrete ball, by dropping the finished product freely down a ramp set 3 m away from the bowling pins (refer to Figure S1 in Supplementary Materials).

Table 3. The information on two random groups attempting design product 1.

Sample Groups	Sample Products	Trial Count	Reason of Failure (Refer to Table 2 for Criteria)	Reason for Success
Group 1a	Concrete bowling ball	two attempts	The mold used was big.	Changed the mold to make a smaller ball
Group 1b		four attempts	1. The size of the ball does not meet the competition's requirements. 2. The product was heavier than the weight limit, which is 5.5 kg and had many holes that were difficult to remove. 3. Adding the paper balls made it easier to break as they had a lot of cracks and took a lot of space, which made the bowling ball weaker; after several tests, It got broken.	Added a plastic ball at the core that balanced the weight required keeping the diameter under the condition.

The students assigned with the bowling ball challenge hardly had opportunities to vary the design of their product regarding the shape, owing to the fixed spherical shape and diameter, in contrast to the concrete boat challenge. Hence, most of their creativity was exhibited in designing the final product. They gave careful consideration in painting their products (Figure S1 in Supplementary Materials) and presenting it to the judges as creativity was one of the criteria in the rubric (refer to Table S2 in Supplementary Materials) set for them.

3.1.2. Design Product 2

Design product 2, chosen by some of the concrete workshop participants, was a concrete boat capable of floating and carrying cargo. The students exhibited a wide caliber of proficiency while designing boats that satisfied the buoyancy and load carrying capacity (refer to Figure 3b). They were examined for their product quality in terms of scientific application and various skillset as they paced from the basic steps of the engineering challenge to successfully presenting a fully functional product. The resulting boats also supported the expected quality of concrete that displayed efficiency in terms of parameters such as workability, durability, strength, cost, and finished appearance. The quality assurance of the product was solely attributed to the student competencies, which ensured not to overlook factors such as the ratio of ingredients, mixing of the ingredients, handling of the fresh concrete, and finally, placing for curing until the ultimate strength was achieved (refer to Figure S2 in Supplementary Materials). Once the concrete boats exhibited fine strength and texture, it was tested by floating in water-filled tanks. In the case of failures such as leakage or inability to float or/and carry weight, the product was subjected to reconstruction or improvisations and retesting.

The students also exhibited remarkable problem-solving skills as they followed a trial-and-error method to construct the sports product and optimize the experiment in a scientific method. From Table 4, it was identifiable that they were able to recognize the reasons for failure and success distinctly, for example, cracks, leakages, inability to float, or even concrete collapsing on mold dismantling. Some groups of students attempted several trials, ranging from a minimum of two to an utmost nine trials, in accomplishing the nearest best solution. Table 4 provides the course of two random groups, 2a and 2b, with their number of attempts and improvisations as represented in PowerPoint presentations. Eventually, this concrete boat challenge was also suitable for drawing their creativity out. It encouraged the students to display artistic talent in addition to STEM learning while sketching their product structure or painting the finished product (refer to Figure S2 in Supplementary Materials).

Table 4. The information on two random groups attempting design product 2.

Sample Groups	Sample Products	Trial Count	Reason of Failure (Refer Table 2 for Criteria)	Reason for Success
Group 2a	Concrete Boat	three attempts	1. Amount of Cement is less than the fly ash and silica. 2. The boat design was not uniform	1. The ratio of concrete materials was appropriate. 2. The design was modified, and the boat floated and held weight.
Group 2b		three attempts	1. The ratio of concrete aggregates was not appropriate. 2. The reinforcing material for the concrete could not hold as the group tried a green concrete mixture.	Succeeded in the right ratio of materials.

3.1.3. Design Product 3

Design product 3, chosen by some of the sports materials workshop students, was a golf ball conditioned to pass an obstacle, rolling down the course to stop at a certain point.

The golf ball challenge was carried out in two distinct phases: Phase 1—constructing the golf course pit and Phase 2—designing a golf ball.

- Phase 1—The students designed and constructed a miniature golf course pit (refer to Figure S3 in Supplementary Materials) so that they could test their product golf balls. They set up a course pit, as shown in Figure 2e, according to the required parameters and implemented synthetic materials that contributed to the effective testing of the sports products. The students also applied the knowledge acquired during the sports materials workshop in successfully designing and building the pit. They constructed the course pit using felt and synthetic grass sheet made from polypropylene, polyethylene, and nylon. They were successful in restricting their product balls within the specified length and width of the designed course. While constructing the course pit, they used a standard golf ball for testing the course pit in meeting the adequate condition. The students tested different materials to lay on the pit and rolled the ball down the PVC tube to pass the obstacle, as shown in Figure 2e. The expected functionality of the laid materials was to restrict the rolling of the ball to a specific length of 1.25 m, as shown in Figure 2b.
- Phase 2—The students successfully designed and tested golf balls (refer to Figure 3c) that were able to satisfy the preset conditions (refer to Table 2). They chose optimum materials that contributed to accomplishing their design criteria, specifically balancing the required rebound ability to cross the obstacle and the desired diameter. Evaluating their techniques, the students also considered the efficiency of the ball's binding process as crucial in obtaining the best results. If the ball was not tightly bound, the rebound results may vary due to the irregularity in its shape and uneven energy transfer. The students also experimented in binding and varying techniques resulting in varying outcomes, as shown in Figure 3c. They studied and applied different scientific principles such as the energy of absorption of different materials when subjected to impact on solid ground.

Resultantly, students applied trial-and-error methods to solve their task, as similar to the other three design product challenges (refer to Table 5), which were retrieved from PowerPoint presentations. They could clearly identify the shortcomings, assess their product, and apply the acquired knowledge to create a successful outcome. In some cases, the students also reattempted to improve the results of the product, even though the first attempt did clear the task. This also detailed their attitude of creating room for continuous self-improvement. In due process, they also bolstered inquiry skills as they continually asked questions such as, "what are the factors" or "what are the materials" for deriving a successful output. Table 5 implicates the course of two random groups who applied the trial-and-error method to create the final successful product.

Table 5. The information on two random groups attempting design product 3.

Sample Groups	Sample Products	Trial Count	Reason of Failure (Refer to Table 2 for Criteria)	Reason for Success
Group 3a	Golf ball	two attempts	The rebound was not enough to jump the obstacle (refer to Figure 2e)	A rubber core was made using glue to create the bouncy effect without increasing weight
Group 3b		two attempts	The golf ball made during the first attempt was considered a failure because the students made a better product that gave better results	Used different ratios of the materials.

The students' creativity was also tested in their choice of materials (as in Figure 3c) used in designing the balls to obtain the desired weight, diameter, and rebound properties. They experimented in applying different materials, such as glue, rubber bands, bouncy balls, etc., to construct either the outer layers or the inner core material, thereby testing their limits to creative imagination.

3.1.4. Design Product 4

Design product 4, chosen by some group of Workshop 2 participants, was a baseball exhibiting a considerable rebound height. The students were focused on choosing materials that contributed to accomplishing the design criteria, specifically the rebound ability. They sandwiched different materials, such as rubber, yarn, fabric, etc., depending upon their weight and rebound ability to construct a ball structure. The order of placing different materials was also varied, looking for the best rebound effect. In some cases, they varied the usage of rubber material, for example, they used a rubber ball as the inner core as well wrapped rubber bands outside to form the outer core. In some cases, they also put forth innovative ideas such as a plastic mini ball as a core, contributing to less weight and best rebound results under restricted diameter. The students also applied techniques while binding the materials that contributed to the product's different properties (refer to Figure 3d) such as spherical shape and rebound effect, etc. A loosely bound ball was observed to rebound less when compared to a tightly bound ball as the ball deformation was varied on-ground impact and energy was distributed unevenly. These observations inspired students to understand basic concepts of science in a better way. The students tested their completed baseball products (refer to Figure 3d) by freely dropping them from a height of 1 m, thereby addressing the product's possible flaws. The students also considered the scientific facts, e.g., how the efficiency of binding contributes to the fineness of the ball surface. The participants also tried different binding patterns and materials, as shown in Figure 3d, which influenced the outcome of each product.

The students also solved their challenges in obtaining a balanced baseball with the desired weight and diameter by implementing the trial-and-error method (refer to Table 6, according to the conclusions from PowerPoint presentations). Moreover, as they introduced unique solutions to solve the problem, portraying the creative side of their cognizance, they referred to materials such as cowhide, yarn, etc. that could help solve the task drawing out the creative collaboration within the group. Table 6 implicates the details of two random groups who applied the trial-and-error method to create the final successful product.

Table 6. The information on two random groups attempting design product 4.

Sample Groups	Sample Products	Trial Count	Reason of Failure (Refer to Table 2 for Criteria)	Reason for Success
Group 4a	Baseball	three attempts	The bouncy ball (the core) was small, so the diameter was big with the right weight. The final surface was not regular and was not smooth enough.	Changed materials by using a bigger bouncy ball, cowhide, yarns, and glue.
Group 4b		two attempts	The rebound was less.	The binding of the materials was made stronger.

3.2. Demonstration and Presentation of Design Projects

A conference was organized at the end of the program as an adjourning event for two days, displaying and examining the students' final products in the presence of an evaluation panel. The panel included leaders from industries (refer to Figure 4) in the STEM domains. Day 1 witnessed all groups' participation, portraying their program journey in PowerPoint presentations, videos, and photographs. They presented their products in the presence of the judges to demonstrate their accomplishments. On day 2, three winning groups (one from each sports product category) displayed their products to a different set of panels that comprised leaders from the best sports facility and community in Qatar.

(**a**) (**b**)

Figure 4. Students displaying their products for evaluation. Students in the image (**a**) are testing their concrete boat by incrementing the weights in the boat thereby testing its load-carrying capacity. (**b**) Bowling pins are laid 3 m away from the ramp for the evaluation of the bowling ball.

Before the evaluation was held on a public platform in the presence of a larger audience, the students improved their oration, body language, public speaking confidence, and vocabulary. As they presented their products to the panel, the students displayed their presentation skills along with the communication dispositions. The participants were assessed critically for their organizational ability, research methods implementation, and creative collaboration as they presented their project experience. They integrally replied to the judges' queries with confidence, proving their skill-based improvement.

3.3. Descriptive Statistical Analysis

Analysis of the study was quantitatively carried out by conducting pre- and post-workshop surveys. The study clearly manifested the increment in students' interest in an interactive STEM curriculum. The analysis also reported considerable growth in their self-efficacy and innovative skills along with their positive inclination toward STEM, both generally and career wise. The pre–post questionnaire analysis of four objective study indicators directed toward students' STEM attitudes was demonstrated, as in Figure 5 and Table 7. The students' pre- and post-questionnaire results were statistically calculated and analyzed using the *t*-test statistical calculator to determine the program effectiveness indicators (*p*-value, t value, mean differences). The *p*-value for the *t*-test conducted for all five cycles was less than 0.05, as in ideal condition (except for the fourth cycle $p = 0.229$). Hence, the results indicate that there was a significant difference between the two sets of data means (pre and post means), concluding the considerable improvement of their attitudes after the program (refer to Table 7 and Figure 5, as well as detailed Tables S3 to S12 in Supplementary Materials). In addition, considering the t value for the confidence interval ($t \leq 2.262$ to reject the null hypothesis), there was strong evidence (except for the fourth cycle $t = 1.22$) to validate that the experiment falls under the range of 95% confidence interval (95% CI). The 95% confidence interval (95% CI) holds a key factor in determining the program's constructive role in the student outlooks toward STEM. For the given set of data, the outcome improved scores, on average, by an approximate value of 0.8. The following STEM interest indicators were used to perform the *t*-test analysis:

- We live in a better world because of science, technology, engineering, and math (STEM);
- Learning science, technology, engineering, and math (STEM) is essential for my future success;
- I would like to have a career as a scientist or researcher;
- I have the skills to implement a scientific experiment.

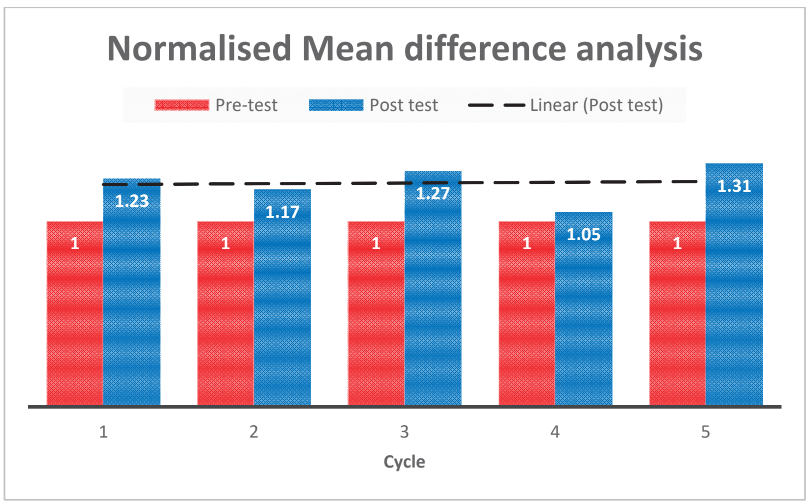

Figure 5. Normalized pre-test and post-test mean difference comparison of the student population for five cycles ($n = 248$). The blue line and red line display the pre-test mean and post-test mean percentages of the questionnaire analysis data collected from the five-year experiment, respectively. It is evident that despite the results drawn from the fourth cycle, the program proves to be effective in improving students' attitudes by a significant margin.

Table 7. "Science in Sports" (SIS) cycles by *t*-test analysis ($n = 248$). The "n" for each cycle is less than the initial number as stated in Table 1, as the analysis is performed only for participants who have performed both pre-test and post-test questionnaires.

Cycle	Statistics			Sample Tests		
	Participants N	Pretest Mean (SD)	Posttest Mean (SD)	Mean Diff (SD)	*t* Value	*p*-Value
1st	51	3.07 (0.932)	3.79 (0.865)	0.730 (1.185)	4.4	0.000
2nd	56	3.38 (1.205)	3.98 (1.032)	0.603 (1.680)	2.68	0.01
3rd	35	2.98 (0.570)	3.81 (0.900)	0.836 (0.889)	5.56	0.000
4th	52	3.46 (0.865)	3.66 (0.913)	0.202 (1.195)	1.22	0.229
5th	54	2.31 (0.746)	3.03 (0.693)	0.722 (0.757)	7.02	0.000

While analyzing the data of student attitude differences between pre-program and post-program, we observed an increasing trend line from cycle 1 to cycle 5. However, we noticed that the dips in the graph areas for cycle 4 and cycle 3 were because those data correspond to students from urban schools. We deduced that students in urban schools are already familiarized with STEM relevance and this had an impact on having less difference between pre- and post-program attitudes. They initially developed high individual opinions toward STEM fields. However, as we started experimenting the study on students from rural areas, we observed that there exists a clear distinction of improvement in their attitudes post program.

4. Discussion

The sports-based program has conferred productive insight into students' cognitive skills development and their attitudes toward STEM domains and aspirations. The SIS program has positively influenced participant students' cognitive development because they successfully designed their sports products. This section explored program outcomes, the improvement in students' learning, sense of efficacy, and the ability to solve problems. The three forms of data for evidence in assessing STEM workshop outcomes, design products, and strength, weakness, opportunities, and threats (SWOT) analysis are the following: (a) workshop outcomes (based on facilitator observation); (b) facilitator's assessments of students' work (design products); and (c) demonstrations of student dispositions (e.g., presentations, facilitator observations, school teachers). We hereafter discuss the outcomes in detail.

4.1. STEM Workshop Outcomes

The STEM workshop conducted during the one week witnessed students' active learning involvement in various sports-driven activities cultivating inquiry, research, logical reasoning, and creativity. The research-directed activity was successfully administered to implement digital tools in their inquiry-based learning process, improving their scientific knowledge in the subject context and productively implementing technology for learning. Experiencing the various hands-on scientific activities, the students enhanced their technical knowledge in terms of precision, accuracy, and measurement, later applied in the design project challenge. The diversity in the scientific experiments and vitality of the sports offered the students positive settings, henceforth cultivating curiosity, creative engagement, and appreciation toward science. The students were seen to be entirely fascinated by exploring the interconnection between sports and engineering, hence engaging keenly in understanding the underlying scientific concepts in sports and thereby addressing STEM learning. The activities also helped them apply different strategies and effectively transfer the acquired knowledge from the workshops to meet the engineering design challenge criteria. The four activities from Workshop 1 were crucial in developing scientific interest because they explored the scientific subject content aiming toward a design goal in informal learning set up [28,29]. As the students learned the necessary knowledge to construct a fail-proof concrete object, they were experiencing learning through hands-on activities similar to the studies conducted prior [22]. For the design project, they integrated scientific content such as floating conditions, Archimedes principle, rolling friction, and frictional interaction between bowling lane surface and ball surface from their regular school lessons into the workshop outcomes to design the ultimate sports product [30].

On the other hand, Workshop 2 acquainted them with visual information and hands-on experience on the rebound behavior and coefficient of restitution, included in their school physics curriculum, however, through the introduction of sports products such as baseball, basketball, etc., which was a relatively new experience. Workshop 2 also provided a novel approach to teaching the energy absorption of different materials such as wood, cow-hide leather, rubber, yarn, etc. through a hands-on approach, which was easier for the students to apply in their design project.

The cognitive development of the students was the main focus of designing and constructing the sports product. On cognitive measures, students enhance their fundamental thinking skills such as inquiry, hypothetic deductive reasoning, comparing and contrasting, and question generating similar to that of workshop activities as observed by previous researchers [25,31]. These skills were embedded in the sports design products, wherein the students nurtured them as they needed to make choices that led to accomplishing their tasks, such as choosing different weight compositions of concrete ingredients or choosing viable materials. Even while choosing the materials, there were different levels of decision making they had to partake, considering weight or surface absorption or any other parameters. Many of the researchers employ these methods in science teaching under the experiential learning process [22,32,33]. The evidence demonstrating the above conclusive results was portrayed in the Results Section analyzing different sports products.

While examining the workshop outcomes and addressing RQ 1 and 2, the *t*-test analysis was conducted on the 248 participants, providing mathematical representations of the difference in the students' attitudes displayed pre and post workshop. *T*-test was conducted on five batches of students, who participated in the SIS program in consecutive years (2012–2017). As shown in Figure 5, a positively increasing trend line displaying the significant difference between pre-test mean and post-test mean shows the effect of similar STEM mentoring programs, capable of improving the STEM preferences in school students. In addition, the trend shows that the study results fall under a 95 % confidence interval, validating the success of the experiment. The outcomes from the success of the product development and application of different STEM methods along with the statistical representations from Table 7 clearly directed toward the RQs, 1 and 2, "Did the student understand the importance of STEM by experiencing science through sports product engineering?" and "Will the student consider STEM driven career resultantly in the future?", respectively. Their future aspirations were dominantly influenced by the program, as demonstrated in Table 7.

4.2. A Facilitator's Outlook on Student Journey with the Design Products

The facilitator keenly observed the growth of students and their dispositions from the first day of the workshop. The field notes and daily reports on the different student groups provided detailed analysis results on their display of diverse STEM dispositions such as problem solving and logical reasoning. Moreover, the facilitator also noticed the progress in their self-confidence as they creatively collaborated with peers and mentors (facilitator and schoolteacher). Their journey with reference to the design product is detailed hereafter.

The facilitator recognized the improvement in students' learning behavior while analyzing the different reasons for failures during the construction of the bowling ball. The students were able to assess the variant flaws accurately either during mold selection, product finishing (removing mold from the dried concrete product), or product testing. In case of unsuccessful attempts, they observed that the students could attribute the cause of failure to valid scientific reasons. They observed that students frequently burst with quick queries, "why" and "what if" much more often than the regular workshop days because they were impatient to solve their challenge.

As the students decided the mold (shape), proportion, and weight of concrete ingredients (appropriate weight), and finish the final product with adequate testing, the facilitator observed pride and satisfaction in achieving a target successfully. It was observed that some of the groups failed during the first attempt due to poor mold choices. For example, while choosing the mold, they attempted to introduce novel ideas such as paper mold, which did not have the strength to hold the concrete mixture, thereby collapsing the end product (as shown in Figure S1 in Supplementary Materials). Apart from choosing mold and making decisions on proper aggregate composition, the groups considered adequate atmospheric conditions to ensure the finished concrete models' essential curing. They performed curing to prolong the hydration (chemical reaction with water molecules) of cement in the concrete structure to develop calcium hydrate silicate gel, a strong binding material to reduce porosity and increase concrete density. This process was crucial in preventing surface crumble or sample breakage. Students also acknowledged the reason for failure in some cases due to breakage or cracks as the lack of providing adequate curing time. The main goal achieved in leading the students through the activities was to ensure that they acquire scientific knowledge in practice rather than a one-sided instructional delivery [34]. These experiences were acting as intrinsic motivators for the students' active participation [20,35]. In due process, the students also invested in learning the scientific principles from sports product engineering, which was an additional practice for the students. They investigated different factors that affected the desired level of "skid–hook–roll" action during the testing process, which was crucial in hitting the pins (Freeman and Hatfield, 2018). It was also observed that the testing of the products offered a consolidated "play-and-learn" opportunity to the participants, enhancing their interest in STEM integration in their regular school driven science concepts. As in the case of bowling ball, they acquainted themselves on the scientific principles such as rolling friction and frictional interaction between lane surface and ball surface, improved by polishing the ball surface to a "glossy" finish, which guaranteed a longer skid and a sharper hook in the back end for the best results (Freeman and Hatfield, 2018). They also correlated the concept of friction, inelastic deformation, and energy conservation (the kinetic energy of the rolling ball was converted in contact with the pins), and as in the case of concrete boats, buoyancy, density, and material compactness were visually experienced through this learning method.

The students were provided with experience studying and testing multiple materials, such as concrete materials, wood, carpet padding, felt, Astroturf, foam rubber, acoustic tiles, linoleum, shag carpet, etc., in laying out the course pit material or choosing materials, as in the baseball challenge. Since this method of bringing the students into the experimental field through an integrated STEM approach and providing opportunities for intermingling with peers successfully enhances STEM literacy, the facilitator found an enhanced level of motivation in the students to address the challenges [30]. Participants also had a wide experience while experimenting with yarn, rubber bands and shreds, felt, fabric scraps, aluminum foil, glue, etc. while constructing a ball that could deliver the desired rebound height and rolling action.

Interestingly, this study witnessed the effective implementation of mathematical concepts such as applied geometry, measurement, ratio, and proportion for studying the physical behavior of concrete under varying conditions, with STEM learning being integrated into the procedure, as effective as in previous studies [5,29,30]. The students applied different mathematical expressions that include density (D), where D = mass/volume, which was relevant to sketch the shape of the boat with increased length, breadth, height ratio, thereby increasing the volume to be greater than the mass of the boat. They learned and applied the coefficient of rolling friction (CR) and coefficient of restitution (COR) formulas in the case of products that involved ball action (baseball, golfball and bowling ball); COR = $\sqrt{\text{height of rebound}}/\sqrt{\text{drop height}}$ and CR, μ = rebound height/distance traveled by the ball.

The facilitator put forward the challenge of building the test golf course pit to the entire batch of participants in the respective school to exploit their problem-solving skills, knowledge transfer capability, teamwork, leadership, and creative collaboration. However, because this was a collaborative endeavor, it was easy for the facilitator to understand the students' development in leadership and peer collaboration. The golf ball challenge provides an excellent "play-and-learn" opportunity for the students because they learned basic science concepts such as rolling friction, rebound, and energy absorption of materials through integrated STEM-driven plays. They explored the interplay between sports and science, attracting the students and influencing their desire for science and STEM subjects. The design challenge has played an imperative role in amplifying science's perception as a positive, "fun" experience. These observations made by the facilitator based on the validated responses from the students addressed the RQ3 research question, "Were the students able to understand and correlate scientific principles to the applications in daily life?". The workshops provided ample grounds for the students to understand the scientific principles while the students employed diverse tactics to solve the problems from a STEM perspective during the trial-and-error method.

The facilitator recalled that students fostered their creativity from effective peer collaboration, apart from critical thinking and reasoning skills as they designed each product's shape and dimensions, reinforcing previous studies [34]. They also noticed that the students, in the process, gained learning outcomes in regard to the application of scientific concepts such as in sports-based real-life scenarios. Creative designing was observed as the students had to limit boat size to be immersed in the testing tank. These creative expressions were also applied during the construction of the mold because some participant groups constructed the mold for the boat from raw materials such as foam sheet, cardboard, or wood (refer to Figure S2 in Supplementary Materials), while the other groups opted for readily available toy boat molds (refer to Figure S2 in Supplementary Materials).

4.3. Discussion on Schoolteachers' Observations

The qualitative responses from schoolteachers and students substantiate their enthusiasm for the program. Teachers especially liked the variety of inquiry-based activities and resources provided in the workshop. They observed positive responses in their students with increased analytical thinking. Teachers also regarded the workshops and design challenges as an inspiring experience that nurtured students' interest in STEM. School teachers also validated that the students were enthusiastic during hands-on activities because they were involved in constructing sports products [36,37]. Due to their cultural orientation toward sports, participants also clearly exhibited their enthusiasm for sports-based engineering assignments. Male participants typically showed less interest in writing activities, as recalled by the teacher, in contrast to hands-on activities that included measurement, preparing concrete mixtures, and testing the products. This type of behavioral differences by different validating researches [12,38]. They generally were motivated during teamwork to work zealously on the products and even collaborated cordially with the facilitator.

4.4. Strength, Weakness, Opportunities, and Threats (SWOT) Analysis

The facilitator well examined the experimental methods and results to develop a SWOT analysis matrix. The SWOT analysis laid out the key observations that pointed out strengths, weaknesses, and future possibilities in the study.

4.4.1. Strengths and Weaknesses

The layout and execution of activities that led the students to design a sports product effectively were pointed out to be a strength. The layout of activities clearly manifested the necessary aid for the students in accomplishing their target objectives. The inquiry-based methodology in the activities opening into a trial-and-error experimental method in satisfying a set of conditions led the students to examine their project from their perspectives, thereby elaborating their thinking capability. In addition, the study methods' creative collaboration was also considered a plus point for the research study.

While assessing the weaknesses, it was observed that the experiment chose a random selection of sports products that were easy to construct in terms of high school students' competency. Although the study was conducted through a well-laid out activity plan leading to design challenges, the relationship between the four sports products was not clearly established. However, this shortcoming was not addressed before the students because they were introduced to a STEM workshop, which by the end, led to the design of two sports products that fall under the same category. The weakness that was highlighted by the facilitator was its limitation in assessing the student competencies using an internationally standardized testing rubric, which will be further considered for future research.

4.4.2. Opportunities and Threats

Taking into account the positive results observed, the study has opened windows for improvement in terms of adding new activities to Workshop 2 that was capable of acquainting students with knowledge on aerodynamics. This new addition could open better sports products that could promise superior quality and educate the students on concepts such as terminal velocity, which is remarkably addressed in aviation and space technology fields. Moreover, the facilitator was very much looking forward to opening pathways for the student to design a new sports equipment/game applying the scientific concepts that were introduced in the activities of Workshop 2. Although the workshop provided ample opportunities for identifying and learning different materials, their physical properties, and their behavior under the limited school laboratory testing conditions, it promises a future scope for experimenting state of art testing conditions such as scanning electron microscopy (SEM) for better results. Resultantly, tests such as SEM analysis will be able to test the water absorption of concrete walls and concrete composition to microscopic detail. Drazan et al. [39–42] experimented in basketball events, exploring different perspectives of implementing science and engineering curriculum. The studies provide us with a solid background, thereby demonstrating opportunities for students in designing performance monitoring devices by analyzing the player performance. The students can relate to the application of analytics in real-life scenarios through similar additional projects.

Threats were minimally observed while assessing the SIS program; however, the facilitator noticed that the students were exhibiting behavioral setbacks while acknowledging failures. Since the design project was carried out through trial-and-error methods, a few students showed impatience and reluctance in moving forward during lapses in the experiment. Moreover, few students did withdraw from the program, which seemed to affect the morale of their peers, causing further setbacks. Meanwhile, the facilitator ensured that the remaining group members were always motivated with positive remarks and applause to heighten their interest.

