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Special Issue Reprint

Effects of Learning Environments on Student Outcomes

Edited by
Myint Swe Khine

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Editor

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Systematic Review

A Reliability Generalization Meta-Analysis of "What Is Happening in This Class?" (WIHIC) Questionnaire

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Abstract: What is Happening In this Class? (WIHIC) is the widely used questionnaire to measure psycho-social aspects of the classroom and explore how these aspects affect student learning and achievement. The purpose of this study is to examine the cumulative estimates of reliability and conduct reliability generalization meta-analysis of Cronbach's alpha for the WIHIC questionnaire. PRISMA framework is used to identify the papers in three major databases. Assuming a random-effects model, the average internal consistency reliability was 0.85, 95% CI [0.83; 0.87] for total scores and ranged from 0.80 to 0.88 for subscales. There was a substantial heterogeneity among the included articles (I^2 = 99.04%, Q (23) = 1481.074, $p < 0.001$). According to mixed model analysis, school context has a significant effect on the total scale and subscales, including teacher support, involvement, investigation, cooperation, and equity. Overall, the reliability generalization analysis of pooling reliability estimates helps in understanding the psychometric properties of the WIHIC inventory in diverse populations.

Keywords: learning environments; What Is Happening In this Class? (WIHIC); reliability; Cronbach's alpha; meta-analysis

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1. Introduction

In recent years, there have been many attempts at school and curriculum reforms in education systems in every country. Educational planners increasingly recognize that success in educating the young generation depends on how well educators and policymakers understand the symbiotic relationships between student learning and social and emotional factors and learning environments [1]. As most instruction takes place in the classroom, it is crucial to examine the nature of the classroom environment, how it functions, and the dynamics involved in the process. Studies on the effects of the learning environment on student outcomes have grown in the last three decades and have been established as one of the critical aspects of educational research [2]. The researchers investigated the relationships between students' and teachers' perceptions of their learning environments, attitudes toward specific subjects, and cognitive outcomes in diverse, multi-cultural settings.

Since the conception of learning environments as a prodigious field of educational research, a considerable numbers of self-report instruments have been developed to measure students' perceptions of the classroom climate [3]. Earlier attempts to conduct research in the learning environment used Learning Environment Inventory (LEI) [4], Questionnaire on Teacher Interaction (QTI) [5], and Science Laboratory Environment Inventory (SLEI) [6]. The most frequently used learning environment instrument is the What is Happening In this Class? (WIHIC), originally developed by [7]. The WIHIC combined relevant features from a wide range of existing questionnaires with additional scales that accommodate contemporary educational thinking, such as equity and constructivism. The WIHIC has 56 items that are divided equally into the seven scales. The internal consistency reliability values for each subscale are 0.81 for student cohesiveness, 0.88 for teacher support, 0.82 for involvement, 0.83 for investigation, 0.89 for task orientation, 0.67 for cooperation, and 0.81 for equity. Table 1 shows the scales in the WIHIC, along with a brief descriptor of each scale and sample items in the questionnaire.

Table 1. Scale Description for each Scale and Example Items in the WIHIC Questionnaire.

Scale	Description	Item
Student Cohesiveness	Extent to which students are friendly and supportive of each other.	I make friendships among students in this class.
Teacher Support	Extent to which the teacher helps, befriends, and is interested in students.	The teacher takes a personal interest in me.
Involvement	Extent to which students have attentive interest, participate in class, and are involved with other students in assessing the viability of new ideas.	I discuss ideas in class.
Investigation	Extent to which there is emphasis on the skills and of inquiry and their use in problem solving and investigation.	I carry out investigations to test my ideas.
Task Orientation	Extent to which it is important to complete planned activities and stay on the subject matter.	Getting a certain amount of work done is important to me.
Cooperation	Extent to which students cooperate with each other during activities.	I cooperate with other students when doing assignment work.
Equity	Extent to which the teacher treats students equally, including distributing praise, question distribution, and opportunities to be included in discussions.	The teacher gives as much attention to my questions as to other students' questions.