5. Conclusions

Sports, being one of the critical motivators that contribute toward upbringing socially intimidated youth to the forefront, is also favored by educators around the globe for enhancing their academic and creative development. The implementation of the sports-driven program, "Science in Sport," in an informal school setting exercising diverse STEM workshops that lead to engineering design challenges, could enhance high school students' inclination toward STEM fields and careers. Participants, self-motivated by sports, bolstered competencies by engaging through the engineering design process while developing a sports product during the challenge. The program exploited the students' enthusiasm in sports to participate in an inquiry-driven learning approach to experience design and engineering. The program outcome also offers opportunities for student enthusiasm and pride through product achievements. They expressed this by learning and applying science concepts such as friction, density, and material compactness in engineering design. The positive observations during the experimental phase complemented the pre-post questionnaires' statistical analysis results that interpreted the improvement in their attitudes toward STEM fields and careers. A normalized analysis of pre–post workshop attitude improvement did highlight the effect of the study on rural- and urban-based participants. The SWOT matrix laid out the strengths of the well-structured program, in addition to the limitations in providing an analysis of participant performance in international standard assessment tests as the aftermath.

The program keenly considers room for expansion with new activities and engineering challenges that could pave for an exciting STEM career pathway. This study can be replicated with university undergraduate students (UG) from sports science disciplines as a capacity-building means and enhancing their knowledge base in sports. We expect that the experiment on UG students may influence their career choices and align them toward the scientific background of the sports industry. The study offers scope in constructing activities based on aerodynamics, thereby leading students to acquire innovative scientific perspectives and build new sports products. Currently, based on the results of this study, we are experimenting on students' ability to innovate sports games, if successful could be patented in the future. The ultimate goal in future development will align toward heightening the students' competencies and knowledge, preparing them for International research and science exposure.

Supplementary Materials: The following are available online at https://www.mdpi.com/2071-1050/13/6/3483/s1, Table S1: Questionnaire sample, Table S2: Example of evaluation rubric handed to judges, Tables S3 to S12: Paired-samples statistics (pre/post tests), Figure S1: Different stages of making a concrete bowling ball from making a mould to testing the end products, Figure S2: Students during a concrete boat product challenge, Figure S3: A golf course is set up and tested by the students in the class.

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sustainability

Article

Finland, A Package Deal: Disciplinary Climate in Science Classes, Science Dispositions and Science Literacy

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Abstract: Finland's educational prowess, though tempered by recent international assessments, has remained intact. This report focused on lessons that could be learned regarding secondary-level science education from the Program for International Student Assessment (PISA) 2015, science-focused assessment. That PISA iteration included not only science literacy but also students' science dispositions (epistemology, enjoyment, interest, and self-efficacy) and the schools' science climate measures (disciplinary climate and teaching support). Due to the hierarchical nature of the PISA data, multilevel models were employed in this Finnish study, involving 5582 students from 167 schools. Science dispositions (as outcome measures) were differently associated with teaching support and disciplinary climate (epistemology with neither; enjoyment and interest, with both). Science literacy (as an outcome measure) was associated with all four science dispositions, whether modeled with each science disposition separately or all four simultaneously. Science literacy was also associated with the disciplinary climate in science classes for all tested models. We concluded that, in the Finnish context, science dispositions and the disciplinary climate were predictive of science literacy. Furthermore, we presented evidence from the literature indicating that these conclusions may well extend to other international contexts.

Keywords: school science climate; disciplinary climate; science dispositions; epistemology; enjoyment; interest; self-efficacy; science literacy

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1. Introduction

Finland's educational journey, from a decidedly ordinary past to its current high-functioning status, has proved to be of enduring interest internationally [1]. While reading literacy has been a particularly strong area for Finland, triennial evaluations by the Program for International Student Assessment (PISA) have revealed high student performance in mathematics and science as well [2–4]. Even in the face of modest declines in science literacy outcomes [3,4], this nation has continued to attract interest from international educators. Sahlberg [1] identified multiple underlying causes for Finland's educational strength, including the national prominence of teaching as a profession (drawing many of their very best students), ongoing professional development programs (finely tuned to teachers' interests), solid financial support for schools (minimizing school-to-school variability in literacy outcomes), and also the firm rejection of "answers" to educational concerns that involve frequent high-stakes testing, extensive homework and tutoring, and national/regional control of content and practice. We note that the science curriculum in Finland emphasizes science literacy as an essential outcome for all students [5], underscoring the value ascribed to science literacy by the Finnish educational community. Furthermore, the literature review below was crafted to provide readers with a brief introduction to the context of this research by reviewing published papers that were both current and relevant.

In a global context of increasing concern about the misunderstanding (and even outright rejection) of science as a contributor to personal life choices and to public decision-making [6,7], enhanced science literacy as an outcome for secondary education is absolutely critical [8]. Some authors [9] have argued that "open-mindedness", particularly as evinced by the adaptive intellectual traits of humility, courage and diligence—as opposed to the maladaptive intellectual traits of arrogance, cowardice and laziness [10]—needs to be developed among the world's populace. In contrast with the highly stratified secondary schools of some European nations (e.g., Benelux nations, Germany), Finland employs a "paraskoulu" (that is, "best school") system of primary and early secondary education. The goal of this "best school" system is to ensure that all schools are of consistently high quality; the mechanisms utilized in the pursuit of that goal include masters-level teacher training programs that produce teaching professionals [11,12], along with local curricular planning, teacher-conducted assessments of effectiveness, and numerous other innovations [13,14]. This approach has successfully "raised all boats"; that is, helped students across schools to attain higher science literacy [15,16]. In contrast, several European nations stratify students by track and grade; for example, Dutch-speaking Belgium's system (invoking significant grade retention and aggressive tracking) has trifurcated science literacy, with substantial differences in science literacy among the three main tracks in early secondary schools [17].

Science achievement has been assessed using a wide variety of metrics (grades in science classes [18,19], performance on standard science content evaluations [20], or large-scale international assessments [21,22]). Science literacy has been the focus of PISA's science assessment since its first science-focused interaction (in 2006); a key part of PISA's science literacy construct [23] is that students are asked to use what they know about science to develop solutions to complex science problems (versus simply supplying science information or solving routine science problems with a variety of included data). Some nations (for example, Greece) may be disadvantaged by the PISA science assessment, since their instructional models for science focus more on information retrieval and solving routine problems [24]. The PISA science-focused cycles (2006, 2015) have included both science dispositions (e.g., enjoyment, interest, self-efficacy) as well as selected science-teaching methods (hands-on activities and student investigations in 2006 [25], and disciplinary climate and teaching support—both in science classes in 2015 [26]).

Science dispositions have been shown to be associated with science literacy in a variety of international contexts [17,25,27,28]. Science enjoyment generally relates to a positive attitude toward science, particularly science learning processes [27,29]. Science interest indicates that a student has inclinations toward a particular science discipline (or multiple science disciplines) [29,30]. Note that this concept represents a broader construct of interest in science than does the "situational interest/situational engagement" widely investigated by Finnish researchers and their colleagues [31–34]. Students with high science self-efficacy believe that they "can do" particular science-related tasks successfully [27]. Science epistemology generally refers to students' beliefs about the nature of science [20,35–37]; in the PISA 2015 context, an adaptative suite of student beliefs about science epistemology involves both an emphasis on experimentation and on the changeability of science inferences [38]. Hereinafter, we simply refer to the aforementioned science dispositions as enjoyment, interest, self-efficacy and epistemology.

Importantly, research in Finland [32,39] and elsewhere [22,27,29,30,40] has considered how certain teaching methods in science classes (which we will generally term the "school science climate") may promote such science dispositions. Indeed, if science dispositions may be associated with enhanced science literacy, the school science climate (primarily experienced by students in their science classrooms) may very well be an important agent by which science teachers (and, thus, schools) are able to foster adaptive science dispositions. The school science climate has been primarily evaluated based on teachers' methods in science classrooms [22,27,29,30,40]; however, an innovation of the 2015 iteration of PISA was to ask individual students to evaluate their experiences in science classrooms [41]. Two key measures—disciplinary climate (in science classrooms) and teaching support (also in science classrooms)—were collected at the student level and designed to be aggregated to the school level. Prompts regarding the disciplinary climate focused on factors that allowed the whole class to "get down to business" in terms of learning about science (e.g., moving past distractions at the outset of class sessions quickly, on to the day's science concepts). Items included in order to construct teaching support in science classes similarly asked about students' experiences of teachers helping them to understand the concepts (versus leaving them to struggle). From a study of 21 nations/regions from PISA 2015, these two key school science climate measures were often associated with a pair of science dispositions—epistemology and enjoyment—as well as with science literacy per se [26]. A comparative study of classrooms, teachers and schools found that school-level features were more important predictors of science achievement than the other two measures [42].

Given the equity-promoting nature of Finnish schools [15,16], along with Finland's strong focus on teacher training [11,12] and teacher empowerment [13,14], we believed that an investigation of the associations among science dispositions, the school science climate, and science literacy could well provide lessons of interest to international science educators. In particular, identifying the extent to which science teaching interventions may enhance science dispositions could allow educators to more finely attune such outcomes. In addition, determining the strength of the associations between specific science dispositions and science literacy as an outcome could help educators to select those science dispositions most likely to have the potential to enhance science literacy. To achieve those ends, our twin research questions for this project were: (i) might the school science climate, over and above student background and school context, be associated with students' science dispositions; and (ii) might the school science climate and/or students' science dispositions (once again, over and above student background and school context) be associated with science literacy?

2. Materials and Methods

Data for this research were drawn from the most recent PISA iteration (2015) that was science-focused [3]. The corresponding dataset [43] provided a range of science dispositions (at the student level) along with an intriguing pair of school science-climate measures (aggregated, for our purposes, to the school level). We took advantage of this combination of observations to explore their relationships with science literacy, the specific measure of science achievement assessed under the PISA construct. Owing to the hierarchical nature of the data, with some measures relating to students within schools and others being expressed at the school level, we chose to implement multilevel modeling methods as our analytical tool. The ensuing sections describe data collection approaches, characterize outcome measures, and expand upon our analytical approaches.

2.1. Data Collection

National-level research specialists identified schools for participation in each round of the triennial PISA cycle; these schools were chosen to represent, as well as possible, the full range of school contexts (e.g., student enrollment, community size) expressed in that nation. For Finland in 2015, this sample included 167 schools. Within each school, approximately 35 students from the 15-year-old cohort were randomly chosen for this assessment (if a school had fewer than 35 students, all students were included). For Finland in 2015, this sample included 5882 students. Sampling weights at both the student and school levels were provided in the datasets [43] and were invoked as part of the analysis below. Missing values at both student- and school levels were managed differently. Missing values for students were treated at the analytical step of multilevel modeling; meanwhile, missing values for schools were treated by using the multiple imputation function within SPSS [44].

2.2. Outcome Measures

In the case of our first research question, four science dispositions (epistemology, enjoyment, interest, and self-efficacy) were successively treated as outcome measures. For our second research question, science literacy was the required outcome of a series of multilevel models. While not treated as outcome measures, two school science climate variables (the disciplinary climate in science classes and teaching support in science classes) were considered in both sets of multilevel models.

Tables A1 and A2 provide detailed information on the constructs that gave rise to the above suite of science-related variables (students' science dispositions and the school science climate). Here, we provide a brief characterization of each of these science measures, within this PISA context [38]. Among science dispositions, epistemology was tied to students' beliefs in experimentation and the possibility of change in scientific inferences. The variable of enjoyment is related to the positive emotions experienced by a student while learning science. The variable of interest took a composite look at students' interest in a series of scientific disciplines. Self-efficacy was derived from the level of students' agreement with statements about their ability to complete specific science-related tasks.

Science literacy, in the PISA context, refers to a student's capacity to implement science in actual life settings; specifically, it is "the ability to understand the characteristics of science and the significance of science in our modern world, to apply scientific knowledge, identify issues, describe scientific phenomena, draw conclusions based on evidence, and the willingness to reflect on and engage with scientific ideas and subjects" [23], p. 22. Note that science literacy was defined in the same way for the 2015 iteration of PISA; one key change was the move from five to ten plausible values for the later study. Other, more nuanced, constructions of science literacy exist [6,7,45]; however, the ready availability of the PISA-derived data based on the above framework for science literacy made it useful for this project.

The disciplinary climate and teaching support for science were both measured in the context of science classes; in addition, both were assessed at the student level but then aggregated to the school level. In this way, we were able to develop student-driven, school-level assessments of both of these school science climate measures. Such student ratings (to assess other teaching approaches) have been validated in a substantive way for 69 PISA 2015 nations/regions [46]. The disciplinary climate essentially addressed the degree to which the science classroom was orderly—getting onto the lesson topic promptly, students being able to hear the teacher, and other variables. Teaching support was related to the sense that individual students' learning mattered to the teacher, that it mattered enough for them to make sure that students were grasping the science ideas being considered.

2.3. Analytical Approaches

Our premise was that additional student- and school-level variables, apart from the science-related measures presented above, could also be associated with the outcome measures of science dispositions (research question #1) and science literacy (research question #2). Thus, we identified a series of likely candidate variables from among both student background and school context measures, then included those potentially important variables at the appropriate level of our multilevel models [47].

2.4. Exogenous Variables

Seven student-background measures were included in these analyses: gender (dummy), age, immigration background (double dummy), home language (double dummy), and an index of economic, social and cultural status (ESCS index). For gender, males were coded as 1, females as 0; no alternative gender identities were included as options on the student questionnaire. Student age was reported in years (within a 12-month bracket centered around 15.75 years). Immigration background considered second-generation immigration status as the reference group (coded as 0 for both dummy variables). Native and first-generation immigrant statuses were each coded as 1 for two separate dummy variables. Similarly, a Swedish home language was the reference group (coded as 0) for both dummy home language variables. Finnish home language and all other home languages were each coded as 1 for the two separate dummy variables regarding home language. Note that home-language coding (for both dummy variables) was based on a match between students' home language and the language in which they took the PISA assessment. Setting aside those students for whom home languages were not recorded (61 and 5 of whom took Finnish and Swedish assessments, respectively), the vast majority of the assessments were taken in Finnish, by Finnish home-speakers (5213/5473; 95.2%). Meanwhile, a less substantial majority of Swedish assessments were taken by Swedish home-speakers (254/343; 74.1%). Of the other home languages group, 246 took the Finnish assessment, while only 6 took the Swedish assessment. In addition, Finnish home-speakers who took their assessment in Swedish ($n = 83$; 1.6% of the total Finnish home-speakers) and Swedish home-speakers who took their assessment in Finnish ($n = 14$; 5.2%) were assigned to the "other home languages" dummy variable, based on a mismatch between their home language and the language of their assessment. Finally, the ESCS index, while showing substantial variability, averaged somewhat higher than the standardized OECD mean for this index (0.259 versus 0.000).

In addition, four school context variables were included: school location, school size, index of the proportion of science teachers who were fully certified, and ESCS index—aggregated (from the student level). School location (as a dummy variable) compared schools located in communities of 100,000 or more residents (coded as 1) with those schools located in smaller communities (coded as 0). School size, reported by PISA as actual enrollment counts, was indexed to a basis of 1000 students (in order to make our primary tables more readable). The remaining pair of school context variables (proportion of teachers certified (ESCS index—aggregated)) were also included to capture a variability in outcome measures that is potentially explained by school context features.

2.5. Multilevel Modeling

In order to properly address the data hierarchy inherent in this PISA dataset, we made use of multilevel modeling strategies [47,48]. Our chosen software package was HLM8 [49]. For our first research question, four successive models were run (one for each of the four science dispositions under consideration as outcome measures). For our second research question (for which science literacy was the outcome), six successive models were invoked—a "basic" model (that included all student background variables, as well as all school context and school climate variables), four models that each included one of the four science dispositions, as independent variables (in addition to all variables from the basic model), and one "combined" model that included any of the science dispositions that achieved both significance ($p < 0.05$) and at least a small effect size ($d \geq 0.20$), once again, in addition to all variables from the basic model.

For all models, the full maximum likelihood approach was utilized; in addition, PISA-supplied weighting factors were included at both the student and school levels. Null models were run for all outcome variables (science dispositions as well as science literacy); such null models allowed us to not only identify the proportion of student- and school-level variance accounted for by subsequent models but also allowed us to calculate intraclass correlation coefficients (ICC), which can help determine the propriety of the inclusion of school-level analyses. In pursuit of parsimonious models, we included all student-level variables (level one included student background for both research questions, and science dispositions, as applicable, for research question #2 only) in the initial model. Student-level variables with the least significant results were iteratively dropped from the level-one model until all remaining variables met the $p < 0.05$ criterion. At that point, all school-level variables were loaded into the level two model; once again, the least significant variable was removed from successive model iterations until all level-two variables were also significant at $p < 0.05$. In order to evaluate model performance, we calculated the proportion of variance explained at both the student and school levels for each parsimonious model [48]. Finally, in order to assess the effect size of each significant variable, we calculated Cohen's d (by dividing the variable's modeled coefficient by its standard deviation). We used

Cohen's [50] relativization of effect sizes (0.20 to 0.49 was taken as small; 0.50 to 0.79, as medium; and ≥0.80 as large).

3. Results

Additional materials for this paper include Tables A1 and A2 (providing the underlying prompts used to construct science dispositions and school climate measures, respectively [23]), as well as descriptive statistics (Table A3) and bivariate correlations among science dispositions (Table A4) and school-level variables (whether context or climate; Table A5). Selected information from those Additional materials is briefly noted here. For example, the Finnish sample implemented for this research included 96% native students, 89.6% of whom spoke Finnish at home, and a mean ESCS index of 0.259 (indicating that the Finnish mean income exceeded the OECD mean). Science dispositions closely approximated OECD means, as did school climate measures. While bivariate correlations were significant among both science dispositions and school-level variables, only one such correlation (between enjoyment and interest) reached the moderate level among science dispositions (none reached this level among school-level variables).

Table 1 presents the results of multilevel models with each of the four science dispositions treated as outcome variables. Among student background variables, ESCS was the only measure associated with all four science dispositions; this association was positive in each case. Perhaps more intriguingly, home language showed a complex association with epistemology. Students who spoke Swedish at home (and took the PISA assessment in Swedish) showed higher levels of epistemology than either Finnish speakers (who took this assessment in Finnish) or speakers of other languages. Among school climate measures, teaching support in science classes was associated with three of the four science dispositions (epistemology was the exception). One could, thus, argue that school-level teaching support may have promoted enjoyment, interest, and self-efficacy. The disciplinary climate in science classes was significantly (and positively) associated with two of the studied science dispositions: enjoyment and interest. We note that these models accounted for modest proportions of the student-level variance (0.02 to 0.08); in addition, ICC data for these models showed a modest level of school-to-school variability (0.02 to 0.05).

Table 1. Multilevel models for science dispositions (as outcomes) for Finland.

	Epistemology		Enjoyment		Interest		Self-Efficacy	
Variable [1]	**Coeff.**	**d [2]**	**Coeff.**	**d**	**Coeff.**	**d**	**Coeff.**	**d**
Student background:								
Gender [3]	–	–	–	–	0.29	0.12	0.26	0.07
Age	–	–	–	–	0.13	0.03	0.16	0.04
Other home lang.	−0.34	0.04	–	–	–	–	–	–
Finn. home lang.	−0.21	0.03	–	–	–	–	–	–
ESCS index	0.23	0.16	0.25	0.16	0.23	0.13	0.31	0.17
School context:								
ESCS ind.–ag.	–	–	–	–	0.23	0.17	–	–
School climate:								
Disc. clim. sci. cl.	–	–	0.28	**0.35**	0.11	0.16	–	–
Tch. sup. sci. cl.	–	–	0.19	**0.39**	0.17	**0.27**	0.12	**0.20**
Prop., student var.	0.08		0.02		0.06		0.04	
Intraclass corr.	0.03		0.03		0.05		0.02	

[1] Significant variables in this column remained in a given model by meeting the $p < 0.05$ criterion; all student background and school variables were tested in each model. Those student- and school-level variables that were not included dropped out of all multilevel models shown. [2] Bolded "d" values met a minimum 0.20 criterion. [3] For more complete variable descriptions, please see the Methods section and Appendix A. Dashes (–) in the table indicate that a given variable dropped out of a given model.

Table 2 catalogs the results of our "basic" (no science dispositions included) multilevel model, taking science literacy as an outcome. Student background variables of female gender, increasing age (within the 15-year-old cohort), native status, Finnish home language and ESCS level were each associated with science literacy. Note that the coefficients in this table directly represent the differences among science literacy scores for the contrasting levels of a given variable. For example, female students averaged higher (7.72) PISA scale points than did males. Smaller school size (a school context measure) and a stronger disciplinary climate in science classes (a school science climate variable) were both significantly associated with science literacy in Finnish students. Based on our effect size analysis, Finnish home language, ESCS index, and disciplinary climate were best attested as strongly meaningful. We note that both the proportion of student-level variance accounted for and the ICC measure were moderate for this model.

Table 2. A basic multilevel model for science literacy in Finland (no science dispositions included).

	Basic Model	
Variable [1]	**Coeff.**	**d** [2]
Student background:		
Gender	−7.72	0.04
Age	22.56	0.08
Native students	45.71	0.19
Finn. home lang.	35.38	**0.45**
ESCS	30.89	**0.53**
School context:		
School size (per 1000)	−25.31	0.16
School climate:		
Disc. clim. sci. cl.	41.80	**0.32**
Prop., student var.	0.10	
Intraclass corr.	0.09	

[1] Significant variables in this column remained in a given model by meeting the $p < 0.05$ criterion; all student background and school variables were tested in each model. No science dispositions were included in this basic model. Variables that were not included failed to meet that criterion for all multilevel models shown. For more complete variable descriptions, please see the Methods section and Appendix A. [2] Bolded "d" values met a minimum 0.20 criterion.

Multilevel model results with science literacy as the outcome are shown in Table 3. We focus our comments upon the four science dispositions, along with the only significant school science climate measure, this being the disciplinary climate in science classes. Coefficients and d-values for student background and school context measures are included to underscore our modeling methods; that is, each model included all student background and school-level measures. We focused on the "above and beyond" associations of science dispositions with science literacy, after taking into account a broad portfolio of student background and school context variables. While all four science dispositions were significantly associated with science literacy, the strengths of those associations, as evaluated by effect sizes, differed dramatically. A large effect size was the result for enjoyment; a medium effect size for self-efficacy and epistemology; and a small effect size for interest. Full unit increases (two standard deviations from the mean) in epistemology, enjoyment, interest, or self-efficacy indicated a gain of 19 to 31 scale points in science literacy (all with small effect sizes) when separately included in science literacy models. Meanwhile, the disciplinary climate in science classes was associated with science literacy for all four models, including single science dispositions. A full unit increase in disciplinary climate (again, two standard deviations) was associated with a gain of 30–41 PISA scale points. Thus, the disciplinary climate in science classes could be regarded as promoting science literacy in the presence of all four studied science dispositions. For each model, the proportion of student-level variance that was accounted for was substantially greater than the 0.10 level accounted for by our basic model.

Table 3. Multilevel models for science literacy in Finland, with science dispositions as independent variables.

	Epistemology		Enjoyment		Interest		Self-Efficacy	
Variable [1]	**Coeff.**	**d** [2]	**Coeff.**	**d**	**Coeff.**	**d**	**Coeff.**	**d**
Student background:								
Gender	−6.49	0.05	−9.70	0.06	−17.20	0.08	−12.64	0.09
Age	19.68	0.07	21.72	0.09	18.56	0.07	20.28	0.08
Native students	36.85	0.16	71.76	0.19	56.06	**0.27**	46.71	**0.22**
Other home lang.	–	–	–	–	−23.00	**0.25**	–	–
Finn. home lang.	37.25	**0.48**	–	–	–	–	30.41	**0.38**
ESCS	23.85	**0.41**	24.04	**0.29**	22.27	**0.29**	24.99	**0.32**
Science disposition	31.12	**0.63**	24.96	**1.40**	31.31	**0.31**	18.81	**0.74**
School context:								
School size (per 1000)	24.87	0.17	–	–	–	–	–	–
School climate:								
Disc. clim. sci. cl.	39.34	**0.29**	30.25	0.19	31.32	**0.23**	40.55	**0.29**
Prop., student var.	0.19		0.17		0.20		0.15	
Delta, student var.	0.09		0.07		0.10		0.05	

[1] Significant variables in this column remained in a given model by meeting the $p < 0.05$ criterion; all student background and school variables were tested in each model. Variables not included in this column dropped out of all multilevel models tested for science literacy as an outcome variable. For more complete variable descriptions, please see the Methods section and Appendix A. [2] Bolded "d" values met a minimum 0.20 criterion. Dashes (–) in the table indicate that a given variable dropped out of a given model.

For Table 4, we focused on science dispositions and the disciplinary climate in science classes, in the context of our "combined" model. This multilevel model simultaneously considered all four of the studied science dispositions; notably, all four science dispositions remained in our combined model. This indicated that each of the four science dispositions was uniquely associated with science literacy as an outcome in the presence of the other three science dispositions. Effect sizes differed; while epistemology reached a modest effect size, and enjoyment and self-efficacy each achieved a small effect size, interest fell just short of a small effect size. The disciplinary climate in science classes remained in this combined model, testifying to the persistence of its association with science literacy in the presence of the quartet of science dispositions considered.

Table 4. A combined multilevel model for science literacy for Finland.

	Combined Model	
Variable [1]	**Coeff.**	**d** [2]
Student background:		
Gender	−14.98	0.12
Age	16.35	0.07
Native students	42.18	**0.23**
Finn. home lang.	31.56	**0.44**
ESCS ind.	16.97	**0.21**
Science disposition		
Epistemology	22.07	**0.56**
Enjoyment	6.26	**0.45**
Interest	19.05	0.17
Self-efficacy	8.62	**0.44**
School context:		
School size (per 1000)	−26.00	0.19
School climate:		
Disc. clim. sci. cl.	33.70	**0.25**
Prop., student var.	0.27	
Delta, student var.	0.17	

[1] Significant variables in this column remained in a given model by meeting the $p < 0.05$ criterion; all student background and school variables were tested in each model. Variables not included failed to meet that criterion for all multilevel models shown. For more complete variable descriptions, please see the Methods section and Appendix A. [2] Bolded "d" values met a minimum 0.20 criterion.

4. Discussion

Our research assessed the potential associations of two school science climate variables with science dispositions and science literacy. The disciplinary climate and teaching support (both in science classes) comprise our first focus here. Furthermore, we have termed this pair of concepts "school science climate" variables, since both specifically refer to the context of science teaching, as evaluated by the students themselves. Note that, for purposes of our analysis, we aggregated student responses to the school level for both disciplinary climate and teaching support variables.

Teaching support and the disciplinary climate were both positively associated with some of the science dispositions evaluated in this research; specifically, these two measures of school science climate were positively associated with both enjoyment and interest (Table 1). Given that both enjoyment and interest remained in our "combined" model, as associated with science literacy (Table 4), one could reasonably infer that both of these aspects of the school science climate could be considered promotive of science literacy. In fact, the disciplinary climate was directly associated with science literacy as an outcome measure for all four models, including a single science disposition (Table 3), and was also associated with science literacy in the combined model (Table 4). Thus, we argue that an emphasis on improving the disciplinary climate of Finnish science classes could potentially be a productive approach to improving science literacy in that national context. Variability between Finnish schools in science literacy for PISA 2015 was quite low (less than 10% between schools, along with Iceland and Norway) in contrast with much more stratified national school systems (nearly 50% variability in Belgium and Germany, and 65% in the Netherlands) [16]. However, variability in the measure of interest here (disciplinary climate in science classes, tested at the school level) was indeed associated with science literacy in all the models we tested (Tables 3 and 4).

4.1. School Science Climate, Selected PISA Measures

Based on PISA 2015 data and invoking multilevel structural equation modeling, potential mechanisms for linkages among students' socioeconomic status (SES), the disciplinary climate in science classes, and science literacy have been investigated in detail [51]. Some support for a "compensation" mechanism was obtained, to wit: "secondary data analysis of the PISA 2015 data from five Nordic countries resulted in consistent and robust evidence supporting the compensation hypothesis, that is, the disciplinary climate's contribution to science achievement above and beyond SES at both the student and school levels" [51], p. 219. Multilevel studies have shown connections among disciplinary climate and science literacy for four Chinese cities (Beijing, Shanghai, Jiangsu, and Guandong) [52]; as well as for Singapore [40]. Notably, the above-mentioned Chinese research was unable to connect teaching support in science classes with science literacy [52]. Recent work has positioned both teaching support and disciplinary climate as associated with a pair of science dispositions (epistemology and enjoyment), as well as with science literacy for many of the 21 diverse nations/regions evaluated in that project [26]. In summary, a diverse suite of studies supports our current conclusions for Finland; particularly, that the disciplinary climate in science classrooms was broadly associated with science literacy.

4.2. Effective Science-Teaching Models, a Student-Centered View

Finnish research, as noted above, has recently emphasized students' engagement in science learning on a nearly instantaneous basis [31,32,34,39]. One profound strength of such work is that it assesses students' engagement in science lessons in response to teaching "moments", rather than focusing on teachers' activities alone [33]. Specifically, these recent studies have shown enhanced situational engagement by bringing a playful, interactive, design and test intervention to physics [34]; developing models and crafting explanations [31], inquiry- and problem-based learning approaches as developed via teacher–researcher collaborations [32], and dialog-based teacher talk [39]. We believe that our current paper aligns well with this research—particularly because it focuses on students' perceptions of their learning environment (rather than fixating on teachers' strategies and approaches per se). Notably, a broad review of PISA 2015 (69 nations/regions) found that student ratings of four different teaching contexts "captured meaningful differences in teaching quality between schools" [46], p. 275. Estonian research supported teacher-centered science instruction as being connected with positive student outcomes (enjoyment); however, this teacher-centered approach remained most prominent in lower secondary classrooms, in spite of teachers' expressed desires to provide a more student-centered learning environment [29]. Of course, in some cases [22], students' perceptions of teaching quality have not been associated with science achievement. Thus, while the responses of a given set of students to specific science teaching and learning environments have been diverse [21,27,30,53,54], we believe that work considering students' own responses to their learning contexts should be highly valued.

4.3. Science Dispositions

All four science dispositions were positively associated with science literacy, not only when tested in separate models but also when tested together in a single combined model. That approach—utilizing a combined model—allowed us to identify those science dispositions most strongly associated with science literacy. Epistemology rose to the top in that combined model (with a moderate effect size); meanwhile, enjoyment and self-efficacy both registered a small effect size in that same model. Hence, we focused on epistemology, enjoyment, and self-efficacy. Recent Finnish research has associated students' epistemic beliefs with their science performance [55]; Taiwanese studies have identified student clusters that held simultaneously divergent levels of epistemic beliefs, enjoyment, and science literacy [37]. In a US context, teachers' epistemic orientations were related to their adoption of science teaching practices [56], indicating that efforts to enhance students' epistemic beliefs around science may need to first address their teachers' epistemic beliefs. A causal linkage among epistemic beliefs in science, intellectual risk-taking and science literacy has been detected [20]; enjoyment has been linked with science literacy for a suite of high-performing nations/regions (Canada, China, Finland, and Hong Kong) [27] along with Turkey [40] and the US [25]; and self-efficacy has been associated with science literacy in multiple contexts [25,27]. Notably, particular science teaching interventions (models [25,31] and hands-on activities [25,57]) that have evoked situational or sustained interest in science learning have been related to this set of science dispositions. Thus, we suggest that teaching interventions focused on enhancing students' experiences of science may not only be related to enhanced science dispositions but also to elevated science literacy. Furthermore, we suggest that a greater emphasis on the epistemic beliefs of science students may be appropriate.

4.4. Surprising Home-Language Associations

While Swedish-speaking students who took the PISA-2015 assessment in Swedish had significantly higher average epistemology than did either Finnish-speakers who took the assessment in Finnish, or other students whose assessment and home languages did not match, the highest average science literacy scores were detected for the Finnish/Finnish group. An understanding of this surprising feature of this study has been elusive; we suggest that the Swedish/Swedish context may require further scrutiny. Particularly, why might an instructional context (Swedish instruction and assessment for Swedish speakers) give rise to higher levels of epistemology, yet show lower science literacy? We note that science teachers are slightly less qualified in Swedish- (93%) compared to Finnish-speaking (98%) schools [58], providing at least a rationale for higher science literacy in the Finnish-speaking students. Furthermore, since Swedish-speaking concentrations (and therefore, Swedish language schools) differ between the more rural west coast communities and more urban communities on the south coast, the selection of schools for the PISA sample could influence science-related outcomes. Many global contexts include multiple home languages in PISA samples; it is less common that PISA assessments are offered in multiple languages within a given nation/region. Spain is a remarkable example of providing PISA assessments in several local languages; differences in outcomes (for example, science literacy) have been noted in Spain on a provincial scale (roughly corresponding to some of the local languages) [59]. Flemish students whose home language did not match the assessment language scored substantially lower in science achievement than those students not dealing with a language mismatch [60]. Language congruence (taking the PISA assessment in one's home language) has also given rise to surprising results elsewhere; for example, minority French-speaking students in Canada had higher science literacy than either English-speakers or speakers of other languages, while German speakers in Italy had lower test anxiety than did Italian speakers [61]. We suspect that instruction—and assessment—in one's home language may be important not only for students' academic achievement but also for their dispositions toward learning [62]. Perhaps the students' opportunity to demonstrate competence could be improved by enhanced language congruence [63–65]?

4.5. Conclusions and Limitations

We draw general conclusions regarding the school science climate, science dispositions, and home language. The disciplinary climate in science classes was associated with science literacy and science dispositions not only in our Finnish research work but also in a variety of other international contexts. More broadly, an emphasis on school science climate could merit more attention. Research drawing upon students' instantaneous and longer-term science engagement appears to have the potential to add substantive value to conversations about well-crafted teaching and learning environments. Furthermore, it seems that the epistemic beliefs of science students may merit a greater focus among research considering science dispositions. There may be a window for expanded research on language coherence and student learning; that is, students may perform better if they are able to experience instruction and assessment in their home languages. In the context of Hong Kong, both lower- and moderate-performing science students benefitted from science instruction in their home (Chinese) language [65].

The primary limitation of this research is the correlational nature of the data upon which it was based. Experimental and/or longitudinal studies can clearly provide more definitive conclusions since their inferences are based on comparisons across treatments or over time. Thus, correlational studies require the support of more definitive research; however, they can obviously provide some intriguing insights as to the directions of that ensuing work. A second limitation relates to the applicability of some of the constructs included in this research. For example, the underlying prompts for epistemology only related to a pair of conceptual underpinnings of students' epistemological beliefs: experimentation (as an important support for students' inferences) and the changeable nature of science's assertions (depending on the emerging results). Obviously, both support for experimentation and comfort with change are important aspects of an adaptative epistemic belief among students; however, other patterns have also been implicated as part of a positive epistemology of science [35,36].

In conclusion, we harmonize with Sahlberg's voice [1] from the third edition of his well-known text. Perhaps his most significant insights centered on contextualization and commitment; that is, could it be that other nations could experience some of Finland's success, not by trying to precisely match their methods but instead through appropriate contextualization of their underlying principles? Furthermore, can one infer from his celebrated review of Finland's educational system that sustained excellence in science education requires a profound commitment to underlying values?

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Appendix A

Table A1. PISA Items Descriptive of Science Dispositions.

Epistemology (Epistemological Beliefs) (First term, as utilized in manuscript; second term (in parentheses), as utilized by PISA)
How much do you disagree or agree with the statements below?
(a) A good way to know if something is true is to do an experiment. (b) Ideas in <broad science> sometimes change. (c) Good answers are based on evidence from many different experiments. (d) It is good to try experiments more than once to make sure of your findings. (e) Sometimes <broad science> scientists change their minds about what is true in science. (f) The ideas in <broad science> science books sometimes change. (1 = Strongly agree, 2 = agree, 3 = disagree, 4 = strongly disagree).
Enjoyment (Enjoyment of Science)
How much do you agree with the statements below?
(a) I generally have fun when I am learning science topics. (b) I like reading about science. (c) I am happy doing science problems. (d) I enjoy acquiring new knowledge in science. (e) I am interested in learning about science. (1 = strongly agree, 2 = agree, 3 = disagree, 4 = strongly disagree).
Interest (Interest in Broad Science Topics)
How much interest do you have in learning about the following science topics?
(a) Topics in physics. (b) Topics in chemistry. (c) The biology of plants. (d) Human biology. (e) Topics in astronomy. (f) Topics in geology. (g) Ways scientists design experiments. (h) What is required for scientific explanations? (1 = high interest, 2 = medium interest, 3 = low interest, 4 = no interest.
Self-efficacy (Science Self-efficacy)
How easy do you think it would be for you to perform the following tasks on your own?
(a) Recognize the science question that underlies a newspaper report on a health issue. (b) Explain why earthquakes occur more frequently in some areas than in others. (c) Describe the role of antibiotics in the treatment of disease. (d) Identify the science question associated with the disposal of garbage. (e) Predict how changes to an environment will affect the survival of certain species. (f) Interpret the scientific information provided on the labeling of food items. (g) Discuss how new evidence can lead you to change your understanding about the possibility of life on Mars. (h) Identify the better of two possible explanations about the formation of acid rain. (1 = I could do this easily, 2 = I could do this with a bit of effort, 3 = I would struggle to do this on my own, 4 = I couldn't do this).

Source: [38].

Table A2. PISA Items Descriptive of School Science Climate Variables.

Disciplinary Climate in Science Classes (aggregated from student level)
How often does the following happen? (a) Students don't listen to what the teacher says. (b) There is noise and disorder. (c) The teacher has to wait a long time for students to quiet down. (d) Students cannot work well. (e) Students don't start working until a long time after the lesson begins. (1 = Every Lesson, 2 = Most Lessons, 3 = Some Lessons, 4 = Never or Hardly Ever).
Teaching Support in Science Classes (aggregated from student level)
How often does the following happen? (a) The teacher shows an interest in every student's learning. (b) The teacher gives extra help to students with their learning. (c) The teacher continues teaching until the students understand. (d) The teacher gives students an opportunity to express opinions. (1 = Every Lesson, 2 = Most Lessons, 3 = Some Lessons, 4 = Never or Hardly Ever).

Source: [38].

Table A3. Descriptive statistics for student- and school-level variables included in the multilevel analysis for Finland.

Variable [1]	***n***	**Mean**	**s.d.**	**min.**	**max.**
Student background:					
Male gender	5882	0.513	0.500	0	1
Age	5882	15.720	0.284	15.250	16.250
First-gen. immig.	5794	0.022	0.146	0	1
Native students	5794	0.960	0.195	0	1
Other home lang.	5816	0.060	0.238	0	1
Finn. home lang.	5816	0.896	0.305	0	1
ESCS index	5812	0.259	0.748	−4.112	3.567
Science disposition:					
Epistemology	5462	−0.071	0.941	−2.790	2.155
Enjoyment	5599	−0.071	1.006	−2.115	2.164
Interest	5510	−0.093	0.972	−2.498	2.451
Self-efficacy	5470	−0.041	1.183	−3.757	3.278
School context:					
School location	167	0.275	0.448	0	1
School size	167	411.620	217.394	15.000	1044.000
Sci. teach. cert.	167	0.929	0.225	0.000	1.000
ESCS index–ag.	167	0.236	0.336	−0.970	1.370
School climate:					
Disc. clim. sci. cl.	167	−0.078	0.382	−1.114	1.884
Tch. sup. sci. cl.	167	0.190	0.285	−1.702	0.821

[1] Variable explanation (details in Methods): gender, males as 1; age, in years; first-gen. immig., first-generation immigrant students as 1; native students, as 1; other home lang., other language spoken at home as 1; Finn. home lang., Finnish spoken at home as 1; ESCS index, index of economic, social, and cultural status; epistemology, epistemological beliefs; enjoyment, enjoyment of science; interest, interest in broad science topics; self-efficacy, science self-efficacy; school location, community of 100,000 or larger as 1; school size, school enrollment; sci. teach. cert., index of science teachers fully certified; ESCS index—agg., index of economic, social, and cultural status, aggregated student variable; disc. clim. sci. cl., disciplinary climate in science classes, aggregated student variable; and tch. supp. sci. cl., teaching support in science classes, aggregated student variable.

Table A4. Bivariate correlations among science dispositions for Finland.

Key Variable	Epist.[1]	Enjoyment	Interest	Self-Eff.
Epistemology	1.000	0.302 **	0.295 **	0.229 **
Enjoyment		1.000	**0.539** **,[2]	0.363 **
Interest			1.000	0.355 **
Self-efficacy				1.000

[1] Variable explanation (details in Methods): epistemology, epistemological beliefs; enjoyment, enjoyment of science; interest, interest in broad science topics; self-efficacy, science self-efficacy. [2] Bolded values indicate a moderate bivariate correlation among indicated pairs of variables (0.400 to 0.799). **, Correlation is significant at the 0.01 level (2-tailed).

Table A5. Bivariate correlations among school-level variables for Finland.

	School	Sci. Teach.	ESCS	Disc. Clim.	Tch. Sup.
Key Variable	**size** [1]	**cert.**	**ind.–ag.**	**sci. cl.**	**sci. cl.**
School size	1.000	0.200 **	0.232 **	−0.076	0.160 *
Sci. teach. cert.		1.000	0.268 **	−0.337 **	−0.150
ESCS ind.–ag.			1.000	0.051	−0.020
Disc. clim. sci. cl.				1.000	0.267 **
Tch. sup. sci. cl.					1.000

[1] Variable explanation (details in the Methods section): school size, school enrollment; sci. teach. cert., index of science teachers fully certified; ESCS index–ag., index of economic, social, and cultural status, aggregated student variable; disc. clim. sci. cl., disciplinary climate in science classes, aggregated student variable; and tch. sup. sci. cl., teaching support in science classes, aggregated student variable. **, *, correlation is significant at the 0.01 and 0.05 levels, respectively (2-tailed).

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Sustainable Education with Local-Wisdom Based Natural Reagent for Green Chemical Analysis with a Smart Device: Experiences in Thailand

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Abstract: To minimize chemical waste and protect the environment, our team has used green analysis with natural reagents. In this work, we designed a natural-reagent assay kit for iron determination and implemented it in chemistry education in Thailand. The iron assay method was adapted from Thai local wisdom of testing water quality using guava leaves. The guava leaf powder served as a natural reagent in the assay. The kit included equipment, standard and buffer solutions and a manual. A smart device with a built-in camera was used as a detector. Educators in six universities in Thailand implemented the kit in laboratories with modifications depending on their learning outcomes. The kit implementation was evaluated using a survey with questions in four aspects: usability, learning achievement, green chemistry and portability. The high average scores for all questions (> 4.00 of 5.00 points), with the average overall score of 4.53 ± 0.60, indicated satisfaction regarding in all aspects. Using a locally available bio-resource as a natural reagent for green analysis in chemistry education supported sustainable education in Thailand, in terms of quality education (SDG 4) and reduced inequalities (SDG 10) and environmental sustainability (SDG 6—Clean water and sanitation, 12—Responsible consumption and production and 14—Life be-low water).

Keywords: Thai local wisdom; green chemical analysis; natural reagent; sustainable education; chemistry education; sustainability development

1. Introduction

The green chemistry concept has provided approaches to reduce the risks of chemistry to the environment [1]. Within the twelve principles of green chemistry, proposed since 1998 by P. T. Anastas and J. C. Warner [2], analytical chemistry was a branch that was difficult to be environmentally friendly. In fact, some of the green chemistry principles, such as waste prevention, safer solvents and auxiliaries, design for energy efficiency, safer chemistry to minimize the potential of chemical accidents and development of instrumental methods, are directly related to analytical chemistry [3]. However, the need for hazardous chemical reagents for some steps in the analytical process, e.g., sample preservation and preparation and chemical analysis, have been one of the causes. Analytical chemists have endeavored to develop greener chemical analyses, leading to more sustainable chemistry [4]. The Organisation for Economic Co-operation and Development (OECD) defined the term "Sustainable chemistry" as *a scientific concept that seeks to improve the efficiency with which natural resources are used to meet human needs for chemical products and services. Sustainable chemistry encompasses the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes* [5].

Our research group interests, since 1991, are in the development of flow-based analysis (FBA) methods for various aspects of chemical analyses. The FBA is a green analytical method that could reduce reagent consumption and, therefore, waste production, from macro- to nano-volume. Moreover, using FBA helps save energy due to its simplicity and rapidity and prevents accidents due to its closed and, sometimes, remote system. However, the use of hazardous chemicals is unavoidable in some cases. The development of green chemical analysis methods utilizing natural reagents has, hence, become our attempt to meet the sustainable chemistry goals and three of the sustainable development goals (SDGs) identified in 2015 by the United Nations (UN), i.e., goal 6-Clean water and sanitation; goal 12-Responsible consumption and production; and goal 14-Life below water.

In 2005, our group reported the use of a natural reagent (guava leaf extract) as an alternative reagent for the flow injection determination of iron, based on Thai local wisdom [6,7]. This local wisdom has been passed down through generations. The ground guava leaves were put in water samples to test whether the water could be used for washing clothes. If the water turned dark purple, it indicated too much iron and the water should not be used. Recently, it was reported that these guava leaves were a source of phenolic compounds, responsible for binding to or chelating with metal ions such as Fe(III) ions [8]. Our group's article in 2005 found that the extract from guava leaves was a promising natural reagent for the iron determination. From the discovery in this publication, we have further adapted Thai local wisdom in detecting chemicals or elements in real samples to the modern analysis, for examples; using guava leaf extract for quality control of iron content in pharmaceutical formulations [8]; exploiting green tea extracts for the iron determination by flow injection analysis (FIA) [9]; determining iron(III) using *Phyllanthus emblica* Linn. as a natural reagent [10]; using Indian almond (*Terminalia Catappa* L.) leaf extract to determine aluminum in wastewater [11]; using *Morinda citrifolia* root to determine aluminum in tea [12] and the attempts succeeded [13–15].

In order to develop sustainability in chemistry education, in this work, the guava leaf extract, among those local wisdom-based innovations, has been investigated further and applied as a green reagent in chemistry experiments for undergraduate education in six Thai universities. The extract was transformed into a ready-to-use reagent powder and packed up with a set of simple experimental equipment and a user manual, as a natural reagent iron assay kit, for the experiment. Each university adapted the kit to achieve its aim of the experiment. Implementing the natural reagent iron assay kit in chemistry courses was studied. Satisfaction with the utilization of the developed assay kit was evaluated using a questionnaire consisting of nine questions, rating satisfaction level in four aspects: the usability of the developed assay kit, the learning achievement, the green chemistry and the portability of the developed assay kit.

2. Materials and Methods

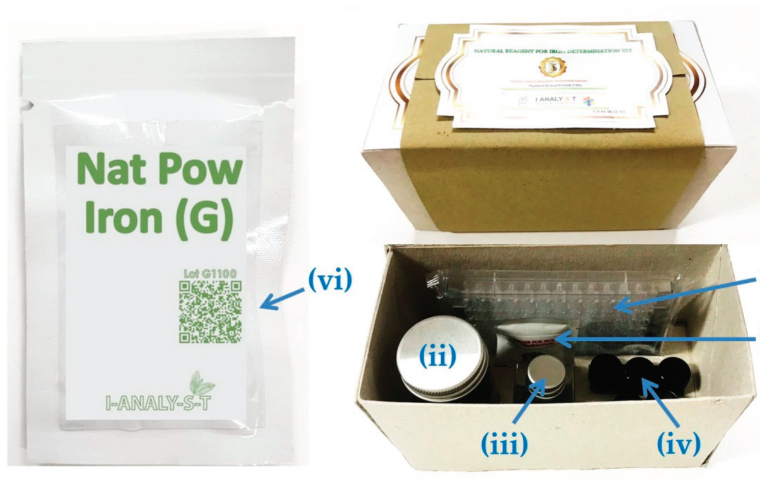
In order to standardize the natural reagent from guava leaf, it was produced in a laboratory at Chiang Mai University, as the supplier and was sent to cooperating universities.

Preparation of the natural reagent from guava leaf, assembling the natural-reagent iron assay kit and the implementation of the kit are described in this part.

2.1. Natural Reagent from Guava Leaf (in Brief)

2.1.1. Production of the Natural Reagent Powder

Firstly, fresh guava leaves were washed and dried in a hot air oven at 60 °C for 24 h. The dried leaves were then ground to powder and sieved to obtain 10–20 mesh powder. Finally, a ready-to-use natural reagent powder was obtained and packed in a tea bag and sealed to an air-tight opaque package to avoid exposure to air and light as shown in Figure 1a. The natural reagent powder from guava leaves for the iron assay was so-called Nat Pow Iron (G).



(**a**) (**b**)

Figure 1. (**a**) Nat Pow Iron (G) sachet; (**b**) natural-reagent iron assay kit.

2.1.2. Preparation of the Natural-Reagent Iron Assay Kit

The natural-reagent iron assay kit (Figure 1b) consists of (i) a sachet of Nat Pow Iron (G), (ii) a vial for extracting the natural reagent, (iii) a vial containing the iron(III) standard, (iv) a vial containing buffer solution, (v) a 96 wells microplate as a reaction platform and (vi) instructions for the reagent preparation as shown in Supplementary Material: Figure S1, which can be accessed by scanning the QR code on a sachet of Nat Pow Iron (G). The chemicals and conditions used were optimized as reported previously [6].

2.1.3. Quality Control of the Nat Pow Iron (G)

The quality control of the Nat Pow Iron (G) was performed using high performance liquid chromatography (HPLC). Every lot of the Nat Pow Iron (G) was sampled for HPLC analysis of active ingredients before packing as the reagent for the iron assay kit. The analysis method is described elsewhere [16]. The major components in the natural reagent extract were phenolic compounds, namely gallic acid, catechin and ellagic acid, as illustrated in Figure 2. Users could check the quality of the Nat Pow Iron (G) by scanning the QR code on the Nat Pow Iron (G) sachet for the HPLC fingerprint of the reagent. The reagent data sheet is also shown in the Supplementary Material: Figure S1.

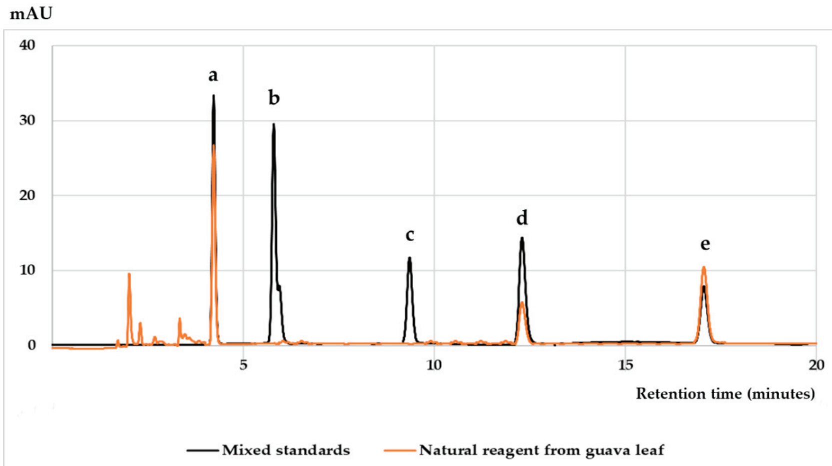


Figure 2. HPLC chromatograms of mixed phenolic compound standards and natural reagent from guava leaf. The peaks are (a): gallic acid; (b): gallocatechin; (c): epigallocatechin; (d): catechin; and (e): ellagic acid.

2.1.4. Using a Smart Device as a Detector

A dark purple complex is the product of the reaction between iron (III) and phenolic compounds in the natural reagent. Its color intensity is directly proportional to the amount of the iron (III). Thus, the amount of iron (III could be measured by detecting the difference in the color intensity of the reaction product. To promote equitable quality education (SDG 4-Quality education), simplifying the detection using a smart device with a built-in camera, i.e., a smartphone or a tablet, was done. A photograph of the product solutions in the well-microplate was taken by a student's smart device. The color value of each solution was analyzed using an image processing program on a computer or an application on the smart device such as ImageJ application, Chemical Sensor System by TRF and I-ANALY-S-T (CSS by TRF & I-ANALY-S-T).

2.2. Implementation of the Natural-Reagent Iron Assay Kit

The natural-reagent iron assay kit was demonstrated at six national universities in Thailand (Figure 3): (i) Faculty of Pharmacy, Chiang Mai University, (ii) Faculty of Science, King Mongkut's University of Technology Thonburi, (iii) Faculty of Science and Engineering, Kasetsart University- Chalermphrakiat Sakon Nakhon Province Campus, (iv) Faculty of Science, Khon Kaen University, (v) School of Science, Mae Fah Luang University and (vi) School of Science, University of Phayao. The use of the developed assay kit was recommended in the procedure manual as shown in Supplementary Material: Figure S2. However, it could be customized by users and course instructors to achieve their goals or the objectives of the experiment and to suit different groups of learners at each university with different working environments. Some components of the kits could be replaced by either suitable or available equipment such as liquid measuring and handling tools.

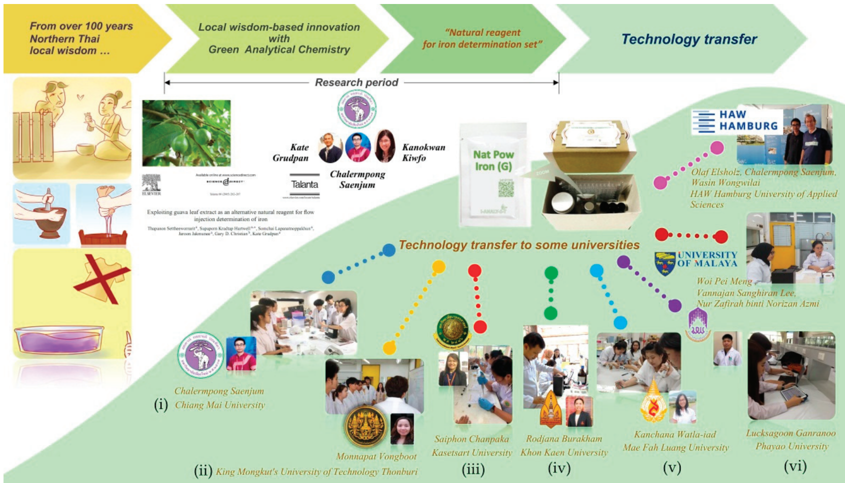


Figure 3. Implementation of the assay kits as a learning material for a green chemical analysis topic in 6 universities: (**i**) Chiang Mai University (20 students); (**ii**) King Mongkut's University of Technology Thonburi (25 students); (**iii**) Kasetsart University—Chalermphrakiat Sakon Nakhon Province Campus (11 students); (**iv**) Khon Kaen University (10 students); (**v**) Mae Fah Luang University (12 students); and (**vi**) University of Phayao (25 students).

Satisfaction level was evaluated using a self-administered questionnaire. The questionnaire was composed of nine issues with a 5-point Likert scale (1 = least satisfied, 2 = less satisfied, 3 = moderately satisfied, 4 = very satisfied, 5 = most satisfied). The issues covered (i) clearness and comprehensibility of the procedure manual, (ii) simplicity of the operation, (iii) suitability of the equipment, (iv) student's comprehensibility in the principle of the iron assay, (v) student's ability in transferring knowledge learned from this experiment to other students, (vi) operator safety, (vii) environmentally friendliness, (viii) feasibility of application for sampling-site chemical analysis and (ix) overall satisfaction with this experiment. The satisfaction was evaluated by 40 students enrolled in two chemistry subjects from two faculties, i.e., Instrumental Methods of Chemical Analysis Laboratory I (CHM363) course (20 students) at the Faculty of Science, King Mongkut's University of Technology Thonburi, Bangkok and Quality Control for Food and Cosmetics (461571) course (20 students) at the Faculty of Pharmacy, Chiang Mai University, Chiang Mai. The difference of the satisfaction scores evaluated by students between the two groups was analyzed using independent *t*-test, with a $p < 0.05$ as significant difference. It should be noted that there was no control group of students who used a standard traditional method for iron analysis.