The WIHIC questionnaire has been extensively used in all levels of education in different countries [8]. The studies have shown that the questionnaire has strong reliability and validity across various contexts. In a recent study, [9] examined the preservice teachers' perceptions of learning environments in a public university in Texas, USA, before and after pandemic-related course disruption. The study used WIHIC to collect quantitative data from 230 teacher education students to explore changes in student perceptions of the learning environment from before to after the switch to remote learning due to the pandemic. The study found a decline in student cohesiveness, teacher support, involvement, task orientation, and equity scales.

In another study, [10] used scales from the WIHIC to measure the perceptions of nursing students on the effect of cooperative learning on academic achievement and the learning environment. The study found a significant difference between the academic achievement of students and their perception of the classroom environment in the experimental and control groups in favor of cooperative learning. [11] developed the New What Is Happening In this Class? (NWIHIC) instrument based on the WIHIC questionnaire by adding two more scales: differentiated instruction and ongoing assessment. The questionnaire was administered to 2556 grade 5 to grade 9 students in China. The study reports the grade and gender differences in the perceptions of their learning environment.

Bizimana et al. [12] investigated whether students taught biology using cooperative mastery learning had different perceptions of learning environment and engagement when compared to those taught using conventional teaching methods. The study involved 298 students, and a modified What Is Happening In this Class? (WIHIC) and Student Engagement Questionnaire (SEQ) were used to collect data. The results indicated a significant difference in the perceptions of the learning environment measured by these two instruments. The cooperative mastery learning group students were perceived as higher on all scales compared to conventional teaching methods group students. In Lithuania, Brandisauskiene et al. [13] highlighted the need for a sustainable school system to ensure the well-being of the young generation. The authors assessed the sustainable school environment variables and students' emotional and behavioral engagement in learning with the What Is Happening in this Class? (WIHIC) questionnaire, a short form of the Learning Climate Questionnaire (LCQ), and the Student Engagement Scale. Cronbach's alpha coefficients for each subscale are 0.915 for student cohesiveness, 0.928 for teacher support, 0.906 for cooperation, 0.931 for equity, 0.929 for learning climate, 0.892 for affective engagement, and 0.832 for behavioral engagement. Cronbach's alpha results suggest that all subscales had an acceptable internal consistency. They found that emotional engagement and behavioral engagement correlated significantly with all WIHIC scales except task orientation. These studies illuminated that the WIHIC questionnaire can be used to examine various dimensions of a learning environment.

Therefore, many studies used the WIHIC questionnaire, reported to be a valid and reliable tool to assess students' perception of the learning environment. To the best of our knowledge, there have been little to no studies that systematically provide an evaluation of the pool estimates of the internal consistency reliability of WIHIC. Therefore, we used the reliability generalization method, which is the application of meta-analysis in exploring the variability in the scores of reliability estimates of WIHIC. Reliability generalization is one of the methods of combining and analyzing the reliability coefficient alpha value from multiple empirical studies [14]. We also investigated the various characteristics of the studies that might affect the reliability estimates.

2. Materials and Methods

To answer the research questions, we conducted a literature review search and analysis according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines [15]. PRISMA is a widely used framework for reporting and synthesizing literature review following four steps: (1) identifying research literature from database searches, (2) screening articles using inclusion and exclusion criteria, (3) assessing full-text articles for eligibility, and (4) analyzing and reporting the final articles including in the review.

2.1. Data Sources and Literature Search

An initial search of the literature was conducted through three databases: *ProQuest*, *Scopus*, and *Web of Science*. The time frame for this review was from 1996 to May 2022, limiting to the period when Fraser et al. published the WIHIC questionnaire in 1996. The combination of keywords *WIHIC* and "learning environment" was used to identify the papers in every database. The detailed search strategy syntax used for each database can be seen in Table 2. Articles were included in this review if they were published in peer-reviewed journals in English. There were no restrictions regarding the design of studies: quantitative, qualitative, or mixed method.