Moreover, we randomly selected students and divided them into three groups of four for the focus group discussion, asking about the advantages, difficulties, limitations, satisfaction and suggestions for improvement. The focus group discussion for each group took approximately 15–20 minutes and the content analysis was conducted.

3. Results

3.1. Implementation of the Developed Assay Kit in On-Site Classes

The iron assay kit using the Nat Pow Iron (G) as a natural reagent was distributed to the six universities for implementation in a hands-on experiment of chemistry courses (Figure 3). As an example, Supplementary Material: Video S1 demonstrated the use of the developed assay kit in a chemistry laboratory at the Department of Chemistry, Faculty of Science, King Mongkut's University of Technology Thonburi. Because the procedure was designed at the beginning to be flexible, the instructors in each university were able to adjust the procedures, including adding steps and changing the provided equipment to available lab equipment, to achieve the specific learning outcomes. For example, to measure the volumes of solutions, the instructors may use different types of measuring equipment, e.g., autopipette, disposable medical syringe, or dropper. The autopipette was used at all six universities because it provided an accurate and precise volume. Four universities additionally used the disposable syringe, while one university used the dropper, both calibrated with the autopipette, to measure the volumes of the solutions. The Supplementary Material: Figure S3 illustrates the example of the laboratory instruction modified from the provided procedure manual.

Despite the fact that students used various smart devices with different operating systems (iOS and Android) and different camera quality, the assay accuracy, as measured by analysis of known-concentration samples, was not significantly different (statistical analysis by independent *t*-test, $p = 1.00$). Moreover, although the procedure manual provided in the assay kit recommended using a smart device as the detection device, the image processing application/program could actually be varied. This flexibility promoted students to learn the importance of chemical data analysis, especially the accuracy and precision of the analysis, which expressed the reliability and reproducibility of the analytical data. In all, three universities used the in-house image processing mobile application; Chemical Sensor System by TRF and I-ANALY-S-T (CSS by TRF & I-ANALY-S-T for Android-APK download) [17], whereas the other three universities used different mobile applications, including Pixel Picker [18], ImageJ [19], Color Detector [20] and Color Grab [21].

3.2. Evaluation of the Utilisation of the Developed Assay Kit as a Learning Material in Chemistry Courses

The responses from all 40 students regarding their satisfaction with the experiment using the natural-reagent iron assay kit as a learning material are shown in Figure 4. Overall, the satisfaction scores evaluated by 40 students from the chosen universities (two universities, 20 students each) showed that the average score for every question was higher than 4.00 (full score = 5.00) points, meaning very satisfied, with the average satisfaction on the natural-reagent iron assay kit of 4.55 ± 0.64. The three issues that had the highest scores were the operator safety (4.78 ± 0.42), the environmental friendliness (4.70 ± 0.46) and the suitability of the equipment (4.63 ± 0.54), respectively. The issue with the lowest score (4.20 ± 0.61) was the student's ability in transferring knowledge learned from the experiment to other students. The score of the student's ability in transferring knowledge given by applied science students in the university U1 was surprisingly below 4.00 points, meaning moderately satisfied. Nevertheless, the satisfaction scores evaluated by pharmacy students (U1) were lower than those by chemistry students (U2) with the significant differences (statistically tested by independent *t*-test, $p < 0.05$) in all issues, except issue 6—Operator safety ($p = 0.06$).

However, the results from the focus group discussion showed that all students (12 students) were very satisfied with the green chemical analysis using the developed assay kit. Most students were impressed with the innovation in green chemical analysis. Some students said that "It was a novel laboratory investigation that used less volume of chemicals, and the chemical reagent was produced from a natural bio-resource. I think it is very good and also safe for students".

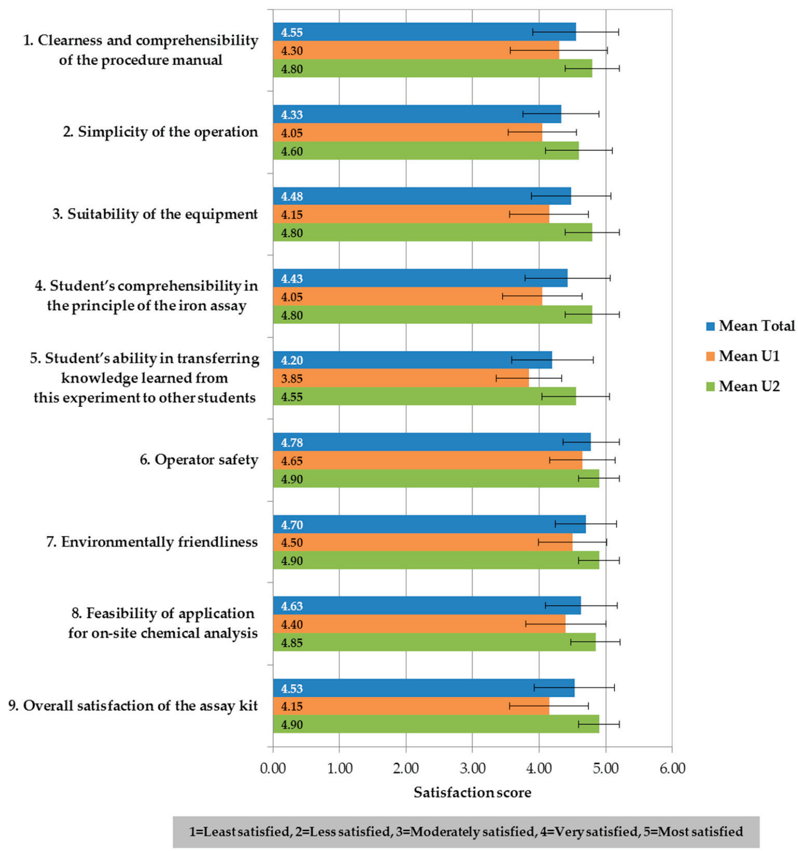


Figure 4. Mean satisfaction on the experiment using the natural-reagent iron assay kit as a learning material evaluated by students (n = 40).

4. Discussion

4.1. Implementation of the Natural-Reagent Iron Assay Kit in Chemistry Education

An academic application of the developed natural-reagent iron assay kit was demonstrated in chemistry education at six universities in Thailand and was used as learning material for an experiment of natural and applied science courses. Although the provided procedure manual in the developed assay kit clearly directed the use, it remained flexible enough to be modified according to the desired learning outcomes of the courses. However, all six universities followed the core procedure to achieve the completion of the expected chemical reaction. The modification was made only in the steps of solution preparation. Using droppers and disposable syringes, calibrated with autopipettes, allowed students to learn with creativity and open-mindedness. They would be able to adapt any kind of volume-measuring equipment available in their laboratory or place to measure accurate and precise volume by appropriately calibrating with standard volume-measuring equipment.

In the current digital and mobile world, it could not be denied that students must possess one of the smart devices as a tool for learning and communication. The employment of smart devices as detection devices led to simplicity and even equity in education, supporting SDG 10 (Reduced inequalities). Instead of a spectrophotometer, which might be unavailable in some laboratories due to its cost, a smart phone could obviously detect the color intensity using its high-quality camera. The results showed that various smart devices with different operating systems and different camera quality did not exhibit a significant difference in the accuracy of the assay. Thus, every student would be able to analyze his or her experimental data and learn how to analyze analytical data, which is the seventh step in the chemical analytical process. Students were excited and mentioned that "The experiment was easy and fun"; It's an exotic lab. It's very interesting; I didn't think I could use my mobile phone for the experiment, and it was very interesting".

The experiment report could also be created in Microsoft Excel spreadsheet and submitted to the instructor via email or other online methods. This increased the convenience for both the students and the instructors and importantly created a paperless culture, the green mind. Moreover, as the instructors at a university created a cloud space, i.e., Google spreadsheet, for sharing the analytical results during the class, the results from students could be discussed at real-time in the class. Students were encouraged to critique as a result of this.

4.2. Evaluation of the Utilisation of the Developed Assay Kit as a Learning Material in Chemistry Courses

Because all of the students had prior experience using the traditional spectrophotometric method for other analyses, no control group was used in this study. The students were able to compare their prior experience with the developed assay kit. Overall, the evaluation results illustrated a high level of satisfaction (average overall score 4.53 ± 0.60) in the utilization of the developed assay kit as a learning material in chemistry courses. Hence, employing the assay kit in chemistry education is promising. However, the statistical *t*-test, comparing the satisfaction scores evaluated by pharmacy (U1) and chemistry students (U2), indicated the pharmacy students' satisfaction scores were significantly lower than those of the chemistry students in all aspects, except the operator safety. The reason was that the pharmacy students were concerned that the assay kit would not be able to be used in pharmaceutical analysis, which needs high levels of precision and accuracy following FDA regulations and pharmaceutical pharmacopoeia. The satisfaction scores for the operator safety evaluated by students in U1 and U2 did not significantly differ. It demonstrated that the assay kit was safe for pharmaceutical and chemistry research. Therefore, the green chemical analysis may be used as an alternative analysis in the pharmaceutical industry, but may be unable to be utilized as the primary analysis. However, some pharmacy students were impressed by the use of natural extract as an environmentally friendly reagent for iron analysis, the simplicity of the analytical procedure and the use of smartphones as the detection device instead of a spectrophotometer.

The questions in the satisfaction survey were categorized, for further discussion, in four aspects: usability of the developed assay kit (questions 1, 2 and 3), learning achievement (questions 4 and 5), green chemistry (questions 6 and 7) and portability (question 8) and were discussed as follows.

4.2.1. Usability of the Developed Assay Kit

The results showed the students were very satisfied with using the assay kit in terms of the clearness and comprehensibility of the procedure manual (score 4.55 ± 0.64), the simplicity of the operation (score 4.33 ± 0.57) and the suitability of the equipment (score 4.48 ± 0.60), indicating the simplicity and user friendliness of the assay kit. Some students expressed their impression as follows:

> "It was my first time discovering that natural reagents could detect iron, and was a lot easier than I imagined, with no need of expensive and complicated laboratory equipment or a teacher's assistance. I am capable of doing all tasks on my own."

Nonetheless, while the majority of students encountered no problems, some did. For example, because of the transparency of the solutions and the small size of the micro-volume well plate, they found it difficult to locate the wells and drop the solutions into the wells. They stated that "We got dizzy when we had to drop the solution into the well because it was so small".

Therefore, the developed assay kit could definitely be employed as a learning material for natural and applied chemistry courses. The developed assay kit showed its flexibility so that educators could modify the procedures in order to achieve their learning outcomes of the course.

4.2.2. Learning Achievement

Most students said in the focus group session that "The experiment can be linked to the lesson and make the lesson more interesting and memorable", which agreed with the evaluation of the developed assay kit. The average score of the issue "student's comprehensibility in the principle of the iron assay" was 4.43 ± 0.64, meaning very satisfied. However, the average score for the issue "Student's ability in transferring knowledge learned from this experiment to other students" was the lowest score (4.20 ± 0.61), but its interpretation was very satisfactory. According to the Learning Theory Pyramid, students will gain approximately 90% of their knowledge by teaching others, resulting in a deeper understanding and long-term memory, as opposed to learning through traditional passive methods such as lecture and reading, which only gain 5–30% of the knowledge. Furthermore, some responses from the participating students via an online survey showed that they were able to learn new things related to green chemical analysis, such as how to colorimetrically determine iron using a natural reagent, accuracy and precision, perform green analytical chemistry and obtain information technology (IT) skills. Therefore, hands-on experiments with simple but intense learning material, such as the developed assay kit, helped promote deeper understanding and long-term memory quite well. Notably, students may not have the opportunity to practice standard laboratory skills such as measuring the volumes of solutions with pipettes and preparing solutions in volumetric flasks. However, these constraints came with more benefits in terms of sustainability.

4.2.3. Green Chemistry

As mentioned earlier, the average satisfaction scores for the green chemistry aspect, i.e., the issues "Operator safety" and "Environmental friendliness", were the highest scores (4.78 ± 0.42 and 4.70 ± 0.46 points, respectively). It indicated that students were deeply concerned with the hazards of chemicals that could harm the operator's and the environmental health. It could be implied that utilization of natural reagents, based on Thai local wisdom, in chemistry education had raised students' awareness of "Responsible consumption and production''—SDG 12, which is concerned with responsible use of natural resources to avoid harmful effects to the environment.

This proposed green chemistry experiment achieved our research group's aim to meet SDG 6—Clean water and sanitation and SDG 14—Life below water successfully. It helped ensure the availability and sustainable management of water sanitation (SDG 6) by reducing the hazardous wastewater released to water resources. Consequently, it conserved the oceans, sea and marine resources (SDG 14). Furthermore, not only does using natural reagents extracted from natural resources in Thailand reduce environmental hazards, but it also reduces inequality within and among countries (SDG 10—Reduced inequalities) by producing cost-effective natural reagents in Thailand, as well as minimizing the relatively high-cost chemical reagents imported from abroad, which some organizations rely on. Referring to the interview of Emeritus Professor in analytical chemistry, Prof. Dr. K. Grudpan, published in a national newspaper [22], the chemical reagents imported from abroad could cost four times more than those produced by using the bio-resources in Thailand. Using natural extracts as natural reagents for chemical analyses could save up to 10 million THB and save time according to the duration of long-distance transportation (up to six months) [23].

Nevertheless, because natural reagents are non-toxic and produced from a locally available bio-resource, their use for chemistry promotes the green chemistry principles

5—safer solvents and auxiliaries and 7—use of renewable feedstocks, respectively. This approach also raised awareness about the importance of utilizing green chemistry and natural reagents in experiments to save the environment and ensure sustainable education and development. This agrees with target 4.7 of SDG 4, stating "By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development".

4.2.4. Portability and Future Application

The satisfaction score for the issue "Feasibility of application for sampling-site chemical analysis" was high (4.63 ± 0.54). It meant that students found the developed assay kit convenient and highly feasible for sampling-site iron analysis. Students also expressed that the developed assay kit did not require expensive and complicated scientific instruments and, thus, could be easily carried to the site. In addition, unlike the traditional analysis method for iron assay, all steps of the analysis using the developed assay kit did not have to be performed in a laboratory because there were fewer hazardous chemicals and harmful procedures.

In our further studies, the developed assay kit could be implemented in an online chemistry laboratory class. As a result of the COVID-19 pandemic, all on-site academic activities were suspended and online learning became a feasible alternative. Science educators and also students may have difficulty with laboratory lessons because students may not have the necessary equipment at home and could not afford to obtain it. Therefore, educators still need to design efficient and effective classes to continue achieving the learning outcomes of the courses. Higher education in chemistry requires hands-on laboratories to allow students to develop laboratory and 21st-century learning skills, i.e., learning and innovation, information, media and technology and life and career. During the first wave of the COVID-19 outbreak, an educator in our research team constructed an online chemistry laboratory using the developed assay kit as a learning tool [22,23]. The developed assay kit was sent to students' homes so that all students enrolled in the course could conduct the analysis in an online laboratory class at their homes. This study will be presented as "Lab-at-Home" in the next series of the development of the natural-reagent iron assay kit based on Thai local wisdom.

5. Conclusions

Much Thai local wisdom, for over hundreds of years, has used Thai natural resources to test or analyze for poisons or toxins. Our research group has been working on utilizing this valuable wisdom to develop green chemical analysis as a green innovation. Moreover, the developed green chemical analysis method was implemented as a learning tool for chemistry education. This work presented an example of developing green innovation adapting the wisdom of detecting iron element in water using ground guava leaf extract to analyze iron(III) ion in a laboratory. The guava leaf extract was served as a natural reagent for this purpose. A set of a sachet of the ground and dried guava leaf powder (Nat Pow Iron (G)), an iron(III) standard solution, a buffer solution, a 96-wells microplate and a procedure manual were packed as a natural-reagent iron assay kit and used for a chemistry experiment of chemistry classes in six Thai universities. The detection of colored complex, the product of the chemical reaction, was simplified using smart devices with built-in cameras, instead of a relatively high-cost spectrophotometer. The instructors of the courses could modify the procedure to achieve the learning outcomes of the courses. The results showed that students were remarkably satisfied with the natural-reagent iron assay kit in terms of the usability of the developed assay kit, learning achievement, green chemistry and portability. Utilizing the developed assay kit supported SDG 4 (quality education), SDG 6 (clean water and sanitation), SDG 10 (reduced inequalities), SDG 12 (responsible consumption and production) and SDG 14 (life below water) and promoted sustainable chemistry education.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su132011147/s1, Figure S1: instruction for the reagent preparation, Figure S2: provided procedure manual, Figure S3: example of the laboratory instruction modified from the provided procedure manual, Video S1: use of natural-reagent iron assay kit in the Instrumental Methods of Chemical Analysis Laboratory I (CHM363) course at Department of Chemistry, Faculty of Science, King Mongkut's University of Technology Thonburi in academic year 2019.

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Lab-at-Home: Hands-On Green Analytical Chemistry Laboratory for New Normal Experimentation

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Abstract: The COVID-19 pandemic has forced analytical chemistry educators in Thailand to change methods of teaching and learning to new normal ones. Higher education has faced additional challenges because of a lack of hands-on experiments and an increasing number of students in foundation chemistry courses being hindered from practicing skills. This work aimed to develop a Lab-at-Home (LAH) for new normal, analytical chemistry experimentation. The LAH implemented a hands-on green chemistry experiment, i.e., colorimetric determination of iron using non-hazardous reagents (supporting Sustainable Development Goal (SDG) 12-responsible consumption and production). The LAH was sent to students at their location before the synchronous class, where the instructors were prompt to supervise. Thus, this supports SDG4-quality education and SDG10-reduced inequalities. The learning outcome achievements, i.e., the analytical characteristics and colorimetry principles comprehension, as well as the ability to perform data analysis, were evaluated by a quiz and laboratory report. LAH satisfaction was assessed by questionnaire and focus group discussion. The learning outcomes were successfully achieved, although students who performed the experiment individually received higher scores than those who did in groups. Students were very satisfied with the LAH as a tool for new normal experimentation, yet some students faced a poor Internet connection during the synchronous online class.

Keywords: Lab-at-Home; new normal experimentation; green analytical chemistry; hands-on remote learning; higher education; sustainability development

1. Introduction

During the COVID-19 pandemic, the forced closure of workplaces since 2019 (including universities, where thousands of faculty staff and students meet regularly), were undeniable. Consequently, higher education methods have suddenly changed from on-site to remote learning, in order to avoid the spread of the coronavirus among people. Educators, especially in the sciences, have had the most frustrating experiences because they had to design remote learning lessons for theoretical and practical classes, aiming to achieve scientific learning outcomes. Laboratory practice is essential in chemistry education because graduates in chemistry need laboratory skills for their careers, i.e., the abilities to conduct experiments, analyze experimental data, and interpret the results.

Kelley has recently reviewed articles reporting the laboratory learning in chemistry and closely related disciplines during the COVID-19 pandemic [1]. She aimed to determine the findings about the types of adjustments made to laboratory curricula and the immediate effect of these adjustments on students. The 91 reviewed articles illustrated the experiences of sudden transmission of teaching and learning methods from January 2020–June 2021 in a variety of institutions in and outside the US, e.g., Australia, Germany, Mexico, Slovakia, Spain, and the UK. Types of laboratory curricular adjustments that were diverted, for example, include (1) adapting experiments to be hands-on, at-home activities with household/school/commercial kit supplies, followed by some form of analysis (29.7%); (2) distributing procedures and non-interactive videos/pictures of experiments, from which students might or might not collect data themselves (50.5%); and (3) using digital simulations, models, augmented reality/virtual reality (AR/VR), games, or interactive videos, from which students might or might not collect simulated/real data themselves (45.1%). The findings evidenced that hands-on experience may improve technical performance (i.e., analyzing data, proposing a procedural step) but did not necessarily impact non-technical performance, such as writing a lab report and answering conceptual questions. Lower comprehension of data and procedures, as well as greater discomfort or poorer quality of interpretation, was found among students without hands-on experience compared with students assigned to perform the hands-on laboratory experiments. Moreover, students commented that performing hands-on work was more helpful for learning than remote alternative activities; however, doing hands-on experiments in a face-to-face laboratory was required. Therefore, to develop students' technical skills efficiently during the closure of the university, chemistry education curricular adjustments with hands-on laboratories were undeniable.

The diversity of hands-on, at-home laboratories for chemistry and related fields, i.e., analytical chemistry, organic chemistry, inorganic chemistry, biochemistry, general chemistry, and chemical engineering, has been reported [2–10]. Since we could not avoid using chemicals in the chemistry laboratory, the chemicals used in the designed hands-on, at-home laboratories must be safe for students and their family members as well as friendly to the environment, so that those chemicals could be discarded as household waste. Therefore, the chemicals used in those proposed laboratories were either kitchen chemicals or chemicals available at pharmacies that were disposable after use.

Analytical chemistry laboratories, especially for second-year-up undergraduate students, aim to encourage students to learn the principles of the analytical process, the steps for performing an analysis, i.e., (1) define the problem, (2) select an analytical method, (3) obtain a representative sample, (4) prepare the sample for the analysis, (5) perform any necessary separations, (6) perform the measurement, and (7) calculate the results and report [11] the analytical characteristics, e.g., accuracy, precision, calibration graph, etc., as well as the principles of instrumental analysis, for example, colorimetry, advanced spectrophotometry, chromatography, and electrochemistry. To meet the learning outcomes in analytical chemistry during the closure of universities, the instructors of analytical chemistry subjects have to design hands-on laboratories that students could perform at home. It should, again, be emphasized that the chemicals used must be less toxic, or even non-toxic, and disposable as household waste. Nevertheless, in general, chemical analyses require chemical reagents to react with analytes, resulting in chemical reaction products that are detected using an analytical method. Thus, the hands-on analytical chemistry experiments for at-home laboratories have been challenging to design. Natural extracts are alternative environmentally friendly chemical reagents that were proposed for a variety of green chemical analyses [12]. However, to date, only one article reported the use of natural extracts for hands-on, at-home analytical chemistry laboratories. Caraballo et al.

proposed using natural extracts, i.e., curcumin and red cabbage extracts, as indicators for an acid-base equilibrium experiment, in which students would learn the main concepts of acid−base equilibrium, buffer capacity, and titration curves, as well as titrimetric analysis [7]. However, the natural extracts they used were exploited as indicators and were indirectly involved in the main acid-base reactions.

Our previous work suggested that using the natural extracts from guava leaves as a reagent for colorimetric determination of iron worked successfully [13]. The phenolic compounds in guava leaf extract played a spot role as the reagent binding to or chelating with iron ions (Fe(III)), resulting in a dark purple complex that could be detected colorimetrically. The use of guava leaf simple extract as the natural reagent for iron assay was developed further as a natural-reagent iron assay kit that was implemented in on-site analytical chemistry laboratories at six Thai universities [14]. The dried and ground guava leaf powder was packed in a tea bag and sealed in an airtight opaque package that was convenient to use. Other nonhazardous reagents, i.e., Fe(III) stock standard solution and acetate/acetic acid buffer solution, both with mild concentrations, as well as the necessary equipment including a vial for extracting the natural reagent and a 96-well microplate as a reaction platform, were provided in the kit. Detecting the color complex, the product of the reaction could be performed using a smart device (a smartphone or a tablet) with a built-in camera. Since the intensity of the color of the product solution indicated the concentration of the Fe(III) ion, compared with a standard calibration graph, the photo of the reacted sample/standard solution was simply processed to obtain the color intensity using an image processing program on a computer or an application on a smart device. Therefore, the use of the natural-reagent iron assay kit is not only promising for hands-on, at-home laboratories but also for promoting sustainability in analytical chemistry education, supporting the Sustainable Development Goals (SDGs) identified by the United Nations (UN) in 2015, namely good health (SDG3), quality education (SDG4), reduced inequalities (SDG10), and responsible consumption and production (SDG12).

Herein, we present the development of a Lab-at-Home (LAH) box set, as the second article in the series to develop the natural-reagent iron assay kit based on Thai local wisdom, for new normal, analytical chemistry experimentation. This work aimed to design and implement the LAH for the remote learning of an analytical chemistry laboratory, i.e., colorimetry experiment, for foundation chemistry students at the Department of Chemistry, Faculty of Science, King Mongkut's University of Technology Thonburi (KMUTT), Bangkok, Thailand. Students (group/individual) received the LAH box set about one week before the synchronous experiment class via Zoom, where the instructors and teaching assistants (TAs) were prompt to advise and answer questions. The student learning outcome achievements including the comprehension of analytical characteristics and colorimetry principles, as well as the ability to analyze statistical data, were evaluated using a post-lab quiz and laboratory report. The satisfaction of the LAH used for new normal, analytical chemistry experimentation was also assessed using questionnaires and focus group discussions.

2. Materials and Methods

2.1. LAH Box Set

The LAH box set was adapted from the natural-reagent iron assay kit that was implemented as a tool in an analytical chemistry experiment (determination of iron by colorimetric method) for undergraduate science students at six Thai universities, as reported previously [14]. Non-toxic chemicals were provided in the LAH box set, similar to the iron assay kit. The guava leaf extract was used as a natural reagent for complexing with the Fe(III) ion. A series of working Fe(III) standard solutions with mild concentrations were provided. A weak acid in vinegar (acetic acid) was used to prepare the acetic/acetate buffer solution, also provided in the box set. A 96-well plate was exploited as a reaction platform. However, instead of the micropipet used in the previous assay kit for measuring the volumes of the solutions, disposable syringes were employed because they are low cost and more readily available in Thailand. In addition, a series of dye solutions were given to practice the calibration graph construction from the data obtained using a smart device camera, followed by processing with an image analyzing application/program.

Therefore, the LAH box set consisted of eight items (Figure 1), i.e., (i) a sachet of Nat Pow Iron (guava leaf powder), (ii) vials containing Fe(III) standard solutions (with different concentrations) and a sample solution, (iii) a bottle of acetic/acetate buffer solution, (iv) vials containing dye solutions with various concentrations, (v) a glass bottle for extracting the natural reagent, (vi) a 96-well plate, (vii) a 10-mL disposable syringe, and (viii) 1-mL disposable syringes. To reduce the inequalities (supporting SDG10) and control the analytical parameters, the LAH box set with equal quantities and qualities of chemicals and materials was sent to all students.

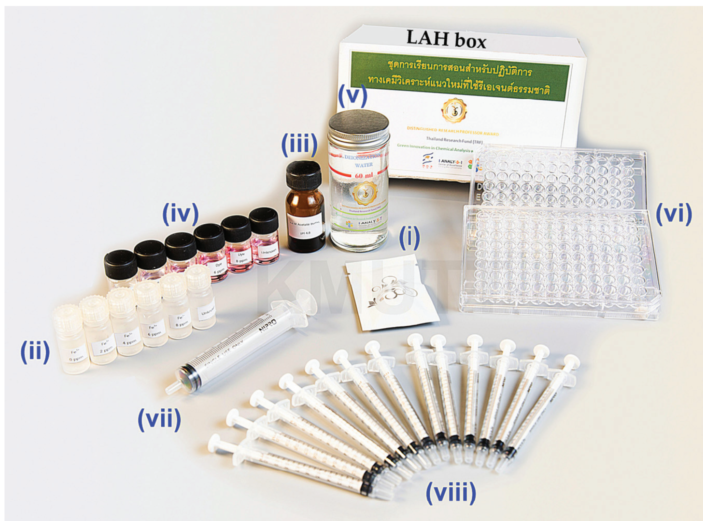

Figure 1. LAH box set: (i) a sachet of Nat Pow Iron, (ii) vials containing Fe(III) standard and sample solutions, (iii) a bottle of acetic/acetate buffer solution, (iv) vials containing dye solutions, (v) a natural reagent extracting bottle, (vi) a 96-well plate, (vii) a 10-mL disposable syringe, and (viii) 1-mL disposable syringes.

2.2. The Design of the LAH Experiment

The LAH was especially designed to suit the foundation analytical chemistry experiment at the undergraduate level in Thailand. In general, the foundation course has a large number of students, for example, 800 students per course, in 20 sections (40 or more students/section) at the Department of Chemistry, Faculty of Science, KMUTT, with a tendency to have more students. A face-to-face on-site laboratory for the large foundation course would consume a large amount of chemicals and budget, require numerous laboratory facilities, and generate a significant amount of chemical waste. The LAH was created to reduce the number of people encountering COVID-19 during the pandemic, and also to address the challenges of large foundation courses using online synchronous experimentation allowing the experiment to be conducted conveniently and safely at a student's residence. All students could conduct the experiment synchronously via a virtual meeting application/program such as Zoom, Microsoft Teams, and Google Meet, and/or a LINE broadcast, where the instructor and TAs were ready to give advice and answer questions. Moreover, other online tools, including Mentimeter, Microsoft Office, and Google Drive, were applied to share ideas and analytical data, facilitating rapid communication, data transmission, and traceability.

For colorimetry experiments, detecting the color intensity is, obviously, important. The LAH experiment used a built-in camera of a smart device (a smartphone/a tablet) as a detector. A photo of the solutions in the 96-well plate was taken as one shot. The intensity (Red-Green-Blue or RGB value) of the color of each solution was evaluated using an image processing application/program, i.e., Color Grab (Loomatix, Haifa, Israel) for Android or Pixel Picker for iOS.

In addition, the LAH was designed to encourage the learning of colorimetry principles and analytical characteristics as well as to practice statistical data analysis skills. The LAH employed the natural reagent because of its ease of use, safety, and waste management, in which the goals of green chemical analysis and sustainability were achieved.

2.3. Course Characteristics

The LAH experiment was implemented in an analytical chemistry experiment for undergraduate students in two sections at the Department of Chemistry, Faculty of Science, KMUTT, in the second semester of academic year 2020 (2nd/2020), from March to April 2021, and the first semester of academic year 2021 (1st/2021), from August to September 2021. Altogether, 38 and 65 students were enrolled in sections of the 2nd/2020 and 1st/2021 semesters, respectively. During the 2nd/2020 semester, classrooms and laboratories were closed due to the moderate level of COVID-19 pandemic in Thailand, but students were permitted to stay at the university dormitories for online remote learning. Furthermore, no more than five students were allowed to meet face-to-face. Thus, the students in sections during the 2nd/2020 semester were divided in ten groups (three to four students/group), and each group conducted the experiment at the dorms using one LAH box set. During the 1st/2021 semester, the university was closed due to the severity of the pandemic, forcing students to leave the dormitories and stay at home. In this latter case, students performed the experiment individually at home. It should be noted that the basic knowledge in chemistry of these two student groups was comparable. Both groups of students had completed previous chemistry courses (General Chemistry and General Chemistry Laboratory).

2.4. Teaching and Learning Method

The goal of the designed teaching and learning approach in this work was to limit the risk of COVID-19 infection and spread, and to solve the challenges of a large foundation course that could occur in the near future, as previously noted. As a result, the proposed method was designed for 100% remote foundation chemistry education, as well as achieving students' learning outcomes.

The experiment employing the LAH was entitled "Determination of iron by modern green chemical analysis employing a natural reagent and with a smartphone", with three objectives, requiring students to be able to (1) explain colorimetry principles and analytical characteristics, e.g., accuracy and precision, and apply the knowledge to perform quantitative analysis, (2) use a smart device for colorimetric detection and analytical data acquisition for chemical analysis, and (3) briefly describe the importance of the green analytical chemistry (GAC) and the benefits of the novel and modern green chemical analysis.

The experiment was divided in two parts: part 1—Determination of a dye solution concentration and part 2—Colorimetric determination of iron. Part 1 was designed for practicing color detection using a smart device, so that students would be familiar with the use of a smart device as an analytical detector as well as the concept of colorimetric detection, before performing the iron analysis. In part 2, students would learn how to perform colorimetric determination and the green analytical chemistry concept. Moreover, students would learn how to handle analytical data and assess analytical characteristics from both parts.

Figure 2 illustrates the stepwise method of the experiment. An online lab briefing session via Zoom was held two weeks before the experiment date to discuss the methods of the online class using a synchronous model, guidelines of the experimental data and report submission, to introduce the concept of the experiment and to discuss the GAC concept and principles related to this experiment. Then, one week before the day of the experiment, LAH box sets were sent to students at their home addresses and the group representative at his/her dormitory, in cases of individual and group assignments, respectively. Students were assigned to self-study the concept and experiment instructions and write up the experiment plan. Students were required to submit the experiment plan to the instructor via Google Drive at least five days before the experiment date, for the instructor's approval.

On the experiment date, the students performed the experiment synchronously at their respective locations using Zoom, while instructors and TAs were available online to advise and answer questions as needed by the students. The students were required to activate the video mode on the device connected to Zoom to show their activities during the LAH experiment. The students engaged in a hands-on experiment at home. After the experiment, the analytical data were immediately submitted online via Google Doc/spreadsheet, whereas the experiment report submission due date was one week after the experiment. Finally, another synchronous session was conducted via Zoom to discuss the analytical results and the comprehension of colorimetry principles, analytical characteristics, and GAC principles, to take the post-lab quiz, and to evaluate the use of the LAH.

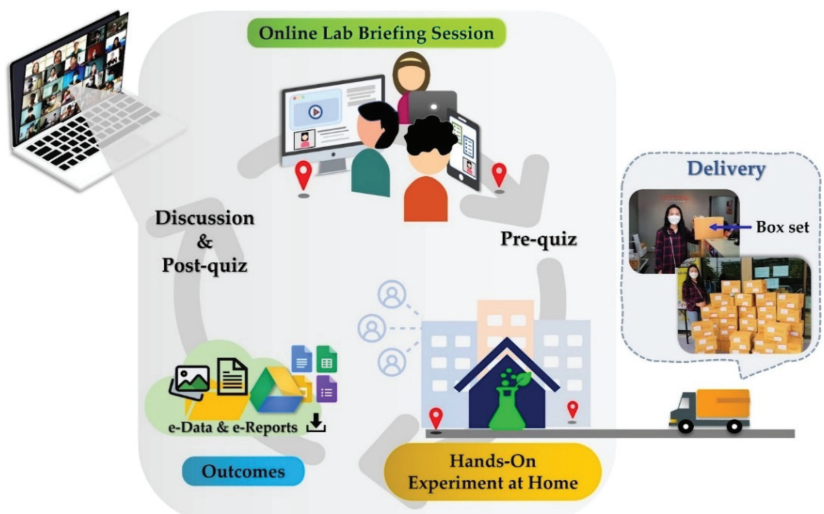

Figure 2. Stepwise method of the LAH experiment.

2.5. Experimental Procedures

The instruction of the experiment (see Supplementary Material: File S1) was included in the LAH box set, so that students could self-study the procedure before the experiment date. The experiment was designed for two parts, with specific objectives as detailed in Section 2.4.

Part 1—Determination of a dye solution concentration

Firstly, the given dye solutions with various known concentrations and a blind sample solution were dropped in designated positions of the 96-well plate (Figure 3). Secondly, a photograph of the plate was taken using the lighting technique that students preferred or found convenient, and the color intensities of the solutions were evaluated using an application on a smart device. Finally, a calibration graph for each row (B, C, D, E, F, and G, Figure 3) of the 96-well plate was constructed by plotting the color intensities against the concentrations of the dye standard solutions. Supplementary Material: Video S1 shows a demonstration of determining the concentration of a dye solution. The colorimetric principle according to the RGB channel was applied. A proper color channel for the measurement was determined based on the slope and the correlation coefficient (R^2) of the calibration graph. The influence of the lighting conditions was discussed.

Part 2—Colorimetric determination of iron

The natural reagent containing polyphenolic compounds was, firstly, extracted from the provided guava leaf powder in a sachet (Nat Pow Iron (G)) by adding 60 mL hot (60–100 °C) clean water in the extraction bottle, already containing the sachet. Secondly, 9 mL of the extract was brought to the buffer bottle containing the buffer solution, and the natural reagent was obtained. Thirdly, the standard Fe(III) solutions, with a series of concentrations and some known concentration samples, were dropped in the 96-well plate at the designated wells (Figure 3). The natural reagent was, fourthly, dropped into the standard and sample solutions. The dark-purple polyphenolic-Fe(III) complex was obtained with different color intensities, proportional to the amount of Fe(III). Finally, for each row, the color intensity against the concentration of Fe(III) was plotted as a calibration graph. The Fe(III) concentrations in the samples were evaluated using the calibration graph. Supplementary Material: Video S2 shows a demonstration of colorimetric determination of iron. Some parameters affecting the analytical results were discussed.

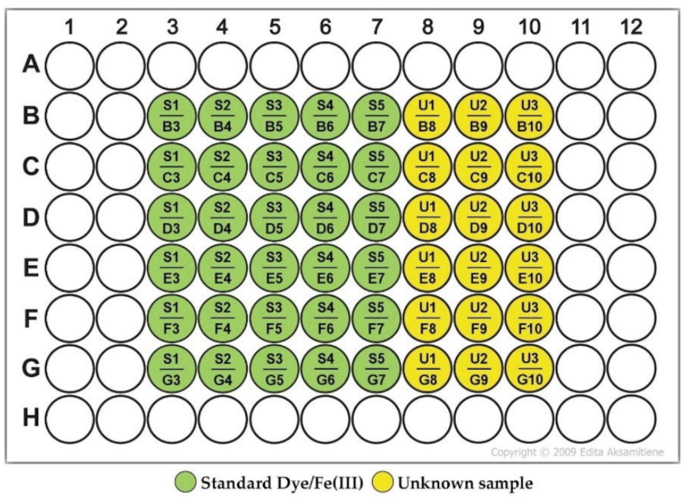

Figure 3. Designated positions for dropping solutions in the 96-well plate, where S is standard, U is unknown, B–G are the rows, the numbers after S and U are the number of standard and unknown solutions, respectively, and the numbers after the rows B–G are the column numbers.

2.6. Evaluation and Statistical Analysis of Student Outcomes

Post-lab quizzes as well as lab report scores were used to evaluate the student learning outcome achievements including comprehending the analytical characteristics and colorimetry principles, and the ability to perform statistical data analysis. The LAH experiment used for remote learning was evaluated using a satisfaction survey with a 5-point Likert scale (1 = least satisfied, 2 = less satisfied, 3 = moderately satisfied, 4 = very satisfied, 5 = most satisfied) and focus group discussion. The student learning outcome achievements and satisfaction with the LAH experiment evaluated by students assigned to perform the experiment as a group (see Supplementary Material: Video S3) were compared with those assigned individually (see Supplementary Material: Video S4) to perform the experiment, using independent *t*-test, with a $p < 0.05$ as significant difference. Bonferroni correction was used to adjust the p-value because of multiple comparisons (10 correlations). The significance level or the *p*-value (0.05) was then adjusted to 0.05/10 = 0.005.

3. Results and Discussion

The LAH was designed for large foundation chemistry courses with a large number of students, such as the General Chemistry course at KMUTT, which has approximately 800 students/semester. In this work, the LAH was introduced to sessions for feasibility planning. Students performed the experimentation individually or in groups at their location using the LAH under the guidance of the instructor and/or TAs. This led to quality education (SDG4) and reduced inequalities (SDG10). The students were able to practice analytical chemistry skills using a hands-on experiment during the COVID-19 pandemic, and they were able to experience green chemistry practice.

3.1. Design of LAH Box Set

The LAH design changed some equipment of the natural-reagent iron assay kit, as reported previously [14]. The reagents/materials provided in the LAH box set were safe for users and the environment, as well as readily available locally, not only for economic reasons, but also for the convenience of the box set preparation. The equipment in the LAH box was lower cost and more readily available in stores/pharmacies, such as disposable syringes to measure the volume of solution, instead of using an autopipet, and a glass bottle to extract the natural reagent that could be reused. The reagents used to determine Fe(III) were the same as those used in the previous study. The dye solutions with a series of concentrations, including blind concentration, were included in the newly designed LAH to determine dye concentration. Students could thus practice using their smart devices to take photographs of the solutions in the well plate and evaluate the color intensity of solutions. The LAH box cost only 200 THB (6 USD) per set (110 THB (3.3 USD) for reusable equipment and 90 THB (2.7 USD) for chemicals and reagents). In addition, the LAH was the first green chemical analysis tool, especially for chemistry laboratory, in Thailand that could be easily and safely performed at home because the reagent was extracted from guava leaves, nonhazardous chemicals were down-scaled, the waste was easily eliminated and was deemed environmentally friendly.

3.2. Learning Process

The learning process planned for the LAH experiment began with an online laboratory briefing session using Zoom, followed by a hands-on experiment using the LAH box set, and finally, an online discussion session. Students received the LAH box set with the laboratory instruction so that they studied the concept and procedure before the online briefing session. On the experiment date, they streamed themselves using Zoom while performing the experiment alongside their friends, while the instructor and TAs observed and were available for advising and answering questions (see Supplementary Materials: Videos S3 and S4). In this way, students felt relieved that they could ask the instructor or TAs for help whenever they needed it, as one student commented: "When we had a serious issue, we could turn on the microphone and ask the instructor. I didn't feel nervous or anxious at all." Since Thai students are typically hesitant to criticize and express their opinions, prior-normal experimentation included a discussion session to encourage them. When transforming to new-normal experimentation, the synchronous session could not be neglected. The results showed that in the online discussion session, students shared and exchanged their opinions with friends and the instructor. Critical thinking skills could be improved in this session, as one student stated: "Sharing mistakes and exchanging ideas with friends helped us understand more and gain a broader perspective." The proposed learning process could be applied in the future to large foundation chemistry courses, which may not have sufficient laboratory space for 800 students. Although the proposed process used synchronous sessions to support the development of Thai students' learning skills, asynchronous virtual laboratories could be used in some cases, such as when students were mature and/or had sufficient learning skills.

3.3. LAH Experimentation

The analytical chemistry experimentation using the LAH as a tool was divided in two parts. Part 1 determined the dye solution concentration using modern green chemical analysis and a smart device. The concept of colorimetric determination, as well as analytical data analysis, was introduced. Students practiced taking photos of the solutions in the 96-well plate using the camera of a smart device and evaluating the RGB color intensities of the solutions by an image processing application. From the focus group discussion, students were impressed using a smart device with an image processing application for analytical data processing and judged it promising for future chemical analysis due to its simplicity. The effects of the color channel on the color intensity evaluation and the lighting condition were studied. Finally, students plotted the calibration graph and determined the analytical characteristics, including accuracy and precision.

3.3.1. RGB Color Intensities

TechTerms.com (accessed on 10 January 2022) defined that "the RGB refers to three hues of light that can be mixed together to create different colors [15]. Combining red, green, and blue light is the standard method of producing color images on screens, such as TVs, computer monitors, and smartphone screens." Levels of R, G, and B can each range from 0% to 100% of full intensity. Each level is represented by the range of decimal numbers from 0 to 255 (256 levels for each color) [16]. The RGB level of the photograph of the solution was determined by Color Grab for Android and Pixel Picker for iOS systems. Figure 4a,b illustrate the examples of the images taken under two different lights. One was taken in a student's room with a fluorescent bulb (Figure 4a), while the other was taken in a room with a white-light LED lamp (Figure 4b). Students read the R, G, and B levels of the solutions in the assigned wells and constructed the calibration graphs, plotting the intensity of each color against the concentration of dye solutions. Figure 4c,d illustrate the examples of the calibration graphs using the R, G, and B levels of standard dye solutions at positions B3 to B7.

According to the sensitivity (the slope of the graph), the linearity (the correlation coefficient, R^2), and the accuracy and precision of the determination, students chose the suitable light color (R, G, or B) for further study. For instance, from Figure 4c under the fluorescent lamp, the sensitivity obtained by plotting the green light intensity ($y = -4.3x + 180.6$) was higher than that obtained by plotting the blue ($y = -2.2x + 172.0$) and red ($y = -0.1x + 186.6$) light intensity, respectively.

Due to the wide use of standard RGB (sRGB) in, for example, digital photography, graphics, multimedia, and Internet imaging, the image is probably encoded in sRGB colors. The JPEG image that the students took using their smart device camera was opened with ImageJ or Java. The pixel values in the resulting data array were R, G, and B components [17]. As mentioned earlier, R, G, and B have integer values from 0 to 255. The different shades of pink have specific integer values of R, G, and B. For example, the RGB integer values for pink, light pink, and hot pink are RGB(255,192,203), RBG(255,182,193), and RGB(255,105,180), respectively [18]. Notably, the integer value of R is 255 for all shades of pink. This could explain the lower slope of the calibration graph obtained by plotting the red intensity. The highest linearity was found when the green light intensity was applied. Interestingly, the highest slope of the calibration graph obtained by plotting the green intensity could have resulted from the largest difference of the G values. Similar findings were obtained under the white-light LED lamp (Figure 4d). In this case, the calibration graph using the green light intensity was selected.

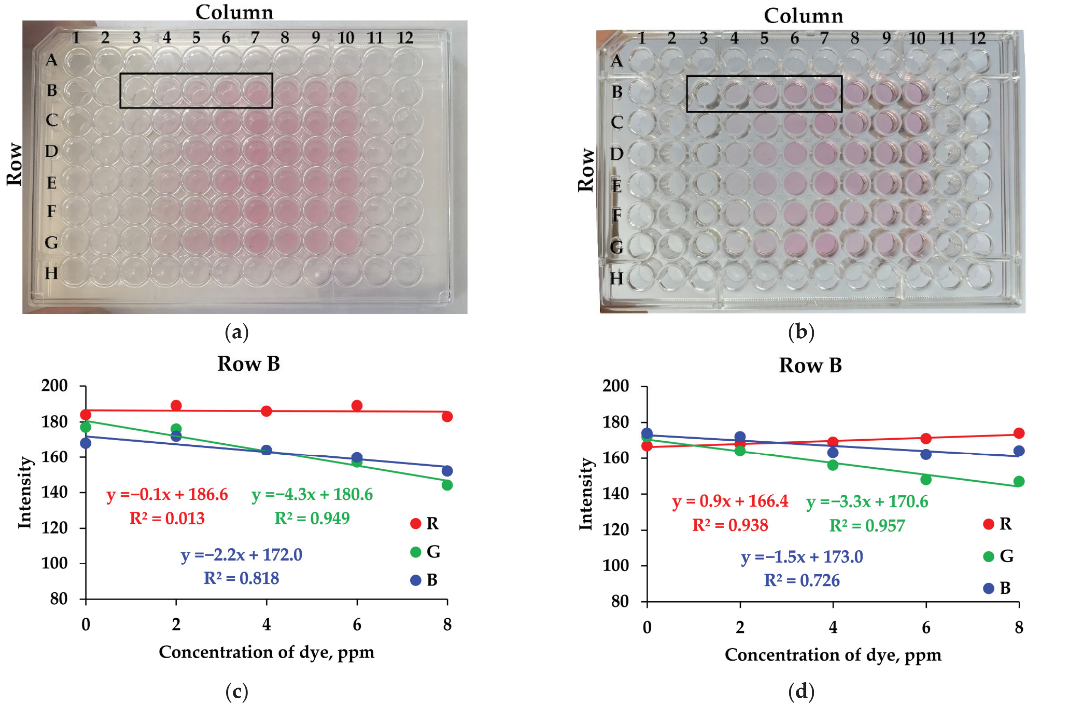

Figure 4. Examples of photographs from experiment part 1 taken (**a**) in a student's room having a fluorescent lamp and (**b**) under a white-light LED lamp, and the calibration graphs plotted the RGB levels of the solutions at positions B3–B7 in the black squares of (**a**,**b**) obtained under (**c**) a fluorescent lamp and (**d**) a white-light LED lamp against the dye concentration, respectively.

3.3.2. The Effect of the Light Condition

Each student or group used a different light condition depending on their preference or convenience. Some examples of light sources were white-light LED lamp, fluorescent lamp, and the sun (resulting in natural light). To discuss the effect of the light condition, students shared their results during the online discussion session, and compared the accuracy and precision of the determination using the calibration graph of the green light intensity from each row of well plates and dye concentrations. Altogether, 10 groups and 65 individual students, each with six calibration graphs from six rows in the well plate, yielded 450 calibration graphs. However, 130 calibration graphs were not linear due to the effect of the light. Consequently, the concentration range of dye in the blind sample was 1 to 8 ppm (true value = 5 ppm), with the average and standard deviation (SD) of 5 and 2 ppm (n = 320), respectively. The overall precision of the determination was low (%RSD = 36). The comparison indicated that the colorimetric determination using a smart device as a detector had been greatly influenced by the light condition. In theory, the sRGB was developed with the goal of creating a precisely specified color space for computer-based and display-oriented applications. This means that precise specifications of factors, such as the white reference point and the ambient lighting conditions, are important [3]. From the results, students would be aware that light condition affects the precision and accuracy of the color intensity when performing the colorimetric determination using a smart device as a detector in the future.

Aside from the light condition effect, the small size of the wells on the reaction plate was another cause of non-linear calibration graphs. When dropping solutions, a student said they had trouble finding the assigned wells on the plate, resulting in the solutions being dropped in the wrong order. Students had to focus intensely on the experiment. However, working from home could involve interruptions by family members and household pets; one student mentioned that their grandmother was so concerned for their safety that she came to see them frequently. These constraints should be kept in mind for future work.

3.3.3. Colorimetric Determination of Iron

In part 2 of the experiment, the dark purple polyphenolic-Fe(III) complex was obtained as the product of the chemical reaction. Its intensity depends on the concentration of Fe(III) ion. Higher Fe(III) concentrations produce higher color intensities. Figure 5 illustrates the examples of images of the polyphenolic-Fe(III) complex solutions in the well plate under different lights and calibration graphs plotting the green color intensity against the Fe(III) concentration. The concentration of Fe(III) in the blind sample in each row was determined using a calibration graph of the same row. For example, the Fe(III) concentration of the sample at positions B8 to B10 was determined using the calibration graph plotting the color intensities of the standards at the position B3–B7. Unsurprisingly, the Fe(III) concentration was strongly affected by light condition during the photographing. Altogether, 127 nonlinear calibration graphs resulted in 323 linear calibration graphs determine Fe(III) concentration. The range of Fe(III) concentration determined by the students was 1 to 8 ppm (n = 323), with an average, SD, and %RSD of 5 ppm, 2 ppm, and 38%, respectively. The students again noticed the influence of light condition and RGB colors on colorimetric determination. They learned the principles of colorimetry as well as analytical characteristics. Students' comprehension was assessed by quiz scores and lab reports.

3.4. Learning Outcome Achievement

At the end of the experiment, students submitted the raw analytical data, calibration graphs, and concentrations of the dye and Fe(III) in blind samples using Google Drive. The students then worked in groups of three to four students to write the lab report. The report must be submitted using Google Drive within one week after the experiment. Students took the post-lab quiz in the online discussion session using Zoom (Zoom Video Communications, Inc., San Jose, USA). To evaluate the learning outcome achievements, the post-lab quiz assessed for the student's comprehension of colorimetry principles, analytical characteristics, statistical analysis of the analytical data, and the green analytical chemistry concept.

3.4.1. Post-Lab Quiz Scores

The average post-lab quiz scores of students who conducted the LAH experiment individually and in groups were 7.00 ± 1.54 (n = 65) and 6.68 ± 1.12 (n = 38), respectively, out of 10 points. The difference between the scores of students who performed the LAH experiment individually and in groups was without statistical significance ($p = 0.951$). When these scores were compared with those of students performing the colorimetry experiment at the university in the first semester of 2019 (August to November 2019), before the COVID-19 pandemic (6.18 ± 1.68 points, n = 79), the average score of students performing the LAH experiment in groups did not significantly differ ($p = 0.283$). However, the average score of students performing the LAH individually was significantly higher ($p = 0.005$). Notably, before the COVID-19 pandemic, students performed the colorimetry experiment in groups. This suggested that individual rather than group work could be used to improve student comprehension. It contrasted with the findings reported by Rawas et al. (2020), that the group-based activities resulted in better test scores compared with the design comprising individual activities for face-to-face flipped classroom [19]. However, results agreed with studies by Achuthan et al. (2021), reporting that providing and enabling a learning environment promoting effective individualized learning and comprehension of experimental concepts and skills could improve educational outcomes in remote laboratories [20].

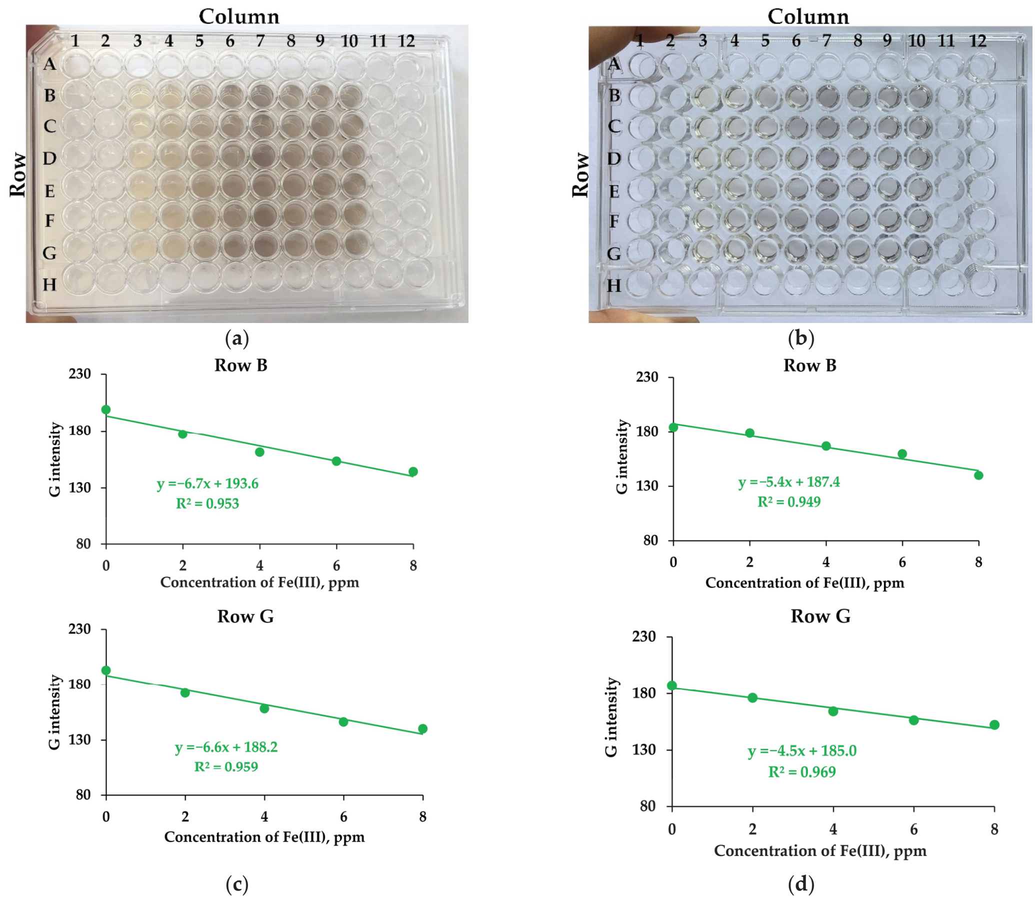

Figure 5. Examples of the photographs from part 2 of the experiment taken under (**a**) fluorescent lamp and (**b**) white-light LED lamp, establishing calibration graphs in (**c**), under (**a**), and for rows B and G as well as calibration graphs in (**d**) under (**b**) for rows B and G.