Table 2. Search Strategy Syntax.

Database	Syntax	Number of Articles
ProQuest	WIHIC AND "learning environment"	133
Scopus	TITLE-ABS-KEY (WIHIC) AND TITLE-ABS-KEY ("learning environment")	68
Web of Science	WIHIC (all fields) AND "Learning environment" (all fields)	34

2.2. Study Selection

The literature search identified a total of 240 articles (see Figure 1). As the purpose of the review is to verify the reliability of the WIHIC questionnaire and examine the characteristics of the studies that might affect the reliability estimates, we determined the inclusion and exclusion criteria based on PICOS (Population, Intervention, Comparison, Outcomes, and Study design) format (see Table 3). After removing the duplicates, the titles and abstracts of the articles were reviewed by the first and second authors if they met the inclusion/exclusion criteria. The last author skimmed and scanned the full papers and assessed their relevance based on the above criteria. Then, the first and second authors reviewed the outputs and finally decided the relevant articles. After applying the PICOS criteria, 84 articles remained for full-text review.

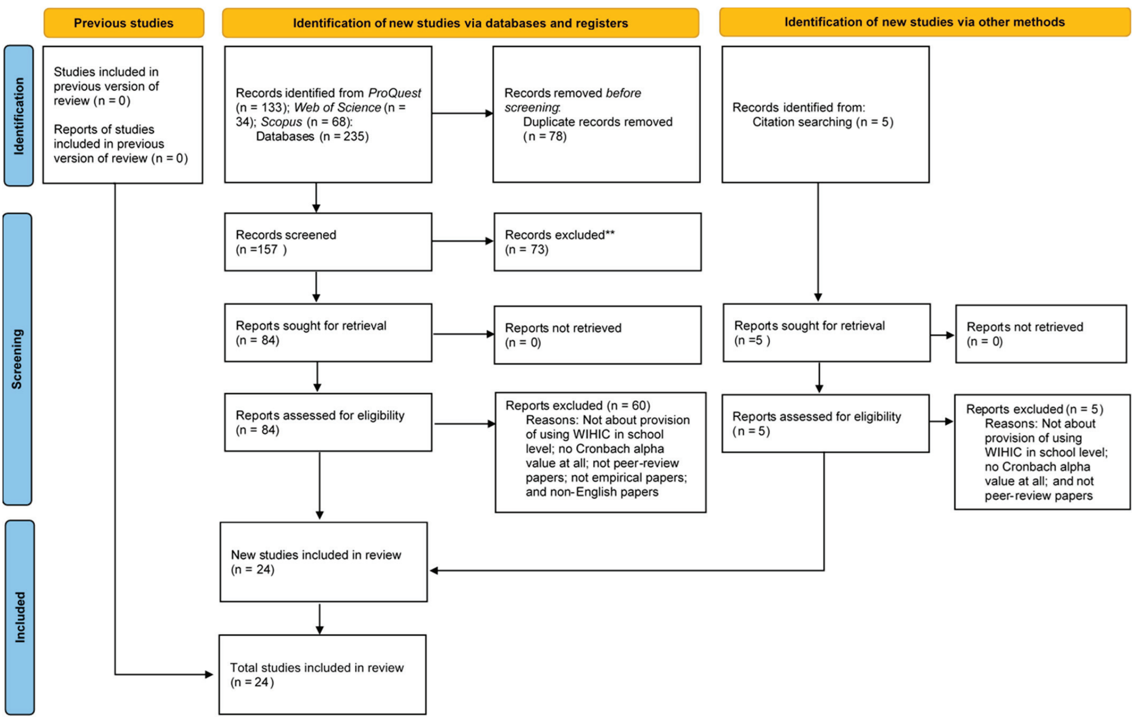

Figure 1. Study Selection Flow Diagram.

Table 3. Inclusion and Exclusion Criteria based on PICOS.

	Inclusion	Exclusion
Population	School level	Not university or college level
Intervention	NA	NA
Comparison	NA	NA
Outcomes	Reported Cronbach's alpha level: whether it is the overall alpha or alpha of the subscales for the WIHIC questionnaire	No Cronbach's alpha value
Study Design	All empirical papers	Not review, discussion, or theoretical papers Non-English papers Not peer-review papers

2.3. Approach to Analysis and Synthesis

The 84 full-text articles were reviewed if there was clear information about the use of WIHIC questionnaire and presented the reliability value. Papers that did not present the Cronbach's alpha value were excluded for final analysis and synthesis. In addition, the articles were excluded if the full text of the articles were presented in another language with their abstracts in English. Following the same shortlisting and consensus-building process above, 24 articles remained for quantitative evidence synthesis.

The random-effects model was performed using a restricted maximum-likelihood method to calculate the cumulative estimates of Cronbach's alpha and confidence intervals. The common measures for heterogeneity, including I^2 and Q statistics, were reported. The publication bias was assessed by fail-safe N analysis using the Rosenthal approach. A mixed-effect model was conducted to examine the role of moderator on the overall estimate of Cronbach's alpha. The analysis was conducted using Jamovi software (Version 2.3.13).

3. Results

We provided a summary of the 24 articles prior to presenting the answers to our research questions. This summary provides an overview of the characteristics of the reported research.

3.1. Characteristics of the Included Articles

This section presents the characteristics of the included articles, including study location; school level, research design, and the number of WIHIC sub-constructs in their studies (see Table 4).

Study location. The twenty-four studies come from thirteen different countries, with eight studies (33%) conducted in the USA, eight studies in Asia, three studies in Australia, and three in Africa. One study was reported for countries such as Turkey, Taiwan, and Australia.

School level (context). Most studies were conducted in secondary schools (83%). Two studies were conducted in primary schools (8%). Two studies were from mixed contexts (primary and secondary schools).

Research design. Eighteen studies (75%) employed a quantitative design. All quantitative studies employed a survey approach. Six studies (25%) employed mixed methods, and these employed more than the survey method, including interviews and observations.

WIHIC questionnaire. In the included studies, fifteen studies used the full version or the shortened form of the original scale. Meanwhile, nine studies used the translated version. In the translated version, the questionnaire was translated into Chinese [16–18], Spanish [19,20], Arabic [21], Turkish [22], Korean [23], and Indonesian [24]. In terms of the subscales, the included studies used from five to seven subscales in their studies, as the original WIHIC questionnaire included seven subscales, and the shortened version included five subscales.

Table 4. Characteristics of the included articles.

Authors	Country	Research Design	Methods	School Context	Translated/Original	Subscales
Adamski et al. [20]	USA	Quantitative	Survey	Mixed	Translated (Spanish)	6
Aldridge et al. [16]	Taiwan and Australia	Mixed-method	Survey, interviews, observations	Secondary	Translated (Chinese)	7
Allen and Fraser [25]	USA	Mixed-method	Survey, interviews, observations	Mixed	Original	6
den Brok et al. [26]	USA	Quantitative	Survey	Secondary	Original	7
den Brok et al. [22]	Turkey	Quantitative	Survey	Secondary	Translated (Turkish)	7