3.4.2. Lab Report Scores

To write a lab report, students worked in groups of three to four, discussing the experiment method, evaluating the analytical results, and drawing conclusions. Thus, the number of reports composed by students who performed the experiment individually (65 students) and in groups (38 students) was 18 and 10, respectively. The lab report was used to assess (1) the understanding of the influences of the RGB color and lighting conditions as a result of using a smart device as a colorimetry detector, (2) the ability in applying colorimetry principles to determine dye and Fe(III) concentrations, and (3) the ability to apply the statistical data analysis principle to explain the analytical results. Overall report scores of the students using the LAH individually (23.33 ± 2.39 points, n = 18) and the students who performed the colorimetry experiment at the university before the COVID-19 pandemic (23.53 ± 2.24 points, n = 20) were significantly higher than those of the students who conducted the LAH experiment in groups (20.00 ± 2.22 points, n = 10) with $p = 0.01$ and < 0.001, respectively. It showed that individualized laboratory practice was just as effective as face-to-face laboratory practice. This was consistent with the studies of Rawas et al. [19] and Achuthan et al. [20], above.

The scores of students performing the LAH experiment individually were compared with those in groups for each learning outcome achievement (Table 1). Students who worked individually and in groups received similar scores, without any statistically significant difference, for their understanding of the influences of the RGB color and lighting conditions, as well as the ability in applying colorimetry principles to determine dye and Fe(III) concentrations. Unexpectedly, students who performed the experiment individually had statistically higher scores for their ability in applying the statistical data analysis principle to explain the analytical results than those who performed the experiment in groups although their basic knowledge of chemistry was likely comparable. To statistically analyze the chemical analysis data, students in groups had to collaborate with peers having different learning styles. The university's semi-closure due to the COVID-19 pandemic during the second semester of academic year 2020 (March–April 2021) resulted in fewer student meetings and fewer face-to-face activities and, therefore, a lack of social and collaborative skill development for students. Moreover, in a report on the importance of group work in mathematics, Koçak et al. (2009) discovered that the efficiency of group work increases with the intensity of the communication that is established among the group members, which is free of teacher-centered studies. The group work that is carried out through a planned and programmed activity and healthy communication among group members are the most important factors. When students are not directed toward a goal, and without planning in place, group work will be nonbeneficial [21].

Table 1. Comparison of the scores of students who performed the LAH experiment individually and in groups assessed by learning outcome achievements.

Learning Outcome Achievement	Score (Mean ± SD) of Students Who Performed the LAH Experiment		*p* Value
	Individually (n = 18)	In Groups (n = 10)	
Understanding of the influences of the RGB color and the lighting conditions (4 points)	3.56 ± 0.51	3.50 ± 0.85	0.830
Ability to apply colorimetry principles to determine dye and Fe(III) concentrations (4 points)	2.33 ± 0.86	1.80 ± 0.68	0.103
Ability to apply the statistical data analysis principle to explain the analytical results (10 points)	8.11 ± 1.88	6.7 ± 1.16	0.041

3.5. Evaluation of Using the LAH for the Analytical Chemistry Experiment

The use of the LAH for the analytical chemistry experiment, i.e., colorimetric determination of Fe(III), was evaluated using a satisfaction survey. Students using the LAH both individually and in groups for the experimentation were asked to rate the satisfaction level of ten issues, using a Likert scale from 1 to 5 (1 = least satisfied, 2 = less satisfied, 3 = moderately satisfied, 4 = very satisfied, 5 = most satisfied). In general, both groups of students were very satisfied with the use of the LAH in all aspects, as shown in Figure 6, with satisfaction scores greater than 3.80. The satisfaction levels rated by students who experimented individually were slightly higher than those rated by students who experimented in groups. When a statistical independent t-test with Bonferroni correction was applied, it was found that the satisfaction scores in five aspects, namely items 2, 3, 4, 6, and 7, rated by students experimenting individually were significantly higher than those by students experimenting in groups ($p < 0.005$), details as shown in Table 2. For the other aspects, namely items 1, 5, 8, 9, and 10, there were trends showing the higher scores among individual experimenting than experimenting in groups were without statistical significance ($p > 0.005$). A student performed the experiment individually expressed her impression that "I enjoy that I can practice working alone because in the future, when I finish my undergraduate degree and go to work, I won't have anyone to assist me with my work".

The overall satisfaction levels rated by the individual and group experiments were 4.35 ± 0.80 and 3.95 ± 0.87, respectively, meaning very satisfied. Many expressed, for example, "I've never had any experience like this before. This LAH could be the first of its kind in the world." and, "Because we see what happens, the hands-on experiment allows us to gain a deeper understanding of concepts. Unlike watching a demonstrated experiment, real-world experience leads to long-term memories." indicating students' impressions of the LAH.

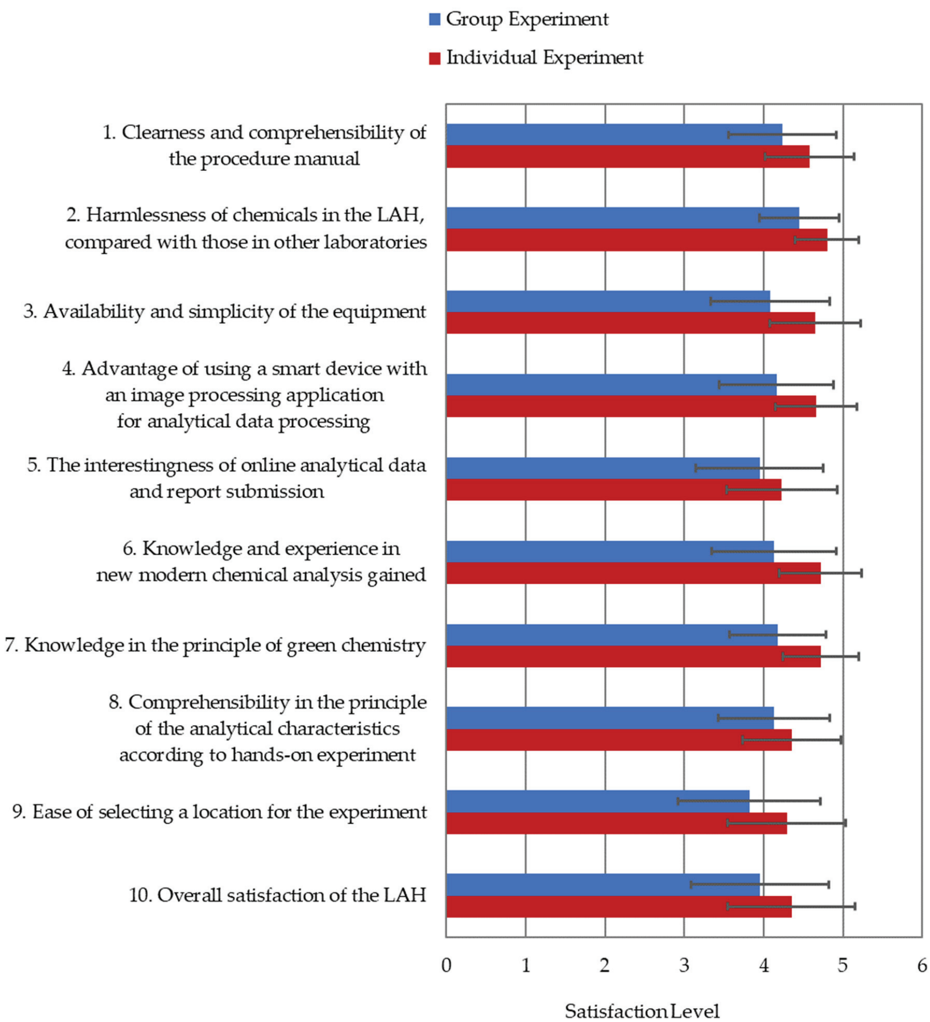

Figure 6. Satisfaction in the use of the LAH for the hands-on experiment at home.

Comparing the issues, students were most satisfied with the harmlessness of chemicals in the LAH, exhibiting satisfaction levels of 4.80 ± 0.40 and 4.45 ± 0.50 rated by students working individually and in groups, respectively. A student commented during the focus group discussion, "I was worried about the hazards of chemicals because the elderly and children were residing in the house, and my mother had a congenital disease. After reading the instructions and hearing from the instructor during the online lab briefing session, I discovered that the reagents were safe because one was guava leaf extract and the two others were a kitchen ingredient (vinegar) and a mineral (iron) at much diluted concentrations. So, I was relieved. My mother was also concerned when the LAH box set arrived, wondering if it would cause any harm. I explained that the material was made from guava leaves and that the chemicals used were extremely low in concentration, even lower than the vinegar we used at home. My mother understood and agreed to let me conduct the experiment at home." Students were impressed not only with the use of non-hazardous chemicals, such as acetic acid, which is less concentrated than the vinegar used in the kitchen, and a natural reagent extracted from guava leaves, but also with the ease of the non-hazardous chemical waste disposal. Moreover, the equipment and containers were reusable. This encouraged students to apply the green analytical chemistry concept in their future work and also supported SDG12 (responsible consumption and production), which is concerned with responsible use of natural resources to avoid harmful effects to the environment.

Table 2. Satisfaction of LAH use rated by students performing the experiment individually and in groups.

Issue	Satisfaction Level (Mean ± SD) Rated by Students Performing the Experiment		*p* Value
	Individually (n = 65)	In Groups (n = 38)	
1. Clearness and comprehensibility of the procedure manual	4.58 ± 0.56	4.24 ± 0.68	0.006
2. Harmlessness of chemicals in the LAH, compared with those in other laboratories	4.80 ± 0.40	4.45 ± 0.50	<0.001
3. Availability and simplicity of the equipment	4.65 ± 0.57	4.08 ± 0.75	<0.001
4. Advantage of using a smart device with an image processing application for analytical data processing	4.66 ± 0.51	4.16 ± 0.72	0.001
5. The interestingness of online analytical data and report submission	4.23 ± 0.70	3.95 ± 0.80	0.064
6. Knowledge and experience in new modern chemical analysis gained	4.72 ± 0.52	4.13 ± 0.78	<0.001
7. Knowledge in the principle of green chemistry	4.72 ± 0.48	4.18 ± 0.61	<0.001
8. Comprehensibility in the principle of the analytical characteristics according to hands-on experiment	4.35 ± 0.62	4.13 ± 0.70	0.099
9. Ease of selecting a location for the experiment	4.29 ± 0.74	3.82 ± 0.90	0.005
10. Overall satisfaction of the LAH	4.35 ± 0.80	3.95 ± 0.87	0.018

On the other hand, the least satisfactory issue for the students performing the LAH experiment individually was the interests in online analytical data and report submission (4.23 ± 0.70), whereas for the students performing the LAH experiment in groups, the least satisfactory issue was the ease of selecting a location for the experiment (3.82 ± 0.90). For students working individually, the low satisfaction score of those interested in online submissions could be due to issues with internet connection at their location. Some students reported that their Zoom connection was frequently lost due to a poor Internet signal. Students performing group work had to find one location in the university with sufficient space for experimentation and where the group members could meet easily. As a result, they may have experienced difficulty doing so. However, using LAH for analytical chemistry practice, either individually or in groups, could help develop the expected learning outcomes of the experiment.

3.6. Sustainability

This work has developed a hands-on analytical chemistry experiment that students in higher education could easily and safely conduct at their home on their own. Using locally available equipment/materials in the LAH box set has somehow ensured equal access for all foundation chemistry students to affordable, supporting inclusive and equitable education. The results also showed that students could develop an understanding of the principle of colorimetry, as well as analytical chemistry skills. It indicated that the LAH ensured quality education. The high scores of the laboratory reports showed that students' lifelong learning skills, such as problem solving, critical thinking, communication, and collaboration, were improved. Thus, the LAH supports sustainable development in quality education (SDG4) to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" and, particularly, Target 4.3 that states "by 2030, ensure equal access for all women and men to affordable and quality technical, vocational and tertiary education, including university."

Analytical chemistry laboratories typically require accurate and precise equipment/instruments, which are relatively expensive. Some Thai universities may be unable to provide sufficient and efficient equipment/instruments, limiting students' opportunities to gain real-world experience with them and practice good chemistry skills. The inexpensive LAH box set means that Thai universities could probably afford to provide each student with one set of the LAH for self-learning anywhere, including in a foundation course having a large number of students, which would help to reduce educational inequalities in Thailand and elsewhere. As a result, Thai universities could be one of the country's mechanisms for ensuring equal opportunity and reducing outcomes inequalities (Target 10.3 of SDG10—Ensure equal opportunity and reduce inequalities of outcome, including by eliminating discriminatory laws, policies, and practices and promoting appropriate legislation, policies, and action in this regard).

Nevertheless, the impacts of the LAH use on human health and the environment were the primary factors that we considered as we designed the experimentation. All the chemicals in the box set must be safe for students and their family. The waste must be easily managed and environmentally friendly. The coloring reagent is most important in colorimetry and is required in high amount. Thus, a nonhazardous natural extract of guava leaves was used as the coloring reagent in the determination of iron. The other chemicals provided in the LAH box set were also nonhazardous. The diluted acetate buffer for controlling the pH of solutions could be prepared from kitchen vinegar and its salt. Fe(III), which is one of the naturally occurring elements and required for plants [22], was prepared as the standard solutions at relatively low concentrations. The dye used for part 1 in the experiment was food grade. The LAH use, therefore, encourages students and faculty to aware of the GAC concept and supports SDG12, Target 12.2—by 2030, achieve the sustainable management and efficient use of natural resources, and Target 12.4—by 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water, and soil in order to minimize their adverse impacts on human health and the environment.

Sustainability, defined by the United Nations Brundtland Commission in 1987 [23] as "meeting the needs of the present without compromising the ability of future generations to meet their own needs", could be developed incrementally by all of us. Since we are chemists and educators, we have developed a tool that would meet the needs of chemistry in the present while also encouraging future generations to meet their own.

4. Conclusions

Not only was the university closed during the continuous COVID-19 pandemic, but also a large number of the students in the foundation chemistry course in Thailand stimulated us to develop LAH experimentation. The LAH box set adapted the natural reagent iron assay kit, reported in our previous work, aiming to increase the local availability and reduce the cost of the materials. Thus, the university could produce sufficient LAH box sets for large numbers of students. It supported quality education (SDG4) and reduced inequalities (SDG10). The LAH reagents and materials were nonhazardous, making it safe to perform the experiment at home and also support responsible consumption and production (SDG12). The method of the LAH was so simple that students could perform the experiment by themselves, in this case under the supervision of the instructor/TAs. However, a poor Internet connection might constitute a constraint of the synchronous online sessions, in which case asynchronous sessions could be used instead. When using a smart device as a colorimetric detector, students should be aware of the effects of the color channels for color intensity evaluation and light conditions for photographing. With the proposed LAH hands-on experimentation, the students' learning outcomes for the colorimetric determination of Fe(III) experiment, i.e., students' comprehension of colorimetry principles, chemistry principles involving determining Fe(III) concentration, analytical characteristics, statistical analysis of the analytical data, and the green analytical chemistry concept, could be successfully achieved. Although students experimenting individually rated higher satisfaction scores than those experimenting in groups, both were very satisfied with using the LAH in all ten aspects.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14063314/s1, File S1: instruction of the LAH experiment (in Thai); Video S1: demonstration of the determination of dye concentration using the LAH box set; Video S2: demonstration of the determination of iron concentration using the LAH box set; Video S3: a group of students performing the hands-on LAH experiment; Video S4: students individually performing the LAH experiment. References [12,13,24–30] are cited in the supplementary materials.

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Article

Engaging Environmental Sciences Students in Statistics through an Inclusive Experience in a Spanish University

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Abstract: In Spain, the issue of people with disability's access to adapted educational material is still unresolved in the university context. Other insufficiently addressed issues comprise actions to include students with intellectual disability in university classrooms, and the awareness-raising and sensitisation of undergraduate students regarding disability. These deficiencies persist despite the known benefits of these types of initiatives for all the agents involved. For this reason, we carried out an inclusive experience at the Pablo de Olavide University, specifically in the statistics subject. Educational resources were adapted, inclusion activities were conducted with students with intellectual disability, and we were in charge of awareness-raising and sensitisation of undergraduate students. The present paper describes the experience as well as its evaluation, which was performed using a survey. Furthermore, the work compares the achievement of students with a more engaging system that incorporates inclusive teaching versus one that does not. The results, which were statistically analysed, report high levels of satisfaction for all the involved agents, as well as improvements in the academic performance of the students. Recommendations directed towards both teaching staff and educational authorities are also provided on how to promote inclusion in universities and more specifically inclusion in science. These suggested educational policies aim to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all, based on the Sustainable Development Goal 4 of the 2030 Agenda for Sustainable Development.

Keywords: accessibility; awareness; disability; higher education; inclusive science; statistics; teaching support

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1. Introduction

According to the World Health Organization, about 15% of the world's population (i.e., more than one billion people) has some form of disability. People with disability thus constitute the largest minority in the world and numbers are increasing with advances in medicine and the growth and aging of the population. That is why the fourth goal of the 2030 Agenda for Sustainable Development aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all [1]. On the other hand, the latest 2017–2018 academic year CRUE report states that 14,930 students with some type of disability are studying for bachelor's degrees in Spanish public universities, of which 12% (1798) are studying in Andalusian universities [2]. Society cannot look the other way in the face of such an obvious reality. Universities play a fundamental role in the training and incorporation of students with disability, a crucial pillar in the improvement of the welfare state.

On 13 December 2006, the International Convention on the Rights of Persons with Disability was approved in New York. It provides measures, of both non-discrimination and positive action, that states must implement to ensure that disabled people enjoy their rights on equal terms with other people. Spain was one of the first countries to ratify this international treaty [3], whose article 24, subsection 5 holds: "Member States shall ensure that persons with disability have general access to higher education, vocational training, adult education and lifelong learning without discrimination and under equal conditions than the others. To this end, Member States shall ensure that reasonable accommodations are made for persons with disability". That is why Spanish public universities must comply with these precepts. In this sense, it is important to highlight that current Spanish regulations reserve 5% of places in each university degree for people with disability (see article 26 of Royal Decree 412/2014, of 6 June 2014 [4]). The incorporation of a quota for people with disability into the laws that regulate access to university represented a great advance in the fight for the educational and social integration of this group. It was a clear example of positive action policies towards people with disability. Recently, Royal Decree 822/2021, of 28 September 2021 [5] extended the reserve quota in force for undergraduate studies to official university master's degrees. In addition, it reserves the places available for students with disability who attend the extraordinary calls for access to university, until 5% of the reserve quota of the total number of places offered in the degree in question is reached. However, there is still a long way to go, as demonstrated by García-González et al. [6], who identified barriers to higher education for students with disabilities in Spain.

Through higher education, Spanish public universities play a crucial role in training professionals, leading to a more accessible, egalitarian and fair society. They also empower people with disability and promote their talents. The Pablo de Olavide University (UPO) is strongly committed to supporting people with disability and is working towards an increasingly accessible and inclusive university, where universal accessibility is a reality in the classroom—not merely a future goal. In fact, articles 6.4 and 133.1 of the UPO Statutes include these fundamental principles as basic rules of organisation and operation (see Decree 298/2003, of 21 October 2003 [7]). Moreover, in 2019, the UPO Vice-Chancellor's Office for Culture and Social Commitment promoted the Second UPO Accessibility and Inclusion Plan for Functional Diversity [8] to regulate actions aimed at UPO people with functional diversity and to guarantee equal opportunities during their stay at the institution. This plan is inspired by the "Independent Living Movement" which promotes the values of integral formation, autonomy, empowerment and responsibility.

The presence of students with disability and specific educational support needs in university classrooms is a reality today. Since 2020, these students have benefited from a good practice guide [9], directed towards facilitating their access to university and preventing first-year university drop-out. University teaching staff must guarantee accessible and inclusive training, so that the necessary tools to guarantee competence acquisition are available to all students, regardless of their learning difficulties. Unfortunately, this scenario does not always play out, and daily students with some type of disability face varying degrees of academic barriers. The Fifth Study on the Degree of Inclusion of the Spanish University System regarding the Realities of People with Disability [10] examined the ways to improve the inclusion of people with disability at university. It concluded that efforts should be mostly oriented towards the adaptation of resources that allow quality distance education. The reason is that 22% of university students with disability considered that the main way to improve their inclusion at the university was to adapt the resources to study from home. This was followed by 14% of students with disability who referred to the elimination of architectural barriers that still existed for people with mobility difficulties. This lack of resources has an additionally negative impact in the case of the statistics subject, due to the idiosyncrasy of the discipline and the scarce amounts of teaching support materials adapted to functional diversity. Aware of these difficulties, the authors of this work undertook the challenge to create specific audiovisual content on descriptive statistics, adapted to people with hearing and visual impairment.

It has been found, moreover, that providing an inclusive education to students with intellectual disability in higher education is an emerging challenge [11]. This latter study confirmed that, from the students' perspective, university environments could be suitable for students with intellectual disability. The creation of inclusive higher education programmes should therefore be encouraged [11]. In this sense, the Training Programme for Employment and Autonomous Life of People with Intellectual Disability (FEVIDA) was established at the UPO in 2017. It is a social innovation university programme designed to train 17 young people between the ages of 18 and 29 to improve their possibilities of employment and autonomous life. During the 2021–2022 academic year, these students with disability are and will be receiving 30 credits worth of training in practical, humanistic and professional subjects on the university campus. Extracurricular activities, activities shared with undergraduate and postgraduate students of official studies, as well as other actions that take place within the university community, complete the Own Title. This fifth edition includes an innovative experience aimed at promoting the autonomous life of these students with functional cognitive diversity. They will spend a week of community immersion, staying at the Flora Tristán university residence. Further information on FEVIDA can be found both in [12] in its classic version, and in [13], in its version adapted for easy reading. The authors of this work, convinced of its potential, incorporated the statistics subject of both the Degree in Environmental Sciences and the Dual Degree in Environmental Sciences and History-Geography at UPO in the FEVIDA's fifth edition.

Despite the need of the current society of inclusive higher education experiences that inspire and motivate other university teachers, there is still not enough work addressing this challenge. However, the study of the inclusion of people with disability at university has been developed with more intensity in recent years in different parts of the world, as can be found in [11,14–24]. Unfortunately, this trend is not as exciting if we focus on the field of science in general and statistics in particular. Nevertheless, in Spain emerging groups of researchers work to make the science accessible to all kind of people regardless of their age, social status, functional diversity and academic level [25–27]. In this sense, both the adapted teaching material and the inclusive workshop prepared by the authors are proposals where the processes of knowledge transfer of statistics are aimed at people with disability. The main goal of these inclusive actions is to make statistics accessible to all audiences without regard to their abilities; at the same time students with disability are encouraged to undertake scientific careers and science teachers to make their work more inclusive.

The present paper describes how this inclusive experience unfolded, detailing the adapted teaching support material elaborated, as well as the inclusive activities shared by undergraduate and FEVIDA students. All these activities took place in an environment of awareness, sensitisation and respect regarding disability and functional diversity within the context of a science subject. A total of 43% of the undergraduate students enrolled in the subject participated in a questionnaire to evaluate the integration experience. The questionnaire data and student academic results were statistically analysed. The intended outcome was the promotion, protection and guarantee of the full and equal enjoyment of all human rights and fundamental freedoms of all persons with disability, as well as the promotion of respect for their inherent dignity (article 1 of the Convention on the Rights of Persons with Disabilities [28]).

2. Materials and Methods

During the first semester of the 2021–2022 academic year, we conducted a series of actions in the statistical subject of the Degree in Environmental Sciences and Dual Degree in Environmental Sciences and History-Geography at the UPO. These actions were designed to make this subject more accessible to students with disability, to incorporate students with some type of intellectual disability, as well as to sensitise the whole class about an increasingly diverse and enriching social environment. Therefore, they sought to achieve the four primary objectives detailed below.

1. Improve the acquisition of competences in the statistics subject of all students, including those with some type of disability, with a special emphasis on hearing and visual impairment. To reach this objective, new audiovisual material specially developed for statistics was created, which was in turn adapted to people with hearing and

visual disability, that facilitated studying the subject and acquiring competencies. In other words, not only the learning process of statistics students was eased, but also everyone was included, since some of the students' special needs were addressed.
2. Promote the inclusion of people with disability at the UPO, especially students with intellectual disability, raising awareness of the need to integrate people with some type of disability into the classroom. A theoretical-practical descriptive statistics session was held, adapted to their special needs in an inclusive way, where the rest of the classmates participated very actively. This allows the UPO graduates to promote respect for diversity, equity and equality when they integrate into the labour market in the future.
3. Make university students aware of diversity, including people with disability, generating experiences that bring this reality closer to students, raising awareness about the importance of educational inclusion, promoting an education based on respect, solidarity and tolerance.
4. Analyse whether the students' average grade improves when the subject is inclusive. If the mark in the different tests increases when the subject is inclusive, the belief that all the actors benefit from an inclusive subject will be strengthened.

To reach these objectives, the authors applied statistical techniques as Pearson's chi-square test for the independence of two qualitative variables, or Fisher's exact test when convenient; likewise, to study the difference between the means, the normality test, the non-parametric technique of Mann-Whitney's and median difference test were studied.

The previous objectives were based on the assumption that both teachers and students prepared materials and activities in a clear and simple language, using short sentences, including images or pictograms, avoiding negative sentences and metaphors and providing easy reading. According to the Une 153101:2018 EX standard, easy reading is a tool that allows us to make texts and documents understandable for everyone. The easy reading method collects a set of guidelines and recommendations related to the writing of a text, the design/layout of documents, and the validation of their comprehensibility, in order to make information accessible to people with reading comprehension difficulties. The easy-to-read materials prepared by the teachers were not only designed for people with disability, but also for people with low educational levels, social problems, language difficulties and immigrants.

Specific activities were developed for the three first objectives and are detailed in the following subsections; meanwhile the fourth objective is addressed in Section 3.

2.1. Creation of Teaching Support Materials Adapted to Functional Diversity

This subsection explains how the authors of this work developed training pills on basic concepts of the subject that were accessible to students with hearing and visual impairment. The purpose of these resources was to work on the competencies required in the descriptive statistics block of the statistics subject taught in the Degree in Environmental Sciences and Dual Degree in Environmental Sciences and History-Geography at the UPO. The teaching or training pills were each of the small parts into which the content was divided in the "microlearning" methodology, which has great advantages in both formal and non-formal education. These teaching pills are much easier to assimilate and are taught through different means, among which the use of new technologies stands out.

The audiovisual material was made accessible to people with hearing disability through subtitling and translation into sign language. Subtitling consists of simultaneously displaying written text and images on the screen. The problem with sign language translation is that each country or region has a different language. This makes it extremely difficult to generate universally accessible audiovisual material. While subtitling is valid for all Spanish-speaking countries, the translation into sign language needs to be adapted to each country or region. The audiovisual material developed by the teachers combined subtitling with sign language translation by an official interpreter. In this way, a person with both hearing disability and low reading abilities could enjoy the statistics subject contents on equal terms with the rest of the students. Teachers had to collaborate with the sign language interpreter to develop their work adequately, for example, by advancing the common technical vocabulary used in order to anticipate the translation into sign language.

In addition, the material developed contained contextualised examples in environments the students are familiar with, which facilitates learning. Likewise, the material addressed descriptive statistics contents very useful in real life, so it also helped people with some mathematical knowledge and a desire to learn.

Specifically, the teachers elaborated the three following teaching pills adapted to the needs of people with hearing disability:

- The arithmetic mean [29], which is the most widely used descriptive statistic in real life. The arithmetic mean or average, or simply the mean or average if the context is clear, is the sum of a set of results divided by the total number of results. By delving into its advantages, disadvantages and different forms of calculation, we better understand its potential. Specifically, the average is theoretically defined, simple examples are given, the pros and cons of its use are analysed and some of its properties are shown. A simple illustration of the weighted arithmetic mean was also defined and presented. Finally, two exercises were given to practice the average for discrete and continuous statistical variables, as well as another exercise to work on the weighted arithmetic mean.
- The median [30], which is a broadly recognised descriptive centralisation statistic, not influenced by atypical values. The median is the midpoint at which no more than half the values are above or below, that is, the median is the value separating the higher half from the lower half of a data sample. The material began with the definition of the median, followed by an explanation of its calculus when the data are not grouped in frequency tables (distinguishing the cases when the total is an odd or even number). An explanation was also given on how the median is calculated for data grouped into frequency tables, differentiating between discrete and continuous statistical variables. The advantages and disadvantages of this descriptive central tendency statistic together with several examples were shown as well.
- The mode [31], which is a widely used descriptive centralisation statistic. The mode is the most frequent value found in a set of data values. This learning capsule begins with the definition of the mode and continues with the explanation of its calculus, distinguishing whether the statistical variable is qualitative, discrete quantitative, or continuous quantitative. Various examples of the three types of variables were presented, including one where the distribution was bimodal. The strengths, weaknesses and properties of this central tendency descriptive statistic were also analysed.

The three training pills contained a support annex that included the complete transcription of the videos and materials, as well as the exact minute of the recording, in order to support all the students in their learning. Furthermore, these annexes are being translated for the ONCE Scientific Editor (EDICO), so that they will be accessible to blind or severely visually impaired students. EDICO is the first Accessible Mathematics Editor that allows blind or severely visually impaired students to follow maths, statistics, physics or chemistry classes, thanks to the transcription into Braille code. That is why these teaching support materials are also adapted to students with visual disability.

It is important to note that students who are blind or have low vision use a software, such as JAWS (Job Access With Speech), which reads everything on the computer screen aloud. However, these screen reader software packages have the limitation of not reading formulas, scientific signs or mathematical signography, an aspect to be covered by EDICO. Consequently, there is a gap in the teaching support material adapted to students with visual impairment in the field of STEM (science, technology, engineering and mathematics) subjects, a gap that increases as one ascends through the different educational levels.

These new teaching support materials were designed to allow students with disability to undertake the studies in which they were enrolled under the same conditions as the rest of the students. They aimed at promoting full inclusion, in accordance with equal opportunity and non-discrimination principles. The goal was thus that all students reach their maximum personal, intellectual, social and emotional development, and that the objectives established in the current law were attained.

Finally, these audiovisual documents have been included in UpoTV, which is UPO's multimedia repository. In this way, these statistics training pills are open to all people who require them, regardless of whether they have disability or whether they are part of the UPO university community or not. This aspect is an important milestone: indeed, such specific, as well as transversal statistical material is almost impossible to find on the internet (whether free of charge or not). To guarantee the technical quality of these training pills, the teachers sought the advice of the UPO Library Multimedia Laboratory.

2.2. Inclusion of Students with Intellectual Disability in University Classrooms

This subsection describes the two-hour workshop on the statistics subject of the Degree in Environmental Sciences and Dual Degree in Environmental Sciences and History-Geography. It took place during the first semester of the 2021–2022 academic year and was adapted to the special needs of people with intellectual disability in the FEVIDA programme. All those enrolled in the subject in both degrees, i.e., a total of 121 students, participated in the FEVIDA workshop as assistants.

At the beginning of the semester, teachers presented the project to the undergraduate and FEVIDA students, providing a Google form in which they registered in the workshop in order to actively participate. Finally, 45 undergraduate students and 11 FEVIDA students signed up to the workshop, out of the 121 students enrolled in the subject and 17 enrolled in FEVIDA. The activity was very well received by the undergraduate students: 1 out of every 4 students in the subject became actively involved; and of these, 73% answered the assessment survey. This allowed us to gather their specific opinions about the activity, and make future improvements, by enhancing the detected strengths and correcting the weaknesses.

Throughout the semester, several face-to-face and virtual sessions took place between the teachers and the undergraduate students via the Blackboard Collaborate Ultra platform. These meetings addressed not only the topics to focus on, but also the way in which to work on them: enhancing FEVIDA students' autonomy, encouraging their active participation, avoiding infantilisation, etc. Following a number of meetings that were held outside class hours, the teachers and the undergraduate students agreed on a series of topics for the inclusive statistics workshop, detailed below.

- Topic 1: arithmetic mean. At the beginning of the workshop, the undergraduate students presented some theoretical notions. FEVIDA students learnt to work out the average, for example, the average mark of several exams. Undergraduate students prepared a variety of highly practical exercises that required the active participation of FEVIDA students. Two concrete examples of mean drawbacks were also presented: one to explain that if the variable is discrete, the average might not belong to the variable's set of values, and another to show that the arithmetic mean is sensitive to extreme values.
- Topic 2: household economy. Undergraduate students prepared some activities where FEVIDA students worked on monthly/annual expense concepts, instilling the monthly savings necessary to meet annual expenses such as car insurance. Various cases of real spending were introduced where FEVIDA students had to manage several house expenses based on a salary or pension.
- Topic 3: discounts. FEVIDA students learned how to calculate the cost of discounted items. Specifically, undergraduate students explained how to compute the price of an item with a 25% or 30% discount, what it meant when a second item was 50% or 70% off, how to calculate the cost of products in the case of promotions such as 2×1 or 3×2, etc.
- Topic 4: games of chance. Undergraduate students introduced the concept of probability calculus based on the Laplace rule. The probabilities were calculated for games of chance with dice, cards and the Christmas lottery. This latter example was chosen because the lottery is highly traditional and popular in Spain.

- Topic 5: statistics in social networks. FEVIDA students learnt to interpret the data provided by social networks on "likes", statistics of photos associated with questions, etc. The practical activity consisted of taking a photo of everyone at the beginning of the class, uploading it to social networks, and analysing the percentage of responses to the questions posed at the end of the class. To carry out this activity, all participants gave their consent for the publication or dissemination of the image.
- Topic 6: Kahoot. Kahoot is known to be a highly motivating method for evaluating and reviewing content. The quiz contained questions related to the contents explained and worked on during the class. FEVIDA students could use the mobile calculator for the resolution. By default, Kahoot allocates 20 s to each question, but undergraduate students adjusted it to 240 s to avoid stressing the FEVIDA students.

The inclusive statistics workshop was eminently practical, dynamic and participatory for both undergraduate and FEVIDA students. In fact, the undergraduate students explained some basic statistics concepts to their FEVIDA classmates adopting a pragmatic perspective. The teachers had a supervising role during the workshop. The result of this experience was twofold: making students with intellectual disability more familiar with statistics, and bringing undergraduate students closer to the realities of people with disability.

2.3. Disability Awareness

Disability awareness, which is part of an inclusive culture, promotes positive attitudes of appreciation, respect, solidarity and tolerance towards disability. Carrying out disability awareness activities encourages coexistence, develops empathy and favours the acceptance of people with disability.

In addition to the preparation of the FEVIDA workshop described in the previous section, examples, exercises and problems in the field of disability were frequently used during the statistics classes. Official statistics on people with disability were also analysed. In this transversal way, the teachers tried, through positive and inclusive language, to make their students gain awareness of the daily difficulties faced by people with disability and their strength at overcoming them. Through these activities, the teachers also encouraged their students to appreciate the abilities and achievements of people with disability. Naturally, in all the developed activities, exercises and examples about statistics were also combined within the context of environmental problems, as well as the conservation and protection of the environment and nature, as is typical of the degree in which the subject is taught.

These activities are essential. Indeed, according to the Universia Foundation [10], less than 31% of students recognise having received sensitisation sessions on people with disability. In addition to promoting awareness about disability across classes, universities should promote training courses on disability aimed at undergraduate students, and they should be recognised as free credits.

3. Results

The evaluation process was similar to any proper academic and educational activity. On the one hand, the undergraduate students were evaluated as specified in the subject's General and Specific Teaching Guides. In addition, undergraduate students prepared assessment exercises for FEVIDA students to perform independently at home. They were delivered to teachers' lockers within a set deadline. The responsibility of delivering homework on time to the teachers' lockers implied that FEVIDA students acquired typical undergraduate student routines, which helped them to feel autonomous and empowered. Moreover, the teaching staff was subject to the student satisfaction surveys about the teaching activity, that is, a teaching staff evaluation process that is institutionally conducted by the UPO.

At the end of the first semester of the 2021–2022 academic year, students enrolled in the statistics subject of the Degree in Environmental Sciences and Dual Degree in Environmental

Sciences and History-Geography at the UPO were invited to take a survey through Google Forms, available in the virtual classroom. The survey was anonymous and participants were assured that their responses would not be identifiable. The questionnaire data were analysed using the statistical package IBM SPSS Statistics 27.0 (IBM, New York, NY, USA). The survey questions that undergraduate students asked about the activity can be found in the Appendix A.

Of note, undergraduate students evaluated this experience through Google Forms. Specifically, 52 undergraduate students filled out the survey: 42% men and 58% women. All students who actively participated in the workshop showed the highest levels of satisfaction with the activity.

Although it was female students who were primarily involved in preparing the FEVIDA workshop activities (almost 2 out of 3 participants in the preparation of exercises were female), no statistical relationship was found between gender and active participation in the workshop activities (Fisher p-value = 0.569). Indeed, the workshop was well received by male and female students alike. In fact, the workshop participants' degree of satisfaction was notable, both that of the attendees and that of the students who organised the activities: 100% indicated being satisfied with the workshop experience and 9 out of 10 students said they were very satisfied or completely satisfied.

However, the first, unfortunate surprising fact was that 63% of undergraduate students said that their level of knowledge of the different types of disability was insufficient. Only 2% claimed that they had very good knowledge of the different types of disability. That is why different educational institutions at all levels should promote integration activities for students with functional diversity, since the benefits generated for all parties are remarkable. It would also be interesting for educational institutions to promote training on the different types of disability, in order to promote general social awareness of the limitations and challenges faced by these individuals on a daily basis.

On the other hand, the survey showed that more than 70% of the students did not doubt the sensitivity of people with disability and only 25% believed that they became difficult to deal with over time. Only a minority thought that older people, due to their age, were people with disability. Indeed, only 13% expressed this opinion, and a large majority of the students surveyed, 62%, were aware that in the future they could develop a disability.

The study also indicated that 81% of those surveyed considered that people with disability were not sufficiently protected in Spain. The perception that not enough was being done was palpable after analysing the results. Almost 9 out of 10 students affirmed that insufficient actions were being taken by the authorities to further integrate people with disability, and 87% said that more money should be spent to remove physical barriers in order to make life easier for people with physical disability.

The inequality suffered by people with disability was confirmed once again: 3 out of 4 students surveyed perceived the lack of real-life opportunities for people with disability who shared the same skills, aptitudes or diplomas as persons without disability.

At this point, we asked whether activities such as the FEVIDA workshop served to raise awareness about the different daily life realities in a society. The answer was resoundingly positive, given that 100% of the students confirmed that dealing with people with disability had helped them to understand another social reality, to gain awareness of the situation of others, and to be conscious that some people in society needed help. Small day-to-day problems were diminished after dealing with people with disability, since after having followed the FEVIDA workshop, 4 out of 5 students believed the problems of their daily life seemed less important. Almost all students became aware that dealing with people with disability had made them to improve as people, and that a functional diversity team enhances everyone's learning.

Having exhaustively analysed the impact of an active participation in the workshop on undergraduate students, we immediately realised that the training activity was a success. Not only had it served to improve the competence worked on in the group work subject, but also all the students affirmed that it taught them to manage time correctly, to help each other, and to progress in the group's objectives through the appropriate execution of the role of each.

The workshop undoubtedly made undergraduate students reflect on disability, although this was not the first time they had done so. A total of 83% stated that they had already reflected on the matter on other occasions.

Finally, undergraduate students were asked about the teachers' underlying motives in setting up such a workshop, involving students with intellectual disability in the statistics subject. The answers obtained are illustrated in Figure 1.

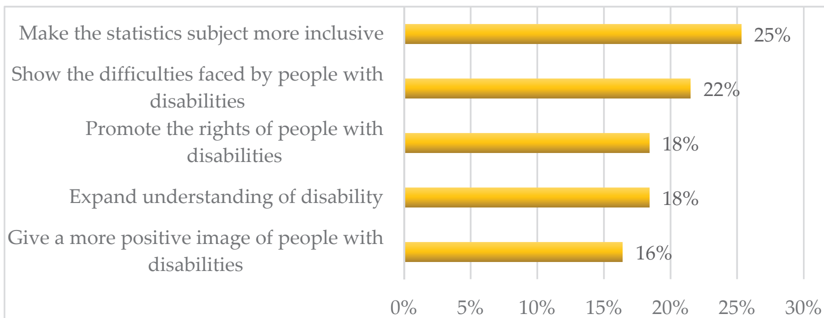

Figure 1. Perception of the purposes of the FEVIDA workshop.

The purpose most referred to by the students attending the workshop was "making the subject more inclusive", followed by "showing the difficulties that people with disability face every day". The undergraduate students also frequently selected the motives of promoting the rights of people with disability in state universities and broadening the understanding of other realities. Finally, it should be noted that among all the purposes, the least mentioned was "giving a positive image of people with disability", which confirms the students' degree of understanding of the purpose of the FEVIDA workshop.

The workshop coordinators highlighted the following elements: the resounding success of the activity; the excellent reflection exercise that took place in the classroom with all the actors involved; and the need to work towards a more inclusive university, where functional diversity is a reality, leading to enriching synergies between students and teachers in the classroom.

In addition, upon data analysis, it is very important to highlight that disability is not a gender issue. No statistical evidence was found relating gender to any of the opinions and perceptions expressed by undergraduate students. In the study's pertinent questions, the answers of male and female students were greatly similar in all cases.

In order to cover the proposed fourth objective of detecting a change or improvement in the average grade when the subject has been inclusive, the average grades of the three exams carried out throughout the semester were analysed to evaluate the students of the Degree in Environmental Sciences. To this goal, the data of two academic years were taken, the 2020–2021 course where there were no students with disability in the classroom, and the 2021–2022 course where the subject was inclusive and the FEVIDA workshop was held. The data showed a significant increase in two of the three exams carried out in the course with the inclusive subject, as shown in Table 1. Both the data distribution and the median of the analysed distributions were statistically different in two of the three evaluation exams. Specifically, the average mark of the first exam increased by almost 13%, from 5.59 to 6.3 points. On the other hand, the mark of the knowledge exam using the SPSS statistical programme further increased the average score in the inclusive course, almost 40%, from 3.64 to 5.05 points.

Table 1. Scores of the statistics exams of the Degree in Environmental Sciences.

	Course 2020–2021		Inclusive Course 2021–2022		*p*-Value
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**	
First exam score	5.59	1.82	6.30	2.26	0.006 */0.039 **
Second exam score	4.56	2.21	4.55	2.65	NS */NS **
Third exam score (SPSS)	3.64	2.10	5.05	2.63	0.002 */0.047 **
Number of students	115		110		

* Non-parametric Mann-Whitney U test. ** Test for median difference. NS = Not significant.

Last but not least, upon completion of the experience, the teachers also reflected on the need for university teachers to receive specialised training on how to make their subjects and classes more inclusive. That is why we concluded that the training unit of any public university should promote educational training and innovation processes for teachers in the field of functional diversity, since faculty members require training and information on inclusive education to meet the needs of students with disability [16]. In addition, this reflection also stemmed from the low percentage of teachers—only 14%—who had received training and guidance on the care of students with disability [10]. According to the report "Persons with Disability in the Andalusian University System" [32], Andalusian university teachers lack training on how to tutor students with disability. Nearly half the tutors (44%) stated they had not received any specific training; some tutors had received instructions or recommendations from the relevant university bodies or from the teaching team (17%), of the others, none (13%), and only 12% had taken training courses. Another motive is the fact that 57% of students with disability perceived that their teachers did not know or did not have up-to-date knowledge of their needs [10]. The competent authorities should take note of this, especially as this is not the first time such requirements have become apparent [20].

4. Discussion

The materials prepared by the teachers included content and activities adapted to the students' diversity. Specifically, the materials were especially adapted to students with hearing and visual impairment. They also followed easy reading standards and were thus accessible to people with low educational levels, with social problems, language difficulties and immigrants. In addition, it was easier for students to control and manage their learning itinerary based on their ability or previous knowledge. Likewise, the material produced was all the more relevant since there is little or no public offer of contents that attend to diversity. Therefore, the didactic materials elaborated are very useful, because they responded to a weakness detected in the teaching-learning of the statistics subject addressed to people with disability. Furthermore, this lack of adapted teaching support materials—that affects all fields of knowledge—is more significant in the field of statistics. Indeed, the absence of adapted material must be added to the necessary prior knowledge of mathematics, as well as the level of abstraction required to understand the subject. There is still, however, a long way to go to achieve true equal opportunities for people with disability in education.

In addition, the inclusion of FEVIDA students in a statistics class of undergraduate students marked a before and after in the teachers' personal and professional lives. The experience made it possible to promote the inclusion of people with intellectual disability at the UPO, raising awareness of the need to integrate people with some type of disability in the classroom. Undergraduate students gained awareness of a diverse society in which all people, regardless of their condition, should have the same opportunities to face life, with all its obstacles and goals. At the same time, FEVIDA students understood that they were an active component of the citizenry, and their talents contributed to a more homogeneous development and progress of the community. In this sense, the research confirms that inclusive education presents high levels of teacher and undergraduate student satisfaction, in addition to improving the academic performance of students. The academic managers of the FEVIDA programme also reported high scores for students with intellectual disability's satisfaction. This fact corroborates the results obtained in [11]; that is, university environments can be suitable for the education of students with intellectual disability and, therefore, the creation of inclusive higher education programmes should be encouraged. That is why the authors suggest generalizing and replicating the successful experiences at the UPO regarding the inclusion of students with disability in the educational system, as recommended in [24].

On the other hand, authorities should develop laws and strategies encouraging university faculties to elaborate inclusive materials in their subjects and to incorporate students with disability in their classes. In the development of these educational policies, the competent authorities cannot lose sight of the fact that the existence of adapted teaching support material decreases as we advance through the different educational levels, being more pressing in the case of STEM subjects. This involves an added difficulty for students with disability studying at university in the scope of STEM. In fact, students with disability tend to study degrees related to engineering and architecture and sciences to a lesser extent than the general population; in contrast, they study in a much higher percentage of arts and humanities degrees, with lower labour insertion rates than other branches [33]. The authors have shown that it is possible to approach and explain the statistics subject to students with disability in a valuable way for this group, banishing prejudices shared by teachers, students and society in general about the distrust in the democratisation of science [27]. Therefore, educational authorities should promote inclusive science teaching (science without barriers) and encourage teachers to develop teaching support materials accessible to all.

Faculty members should be aware of the need to guarantee quality and inclusive educational materials; in particular, statistics subject resources, for all people with disability. Obviously, these adapted teaching support materials should be openly accessible and free of charge. It is necessary to raise awareness and sensitise the university community (teaching and research staff, administration and services staff, and students) to promote the inclusion of students with disability at university. This educational recommendation working to raise the awareness was already suggested in the inclusion of deaf and hard-of-hearing students at university [24].

Finally, university teachers should undergo training in inclusive education for people with disability. These courses should meet diverse objectives and cover varying degrees of complexity and themes. Universities must have teachers with inclusive profiles who are interested in continuous training [17]. In fact, González-Castellano et al. [17] showed that the more accessible and inclusive the universities are, the more continuous training teachers have and therefore the more interest they have in continuing training. Ortiz Colón et al. [19] also confirm the need for training in special needs processes to enable university teaching staff to participate in an inclusive model and reveal the teaching staff do not consider themselves sufficiently prepared to provide an educational response to students with a disability. In a similar sense, Carballo et al. [16] state inclusive faculty members recommend that other teachers become informed about disability, develop a good and close relationship with their students and value their abilities, not their limitations.

5. Conclusions

Among the most relevant conclusions that we can draw from the research work carried out is the lack of previous inclusive experiences and adapted teaching material in mathematics and statistics subjects in the university context. The deficit of integration experiences is much more significant in the case of students with intellectual disability. All this entails a gap in the protocols and procedures to support university professors in their teaching work in these subjects. In this sense, the authors propose activities that have proven successfully with students with mild intellectual disabilities. In addition, several audiovisual materials adapted to various disabilities have been proposed by the authors to understand the different theoretical concepts of statistics.

This contrasts with the fact that the proliferation of free educational videos of any statistical content has grown exponentially over the past decade. Students today have at their disposal a large amount of audiovisual material to review the contents explained in class. However, it is almost impossible to find material adapted to the needs of people with disability. This evidence, together with the fact that the statistics subject is taught in the first year of many university degrees, led us to focus on this line of research and to pursue the publication of statistics contents adapted to students with different types of disability. In this way, the statistics subject has been made more accessible to everyone, and we progressed towards a more egalitarian university, one that is aware of the enrichment that comes with student diversity.

The initiative exposed above aims to raise awareness in the educational community generally, and the university community in particular. It sought to respond to the lack of educational materials adapted to people with disability, especially in the area of the STEM subjects. We suggest furthermore that the National Agency for Quality Assessment and Accreditation (ANECA)—responsible for the evaluation process of various university teaching staff members—includes specific assessment criteria on the actions and measures it promotes to develop the inclusion and equal opportunities of university students with disability. That is, the educational authorities should positively value university teachers who develop adapted resources and conduct inclusion and awareness activities in their classes. Under these conditions, university teachers would be further incentivised to make their subjects more inclusive.

The experience was highly gratifying for all the people involved: the FEVIDA and undergraduate students and the teachers. In fact, teachers are hoping to repeat the experience in the coming academic year and to incorporate improvements, new topics of interest, etc. Teachers are convinced that these types of activities allow everyone to grow, in the broadest sense of the term. Students with disabilities represent a positive professional challenge for the faculty, leading to new learnings and greater professional satisfaction [22]. Therefore, we will pursue our efforts towards the achievement of a more accessible and inclusive university. University lecturers should, however, receive training on inclusive education [11]. In addition, students with disabilities emphasised the need to provide training and/or information on disability [21], a reflection we mentioned in Section 3.

The role of public Spanish universities is a key in promoting the talents of people with disability. Therefore, they must continue to develop policies to achieve real and effective equality of opportunities for people with disability in the higher education environment. This goal reflects a societal need but it also corresponds to the fourth objective to transform our world; that is, to guarantee inclusive, equitable and quality education and promote lifelong learning opportunities for all, featuring in the 2030 Agenda for Sustainable Development and approved by the United Nations Organization in 2015 (United Nations Organization) [1].

6. Limitations and Future Research

Among the limitations that the authors have found in their research we highlight the lack of previous inclusive experiences as well as adapted material for the statistics subject in the university context. These drawbacks, together with the scarcity of teacher training in students with special needs or disability, have made authors self-taught in the field of inclusive statistics, marking a new path that is expected to serve as a model for other university teachers.

Moreover, the authors lack the academic authorities' recognition for implementing inclusive activities as well as preparing material adapted to students with disability, because this type of experience involves a large amount of invisible work by teachers.

This study also includes some limitations that entail challenges for future works. The research has been carried out in a specific subject and university context, so it would be necessary to conduct a comparative analysis of subjects of the same nature in different branches of knowledge and universities. At the same time, it would be interesting to accomplish studies differentiating according to the type of student disability. Furthermore, to develop a more inclusive higher education, the authors have decided as future research to create a workshop on statistics in the Degree in Computer Engineering in Information Systems, adapted to people with disability, where the use of information and communications technology is the main actor to promote the acquisition of basic statistical concepts. The realisation of this inclusive workshop will involve, among other aspects, the analysis of the accessibility of different computer applications for mobile devices and tablets, differentiating according to the type of disability or special need.

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Appendix A

Survey questions undergraduate students

1. Have you actively participated in the FEVIDA workshop organised in the subject of statistics of the Degree in Environmental Sciences and the Dual Degree in Environmental Sciences and History-Geography?
   - Yes, I have taken part in a working group.
   - No, I only attended the workshop.
   - I have not participated in the preparation of the activities nor have I attended the workshop.
2. Please specify whether you are male/female.
3. How satisfied are you with the FEVIDA workshop (1/2/3/4/5), where 1 is "not at all satisfied" and 5 is "very satisfied".
4. Evaluation of cooperative teamwork (needs improvement/good/very good):
   - Have we all learned?
   - Did we use our time efficiently?
   - Did we finish the job on time?
   - Have we helped each other?
   - Have we made progress in our group goals?
   - Have we each fulfilled our mission?
   - Did everyone correctly exercise their individual role?
5. How much do you know about the different types of disability?
   - I know almost nothing.
   - I do not know enough.
   - I know quite a lot.
   - I know a lot.

6. Do you think that people with disability are sufficiently protected in Spain? Yes/No.
7. Please read the following statements carefully and tell us how much you agree or disagree (strongly disagree/quite disagree/quite agree/totally agree):
   - My life is easier than that of a person with disability.
   - People with disability are very sensitive.
   - Older people are people with disability.
   - People with disability become difficult to deal with.
   - I may also become a person with a disability.
   - More actions should be taken to further integrate people with disability into society.
   - More money should be invested in bringing down the physical barriers that make life more difficult for people with physical disability.
8. What opportunities do you believe people with disability have to get a job, training or promotion compared to people without any type of disability and with the same skills, aptitudes or diplomas? Fewer opportunities/The same opportunities/More opportunities.
9. Do you think that dealing with people with disability can help you to . . . ? Yes/No.
   - To understand another social reality.
   - To be more aware of other peoples' situations.
   - To give less importance to small problems.
   - To understand that some people need help.
   - To improve as a person.
10. Did your participation in this project make you reflect seriously for the first time on the reality of people with disability? Yes/No.
11. Please indicate the purposes of this project (multiple answer).
    - To improve the understanding of issues related to disability.
    - To promote the rights of people with disability.
    - To give a more positive image of people with disability.
    - To show the difficulties faced by people with disability in their daily lives.
    - To make the statistics subject more inclusive.
    - Other.

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Multinomial Cross-Sectional Regression Models to Estimate and Predict the Determinants of Academic Performance: The Case of Auditor Accountant of the Pontifical Catholic University of Valparaíso

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Abstract: The debate on the primary cross-curricular skills or fundamental competencies that must be improved in higher education has increased in the last few years. This is especially important in the new distant learning environments, which bring new challenges to the educational process. Econometric models have been designed to explain the students' academic performance, which has been measured using their qualifications average, the number of failed subjects, passed subjects, and withdrawn subjects, and the level of progress, among other indicators, to try to understand the influence of variables such as students' self-esteem, reading comprehension, English proficiency level, and performance in a mathematics-related subject on the students of accountant auditor program from Pontificia Universidad Católica de Valparaiso. Students were asked to fill in a questionnaire to collect data on the psychological and pedagogical variables, while the socio-economic and socio-demographic data were collected from the university. The results have shown that the most significant variables in the development level of this skill type are socio-demographic and socio-economic characteristics. Some of the psychological and pedagogical variables that have, to a lesser degree, some influences are self-regulation in the learning process and the self-perception of anxiety levels. Lastly, some recommendations to intervene in the students' learning process are presented with the objective of achieving a higher level of development in this type of competences.

Keywords: multinomial logistic regression; academic performance; econometric models

1. Introduction

1.1. Academic Performance in Chile and the World

Addressing a study variable such as the academic performance of students in these times becomes a challenge without falling into value judgments or subjectivities due to the social impact that this topic causes in the life of a human being and, as such, in the university student specifically. In addition, different life situations have a notorious impact on their academic training, on the development of their skills, and how these are ted at work. All this marks differentiating qualities that will make human talent authentic and distinctive, which is a sign that generates value to its environment through its contributions or actions, reducing risks that alter the productive life of its services. According to the research carried out by Véliz, Dorner, and Sandoval [1], the results indicate that one of the variables that must be worked on in university life is academic self-efficacy, which would contribute to favoring academic performance and the processes of adaptation to higher education.

In this sense, academic performance today is affected by environmental, social, and economic factors [2] that undermine the effectiveness of sustainability and sustainability in the global world [3,4], altering the raison d'être of educational organizations in search of learning assurance and of generic and technical skills that help students to exercise their professional role in the market with ethical and quality indicators. People are immersed in a bubble wherein they recreates their lives, overloaded with information, stimulated by external and internal factors, and exposed to constant changes, which has caused the best of the universities in Latin America to revolve around new proposals for flexible academic programs [5–7] and their to curricula adapt to the requirements of the environment. In this approach, the center of everything is learning that develops the student's skills for their daily work; that is, it prepares the student for life, with a humanizing, recursive, and holistic approach, which allows the student to obtain tools to put in practice in their personal and work area [8–10].

To the above, we must add the effects of environmental deterioration and biological damage, which have caused universities in countries such as Argentina [11,12], Mexico [13,14], Brazil [15–17], and Chile [18,19] to generate new models for the creation of educational organizations, new teaching practices have been implemented that maximize the academic performance of the students, and learning spaces (laboratories) have been recreated that allow them to experience new forms of learning and knowledge where constructivism and constructionism have value have been put into practice. At the same time, these new practices promote initiatives for the internationalization of the curriculum, promoting global cultural experiences, and new learning styles are generated, impacting pedagogical models. In contrast, new communication tools and digital platforms are being used that generate new connectivity alternatives, aiming at the freedom of education and the free transit of knowledge. For Ramírez, Villalobos, Lay, and Herrera [20], the media allow the appropriation of knowledge and are influenced by interactive models with emerging perspectives on knowledge.

Due to social problems in Chile, academic performance has undergone dizzying changes, where young talent has had to leave their classes to join the labor area informally, seeking to improve their quality of life. Due to these notable cases, it becomes essential to obtain practical skills through training that allows students to opt for job improvements, which later are rewarded in personal and family well-being. The 21st century will offer unprecedented resources for the circulation and storage of information and communication. It will pose a double demand on education that, at first glance, may seem almost contradictory: education must massively and efficiently transmit an increasing volume of evolutionary theoretical and technical knowledge, adapted to the cognitive civilization, because they are the bases of the competencies of the future [21].

The purpose of the research is to identify and measure the impact of the variables affecting the increase in the academic performance of the students of the accounting auditor program of the Pontificia Universidad Católica de Valparaíso to assess the finding that allows conclusions to be drawn about the study variable, so that contributions can be generated for the study for the advancement of science, technology, and innovation. Thus, in this research, our questions are how variables such as reading comprehension, level of English, academic self-esteem, general self-esteem, theoretical value, theoretical value, nutrition, student entry, math test, self-updating, graduation, middle school score, religious value, and exercise affect the academic performance through the design of an econometric model that will allow for the measuring and quantifying of said effect.

Some previous studies have examined how to understand and overcome learning difficulties. Most researchers analyze their research data using multiple regression analyses but do not consider learning difficulties as the dependent variable in qualitative data [10,22,23]. Therefore, this article presents a further analysis of previous studies. Multinomial logistic regression (MLR) analysis is a suitable model to solve this problem. That is because the students' tests (on their perceptions) are answers based on alternatives (categorical or qualitative). Additionally, the students' characteristics are nominal and ordinal data. In contrast, other studies have used MLR with different objectives, such as [24–27]. However, the approach to the problem faced is not the same as that of those investigations.

This paper is organized as follows. Section 1 presents the introduction, which includes a literature review. The materials and methods are presented in Section 2. The results are shown in Section 3. Section 4 presents the discussion and conclusions of this research.

1.2. Competencies in Higher Education

Over time, the evolution of institutions has been glimpsed in terms of strengthening the skills of their students. In previous centuries, all those physical skills and strength were required due to the jobs that demanded an effort on the part of the student. Man, however, with various industrial revolutions, has changed this. Currently, organizations focus their attention on developing technical skills [28–30]. This is due to the need for humanized capital in the new global era, with essential skills for executing administrative and operational processes according to the corresponding soft areas. The educational institutions that innovate their curriculum [31–33] and bet on the training of students by challenges have been oriented to the solution of problems that the productive industry sector demands, with a holistic vision, creativity, and innovation, for the generation of value and competitiveness against the challenges of the environment, forming comprehensive leaders with skills that enhance the work of companies.

This demand has been linked to the progress of information technologies, expanding access to tools, knowledge, and networks for the expansion of meaningful learning that brings students closer to natural spaces that allow them to make decisions and be guided by what they do. This can be seen in the virtualization of multiple processes and training, work, and interaction activities through simulators, leading the participant to develop skills by making logical, rational, and analytical decisions that strengthen their work. All of this originates innovative strategies that promote the recovery and reactivation of the nation's economy and contribute to a sustainable development that minimizes the devastating effects of the environment, being focused on the responses of the human being as a strategic partner that generates value for companies following their skills acquired at the university.

Competencies in higher education refer to the set of skills, aptitudes, attitudes, and knowledge an individual has. For Fuentes, Moreno-Murcia, Rincón-Tellez, and Silva-García [34], competencies are the grouping of behaviors, measurable and perceptible, that can be evaluated in a person. Hence, it is necessary to determine which skills are required to execute activities. According to Carrión-Martínez, Fernández-Martínez, Pérez-Fuentes, and Gázquez-Linares [35], the outstanding segments for the grouping of skills and abilities are guided by cognitive traits (logical thinking and theoretical knowledge), followed by cognitive traits, social traits (communicative skills), and psychosocial traits (motivational skills). When referring to generic skills, we speak of those universal skills that must be acquired regardless of the study area. These allow for the carrying out of simple but essential processes for developing and improving local economies.

Research carried out by Echeverría-Ramírez and Mazzitelli [36], Preciado-Serrano, González, Colunga-Rodríguez, Vázquez-Colunga, Esparza-Zamora, Vázquez-Juárez, and Obando-Changuán [37] and Sagredo, Etchepare, Mendizabal, and Wilson [38] make it clear that generic competencies in higher education emphasize general attributes and abilities for the development of activities such as analytical and critical thinking, conflict resolution, communication skills, and teamwork. However, these are situational, therefore it is imperative to analyze the current and future situations to master the required skills. In contrast, technical skills in the educational context are those skills and abilities obtained by carrying out activities or, failing that, by experience. Technical or complex skills are all those qualities and knowledge acquired through experience in developing activities. It should be noted that these technical skills are more specific to the sector or type of industry to work.

Nowadays, social, economic, political, environmental, and biological factors have notoriously influenced human beings to reinvent themselves, adapting to new environmental changes. These changes force us to enhance the competence of the living being through dynamic capabilities to systemically solve the problems that human talent itself recreates, made up of opportunities and threats. For this reason, the articulation of competencies in higher education is relevant, where students are trained with abilities, knowledge, and skills that allow them to respond to this new global era that is increasingly volatile and competitive. According to the investigations of Jiménez, Pérez, and Gómez [39] and León, Mendoza, and Gilar [40], there are social, economic, and environmental factors in universities that have a notorious impact on student performance. For this reason, it is evident to generate innovative initiatives that enhance the learner's skills to mitigate the adverse effects of these factors that threaten the development of learners' skills.

According to Sukier, Ramírez, Parra, Martínez, Fernández, and Lay [41], companies must change their models of strategic management of human talent, adapting to the dynamic challenges of the environment. These models are increasingly unstable, aggressive, and turbulent, condemning people to reinvent themselves and rely on tools to consolidate their goals and improve their skills. In recent months, the multiple effects caused by the COVID-19 virus have been evidenced. At current times, at the global level, the slowdown in economic growth, reduction in income, loss of profitability and economic insolvency, high level of unemployment, and the disappearance of companies have been observed [42–44]. At the same time, society has feared physical contact, which characterizes human beings. The Chilean economic context has not been different from the global one [45].

In the following section, we describe how the measurement of certain competencies were used for the development of this research.

1.3. Meauserement of Competencies

The instruments used to measure the skills of higher education students were the following six tests: Psychosocial Motivations Scale (MPS) by J. L. Fernández (1987) [46], Gordon Allport's values study test (1968–1972) [47], Lifestyle Profile (PEPS-I) by Nola Pender (1996) [48], Wonderlic by Eldon F. Wonderlic (1936) [49], ICT Questionnaire in Personal Training (REATIC) [50], Stanley Coopersmith's self-esteem inventory (1967) [51]. Below is a summary of each of the tests used.

Psychosocial Motivations Scale (MPS) by J. L. Fernández (1987) [46]. The instrument was designed to measure the motivation system of individuals, published by TEA Ediciones in 1987. The scale seeks to appreciate the individual's motivational system's differential structure and functional dynamics (emotional, cognitive, and situational) and predict the person's future behavior. Said evaluation is of six factors and five components of psychosocial motivations in the work context. The scale factors are acceptance and social integration, social recognition, self-concept, self-development, power, security. Its reliability coefficient is 0.53–0.83. It consists of three parts, with a total of 173 items.

In its first part, a true or false answer is given to each item for the levels of Activation, Expectation, and Execution. In its second part and, in turn, the third, it is answered using an evaluation scale of the elements chosen by the individual in the Incentives and Satisfaction of each item. The rating ranges from 1 ("some"), 2 ("normal"), 3 ("a lot"), 4 ("very much").

Allport Values. Gordon Allport's values study test (1968–1972) [47] applied his study of values inspired by the types of men of Stranger (1964), and defines the ways of life of man in six interests or basic motives in personality: the social, political, aesthetic, economic, theoretical, and religious. It consists of two parts; in the first one, there are statements or questions with two alternative answers. In the second part, situations are presented, followed by four possible attitudes or responses, where the individual must classify these responses in the order of personal preference, noting the score according to the degree of preference. Finally, the test classifies each interest style as high, average, and low.

Lifestyle Profile (PEPS-I) by Nola Pender (1996) [48]. The questionnaire quantitatively measures the level of the individual's lifestyle. It is made up of 48 Likert-type items, which are subdivided into the dimensions of nutrition (6 items), exercise (5 items), responsibility in health (10 items), stress management (7 items), interpersonal support (7 items), and self-updating

(13 items). This questionnaire asks the respondent to identify how often they have practiced each statement in the last 30 days and to circle the answer that best reflects their current lifestyle. Each item has a minimum score of 1 ("never") and a maximum of 4 ("always"), adding a minimum overall score of 48 and a maximum of 192. The scores define high lifestyles (132–192), medium (108–131), and low (48–107) according to 0.75 standard deviations above or below the mean score.

Wonderlic test by Eldon F. Wonderlic [49]. This instrument has 50 logical reasoning and problem-solving questions distributed from least to significant difficulty. It is made up of three subtests: vocabulary, arithmetic reasoning, and spatial reasoning. It presents a correlational validity between teaching and academic achievement between r = 0.30 and r = 0.80, with a reliability coefficient between 0.73 and 0.95. The Wonderlic Personnel Test (WPT) is a general intelligence test used in personnel selection and vocational guidance. It has an execution time of 12 min for the resolution of the test. The scores define each student's work and academic and training potential, distributed in six ranges below 10 points, between 10 and 15 points, between 16 and 20 points, between 21 and 23 points, between 24 and 27 points, and above 28 points. It also has a correction table according to the age of the person evaluated.

ICT Questionnaire in Personal Training (REATIC), the De Moya questionnaire [50], comprises 60 items through which the greater or lesser degree of knowledge, use, and existing assessment of information technologies can be established and communicated in university education. Therefore, the purpose of the instrument is to determine the conditions of a student's management and the positive assessment of the implementation of ICT in their academic and personal life. The test is divided into four subgroups: I know (item 1 to 14), I use (15 to 28), I consider ICT (item 29 to 44), and I use ICT according to learning style (item 45 to 60).

Stanley Coopersmith's self-esteem inventory in 1967 [51]. This instrument aims to identify the evaluation that a person makes and maintains about himself, indicating the degree to which he considers himself capable, competent, and successful. It has 25 items on a dichotomous scale (yes–no), separated into three areas, i.e., General Self, Social, and Family, establishing the following intervals for a maximum score of 100 points. Low level of self-esteem (0 to 24 points), Medium–low level of self-esteem (25 to 49 points), Medium–high level (50 to 74 points), and High-level (75 to 100 points). Its reliability is 0.79, based on the Tarazona study.

2. Materials and Methods

The analysis is carried out for the career of Accountant Auditor of the Pontifical Catholic University of Valparaíso (PUCV), Chile. It is a sample of 82 students of both genders, of which 34% are male and 66% are female. This research considered different ways of measuring the endogenous variable: average of grades; the number of approved courses; the number of failed courses; the number of retirees; the degree of advancement; the minimum qualification; the maximum qualification; and the standard deviation of qualification [52]. Both the data for the endogenous and exogenous variables of the proposed models are obtained from each of the surveys. Given the above, and following the proposed objectives, the analysis aims to establish the determining factors of the training competencies of the students of the Accountant Auditor at the PUCV, Chile, and their impact on the students' academic performance.

The instruments used to collect the information come from the different tests that the students of the Accountant Auditor career take upon entering the university. This is how students develop various tests, where the general self-esteem tests corresponding to the Coopersmith self-esteem inventory, academic self-esteem, reading comprehension, and a diagnostic test of English [51–55] stand out, considering the leveling given by the Council of the Common European Framework of Reference for the Languages (CEFR). For this research, the results obtained by each student participating in the study have been collected directly from the Directorate of Institutional Analysis and Strategic Development (DAIDE) of the Pontifical Catholic University of Valparaíso.

Both types of data have been collected (among 2016 and 2021) by different platforms and systems in the PUCV and a unique code has been used to identify the data of each student. A protocol was established so that only one person knew the link between said code and the individualization of each student. This relationship data was not disclosed to anyone else. All this is due to the procedures for the private use of said data, respecting the individualization of the students. Similarly, when the students were surveyed, they had been informed of how the data would be used, protecting their identity. These tests were only been carried out if the participant granted their approval and consent.

The first stage of the study consists of carrying out an exploratory analysis of the variables under study to understand the behavior of each of the variables involved in the research. Subsequently, cross-sectional econometric models are used to establish the determining factors of the fundamental training competencies of the Auditor Accountant students. Cross-sectional data, or a cross-section of a study population, in econometrics, is a type of data collected by observing many subjects (such as individuals, firms, countries, or regions) at one point or period of time. The analysis might also have no regard for differences in time. Cross-sectional data can be used in cross-sectional regression, which is a regression analysis of cross-sectional data, which was conducted in this research. Analysis of cross-sectional data usually consists of comparing the differences among selected subjects, through which the assumptions associated with the problem of spherical disturbances are reviewed and evaluated and the other tests are proposed for its validation [56], performing the necessary transformations for its validation without affecting the economic nature of the model [57].

3. Results

This section presents the results of the econometric estimation of the mixed model, defined as an estimation of the academic performance of an accountant auditor student at the Pontifical Catholic University of Valparaíso, Chile.

Among the research results, determining factors were evidenced in the academic performance measured by the indicator of courses approved by students, which correspond to the scores obtained in evaluations carried out upon entering university, which sought to identify psychological elements such as levels of general and academic, or educational, self-esteem, such as performance in the English language diagnostic test or reading comprehension, that allow us to approach the objective of identifying elements that are related to the development of fundamental training competence in the students under study. Thus, the descriptive statistics of the variables used in the model are shown in Table 1

Table 1. Descriptive analysis variables of the research.

	N	Minimum	Maximum	Mean	Std. Deviation
Average of grades	82	4.17	6.62	5.42	0.65
Approved courses	82	0.50	1	0.83	0.14
Failed courses	82	0.00	0.23	0.057	0.076
Retirees courses	82	0.00	0.30	0.087	0.086
Degree of advancement	82	0.105	0.926	0.440	0.300
Minimum qualification	82	1.0	6.3	3.72	1.52
Maximum qualification	82	5.8	7.0	6.7	0.30
Standard deviation of Qualification	82	0.206	1.269	0.793	0.236
Theoretical value	82	1	5	3.93	0.890
Nutrition	82	7	24	15.66	4.054
Exercise	82	5	18	9.34	3.181
General self-esteem	82	28.0	104.0	67.92	24.192
Academic self-esteem	82	4.0	16.0	11.882	3.3802
Reading Comprehension	82	2.0	10.0	6.039	1.9896

Table 1. *Cont.*

	N	Minimum	Maximum	Mean	Std. Deviation
Level of English	82	9.0	74.0	28.302	14.8823
Maths test	82	1.0	23.0	13.360	5.3443
Self-updating	82	24	50	38.49	6.784
Religious value	82	13	45	25.86	7.236
Middle school score	82	5.2	6.8	6.070	0.3259

From the analysis of Table 1, we can see that the ranges of the exogenous variables are wide because they are related to the characterization of a heterogeneous sample, composed of students who are at different times in the curriculum of the career of the Accountant Auditor. When analyzing the standard deviation presented by some variables, this is confirmed since the high levels of dispersion with respect to their mean reinforce the idea of a heterogeneous sample, which is therefore representative of the population under study. For example, when considering variables such as the level of English of the students in the sample or the results obtained in the general self-esteem test, it is evident that these are characteristic aspects of the students themselves and that they influence the degree of development of the fundamental competencies.

Econometric Models

With the previously exposed variables, a cross-sectional econometric model has been developed. With the above, through the cross-sectional model, the intention is to assess the degree of development of fundamental competencies and their impact on the academic performance of students. The endogenous variables tested in this study are: average of grades; the number of approved courses; the number of failed courses; the number of retirees; the degree of advancement; the minimum qualification; the maximum qualification and the standard deviation of qualification. Moreover, the exogenous variables are: the results in the entrance tests of reading comprehension; level of English; academic self-esteem and general self-esteem. All discrete variables of real scale that constitute the determining factors in the degree of development of fundamental competencies.

To estimate the functional relationship of the model based on Equation (1), we propose a mixed model to explain the response variable Y in terms of a set of explanatory variables. The functional relationship of the model is defined as follows (see Equation (1)):

$$Y_{ij} = \beta_0 + \sum_{s=1}^{S} \beta_s X_{sij} + u_{i0} + e_{ij}, \tag{1}$$

where Y_{ij} corresponds to the dependent variable measured by academic performance from each auditor accountant student i over different measures of academic performance j; β_0 corresponds to a baseline parameter of the model; and β is a parameter vector that corresponds to the parameters related to variables that affect the academic performance of students i. x_{ij} corresponds to the following variables: reading comprehension, level of English, academic self-esteem, general self-esteem, theoretical value, theoretical value, nutrition, student entry, maths test, self-updating, nutrition, student entry, maths test, self-updating, graduation, middle school score, religious value, exercise; from each auditor accountant student i over different measures of academic performance j. Finally, i = auditor accountant students and j = different measures of academic performance.

From the analysis of Table 2, we can see that multiple cross-sectional econometric models have been tested for each of the endogenous variables under study. Thus, in the case of the academic performance of students measured by average of grades, the best model is explained by the variables theoretical value and nutrition. In the case of the number of approved courses, the best model is explained by the variables general self-esteem, academic self-esteem, reading comprehension, and level of English; for the model with endogenous variable failed courses, the best model is explained with the variables theoretical value, student entry, math's test, self-updating; for the measurement of academic performance through the retirees courses variable, the best model is explained by the variables general self-esteem and academic self-esteem; with the model measured through the endogenous variable degree of advancement, the variables that explain are graduation; in the case of measuring academic performance through the minimum qualification variable, the best model is explained by the variables religious value and student entry; for the measurement through maximum qualification of student, the model is explained by the variables exercise and religious value; and, finally, for the academic performance model measured through the standard deviation of qualification variable, the best model is explained through the theoretical value variable.

Table 2. Results of the estimation of the cross-section model and its goodness of fit.

		Average of grades		
	Model 1	Model 2		
R Square	0.321	0.321		
ANOVA (*p*-value)	0.003	0.000		
Variables	Theoretical value 0.280 (3.369)	Theoretical value 0.294 (4.045)		
		Nutrition −0.047 (−2.931)		
		Approved courses		
	Model 1	Model 2	Model 3	Model 4
R Square	0.301	0.568	0.639	0.708
ANOVA (*p*-value)	0.004	0.000	0.000	0.000
Variables	General self-esteem −0.003 (−3.218)	General self-esteem −0.003 (−4.715)	General self-esteem −0.003 (−4.946)	General self-esteem 0.003 (5.525)
		Academic self-esteem 0.019 (3.772)	Academic self-esteem 0.023 (4.529)	Academic self-esteem 0.022 (4.628)
			Reading comprehension 0.019 (2.082)	Reading comprehension 0.020 (2.426)
				Level of English −0.002 (−2.230)
		Failed courses		
	Model 1	Model 2	Model 3	Model 4
R Square	0.416	0.573	0.652	0.751
ANOVA (*p*-value)	0.000	0.000	0.000	0.000
Variables	Theoretical value −0.061 (−4.135)	Theoretical value −0.071 (−5.320)	Theoretical value −0.069 (−5.534)	Theoretical value −0.071 (−6.588)
		Student entry −0.055 (−2.906)	Student entry −0.066 (−3.661)	Student entry −0.066 (−4.218)
			Maths test −0.004 (−2.232)	Maths test −0.005 (−3.160)
				Self-updating −0.004 (−2.891)

Table 2. *Cont.*

	Retirees courses	
	Model 1	Model 2
R Square	0.446	0.554
ANOVA (*p*-value)	0.000	0.000
Variables	General self-esteem 0.002 (4.400)	General self-esteem 0.002 (5.190)
		Academic self-esteem −0.007 (−2.358)
	Degree of advancement	
	Model 1	
R Square	0.414	
ANOVA (*p*-value)	0.000	
Variables	Graduation −0.130 (−4.116)	
	Minimum qualification	
	Model 1	Model 2
R Square	0.314	0.488
ANOVA (*p*-value)	0.003	0.000
Variables	Religious value −1.138 (−3.313)	Religious value −1.410 (−4.428)
		Student entry 0.779 (2.797)
	Maximum qualification	
	Model 1	Model 2
R Square	0.493	0.583
ANOVA (*p*-value)	0.000	0.000
Variables	Exercise −0.065 (−4.834)	Exercise −0.077 (−5.671)
		Religious value 0.196 (2.225)
	Standard deviation of qualification	
	Model 1	Model 2
R Square	0.214	0.356
ANOVA (*p*-value)	0.017	0.006
Variables	Middle school score −0.250 (−2.559)	Middle school score −0.216 (−2.358)
		Theoretical value −0.083 (−2.252)

The above information is presented in summary form in Table 3.

In the first model, we can see that the cognitive attitude favorably influences the grade point average, unlike the effect of concern for a healthy diet and a lifestyle that considers the importance of nutritional aspects in students; in the second model, we can see that higher levels of general self-esteem and academic self-esteem positively influence the number of approved courses, as well as the results obtained in the reading comprehension tests, while knowledge of the English language has a negative effect on the endogenous variable; for the model that considers failed courses as an endogenous variable, the relationship of the exogenous variables with it is negative, since, the higher the cognitive attitude score achieved in the mathematics test and self-updating, the lower the expected number of failed courses obtained by students in the development of the study plan—the same impact generated by considering the type of entry of students to the career of Accountant Auditor; on the model whose endogenous variable is represented by the withdrawn courses, the general self-esteem positively affects this, while the higher the academic self-esteem, the lower the number of courses that a student is expected to be able to withdraw from during their career. For the model whose endogenous variable is defined by the minimum qualification, we note that the development of a religious life has a direct relationship with obtaining lower minimum marks, unlike the effect generated by the type of income. When the endogenous variable is defined by the maximum qualification, the religious value has a positive effect, which his quite the opposite of the effect of that generated by lifestyle when linked to sport. Finally, if we consider the model whose endogenous variable is the standard deviation of the grades, the theoretical value negatively influences this variable, that is, those students with a higher cognitive attitude present lower levels of dispersion in their grades with respect to the mean being more stable their qualifications.

Table 3. Best cross-sectional econometric model per variable.

Endogenous Variable	Explanatory Variables
Academic performance of students measured (by average of grades)	Theoretical value and nutrition
Number of approved courses	General self-esteem, academic self-esteem, reading comprehension and level of English
Failed courses	Theoretical value, student entry, maths test, self-updating
Academic performance (through the retirees courses variable)	General self-esteem and academic self-esteem
Degree of advancement	Graduation
Academic performance (by minimum qualification variable)	Religious value and student entry
Maximum qualification of student	Exercise and religious value
Academic performance model	Theoretical value

Once the analysis of the resulting models has been carried out, we can see that the theoretical value, general self-esteem, and academic self-esteem are the most significant and influential variables when we search the determining factors of the training competencies of the students of the Accountant Auditor of the PUCV, Chile, measured through indicators of academic performance. In addition, it is possible to observe that the effect that these variables have on the endogenous variables is consistent. For example, the theoretical value positively affects the explanation of the performance of students (measured by average of grades), while it negatively affects the explanation of failed courses. Other variables that maintain the same type of consistency are academic self-esteem and religious value. Additionally, the knowledge and skills of the students, measured by theoretical value, maths test, reading comprehension, and self-updating, are consistent with the expected performance, since, to the extent that they are higher, it is expected that the degree of progress and approved courses are also approved.

4. Conclusions and Discussion

According to what was mentioned in the previous section in this study, it was possible to estimate and predict the determinants of academic performance for the students of the Auditor Accountant of the Pontifical Catholic University of Valparaíso career.

The results made it possible to show that the most significant variables in the level of development of this type of skill are related to socio-demographic and socio-economic characteristics. This is somewhat related to the case studied, which is found in the Latin American [58–61] country—in the process of economic development—of Chile, in which such characteristics are heterogeneous in the study population. In this sense, both theoretical and applied studies are clear in indicating how socioeconomic variables influence academic performance in the world [62–65], in Latin America, and in the Chilean case [66–69].

This is quite helpful in improving the material elements in the broader university context and at the national level, and could subsequently improve the acquisition of the skills detailed above.

From the results, it is possible to observe that, in the sample, the self-esteem of the students is one of the strongest and most significant factors in the different models used in this research. Students' prior knowledge level, measured by the grades they obtained before enrolling in the University, is a factor that significantly explains the dispersion of university academic performance. However, what is interesting is that the levels of reading comprehension and mathematics were less significant for the average academic performance. The above could mean that this baseline and prior knowledge only contribute to significant but decreasing baseline development. On the other hand, the self-esteem that students have of themselves is even more relevant.

At another level, the psychological and pedagogical variables had, to a lesser degree, some influence on self-regulation in the learning process and the self-perception of anxiety levels. From the psychology of learning, it has been widely documented how emotional self-regulation is important to obtain academic achievement [70–75]. The same is true for self-perception of anxiety levels [76–78]. Additionally, it can be commented that the measurements of both variables were taken in a confinement context due to the COVID-19 pandemic, thus that variable has been shown with a higher estimate. Coincidentally, both the social characteristics mentioned above and confinement have a large material component at the base of the learning of the students studied.

The identification of factors associated with academic performance can allow university authorities to design policies that improve the academic quality of undergraduate students. In specific terms, the authorities could strengthen university programs and activities that foster confidence in young people and create coaching programs. According to this research, this type of activity could contribute more to improving student learning than reinforcing activities with technical program content.

This research could serve as a starting point for a broader investigation. On the one hand, expanding the number of students analyzed by incorporating other cohorts of graduates, which would also make it possible to carry out various cross-sectional studies and identify possible changes in the predictor variables that could occur. In addition, this research could be developed in other degrees and universities, which would also allow comparative studies. Specifically, according to the data collected in this research, making controlled variations of more heterogeneous samples in the social conditions of the students could provide more significant evidence.

Moreover, it is expected that the conclusions reached by this research can serve as a basis for future analyses and/or modifications of the study plan, considering it essential to become a support for the accompaniment of students in this stage of adaptation, such as, in the first year, introducing students to the opportunities that arise when the person has perseverance in the study, and fostering loyalty to the institution, creating a good image and retention from responsible academic work.

In order to safeguard the learning and social process of young people who are immersed in university, it is imperative to carry out psychosocial interventions from the field of mainly prevention through an induction that facilitates the process of adapting to university; however, when detecting students who may be more likely to have mental health disorders, it is necessary to support them through two aspects, namely counseling or individual therapy and workshops for a targeted group of students at risk. Research indicates that the streams with better results are cognitive, behavioral, and mindfulness interventions, mainly in reducing stress in students; this could be a good path to start an intervention aimed at student assets.

It remains to be seen in future studies in this same population if the same estimates are maintained for the determined variables exposed in the proposed models. It is important for the analysis of this case that the measurement was made at a time of confinement due to the pandemic.

Notwithstanding the foregoing, the proposed models are important to be able to estimate the effects of the study variables on academic performance and a subsequent achievement of educational excellence.

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