Table 4. *Cont.*

Authors	Country	Research Design	Methods	School Context	Translated/Original	Subscales
Charalampous and Kokkinos [27]	Africa	Mixed-method	Survey, interview	Primary	Original	7
Chionh and Fraser [28]	Asia	Quantitative	Survey	Secondary	Original	7
Dorman [29]	Australia	Quantitative	Survey	Secondary	Original	7
Dorman [30]	Australia	Quantitative	Survey	Secondary	Original	7
Helding and Fraser [31]	USA	Quantitative	Survey	Secondary	Original	7
Khalil and Aldridge [21]	Asia	Quantitative	Survey	Secondary	Translated (Arabic)	5
Kim et al. [23]	Asia	Quantitative	Survey	Secondary	Translated (Korean)	7
Koul and Fisher [32]	Asia	Quantitative	Survey	Secondary	Original	7
Lim and Fraser [33]	Asia	Quantitative	Survey	Secondary	Original	6
Liu et al. [18]	Asia	Mixed-method	Survey, interviews, observations	Secondary	Translated (Chinese)	5
Opolot-Okurut [34]	Africa	Quantitative	Survey	Secondary	Original	5
Rita and Mar-tin-Dunlop [35]	USA	Mixed-method	Survey, interview	Secondary	Original	7
Robinson and Fraser [19]	USA	Quantitative	Survey	Primary	Translated (Spanish)	5
Shadreck [36]	Africa	Quantitative	Survey	Secondary	Original	7
Stein and Klosterman [37]	USA	Quantitative	Survey	Secondary	Original	6
Taylor and Fraser [38]	USA	Quantitative	Survey	Secondary	Original	7
Wahyudi and Treagust [24]	Asia	Quantitative	Survey	Secondary	Translated (Indonesian)	7
Waldrip et al. [39]	Australia	Mixed-method	Survey, interview	Secondary	Original	5
Yang [17]	Asia	Quantitative	Survey	Secondary	Translated (Mandarin)	7

3.2. Reliability and Heterogeneity

Of the 24 eligible studies, no study reported a Cronbach's alpha value for the overall scale. Therefore, an average alpha value was calculated by transforming each subscale alpha value into z values using Fisher's z [40]. Then, the mean of those z values was calculated and back-transformed into Cronbach's alpha value. The total sample size was 28,696 participants (range $n = 81$ to $n = 3248$), with $M = 1196$ and $SD = 924$. The main summary statistics for the alpha coefficients of WIHIC total scale and seven subscales can be seen in Table 5.

From the estimate of the random effects meta-analysis, the mean of total scale alpha coefficients is 0.85, 95% CI [0.83; 0.87]. Regarding student cohesiveness subscale, 22 studies totaling 28,365 participants were meta-analyzed and yielded an estimate of $\alpha = 0.80$, 95% CI [0.77; 0.84]. Regarding the teacher support subscale, 23 studies containing a total of 25,827 participants were meta-analyzed and yielded an estimate of $\alpha = 0.87$, 95% CI [0.85; 0.90]. Regarding the involvement subscale, 24 studies comprising 28,696 participants were meta-analyzed and yielded an estimate of $\alpha = 0.85$, 95% CI [0.82; 0.87]. Regarding the investigation subscale, 16 studies comprising 19,738 participants were meta-analyzed and yielded an estimate of $\alpha = 0.86$, 95% CI [0.83; 0.89]. Regarding the task orientation subscale, 22 studies comprising 27,662 participants were meta-analyzed and yielded an estimate of $\alpha = 0.82$, 95% CI [0.79; 0.86]. Regarding the cooperation subscale, 22 studies containing a total of 24,928 participants were meta-analyzed and yielded an estimate of $\alpha = 0.86$, 95% CI [0.84; 0.89]. Regarding the equity subscale, 22 studies totaling 23,372 participants were meta-analyzed and yielded an estimate of α = 0.88, 95% CI [0.86; 0.91]. Comparing the mean reliability coefficients of these subscales, the teacher support subscale yielded largest estimates (M = 0.87), while student cohesiveness estimated the poorest average reliability (M = 0.80).

Table 5. Mean alpha coefficients, 95% confidence intervals, and heterogeneity statistics for WIHIC total scale and the seven subscales.

Total Scale/Subscale	*n*	α	LL	UL	*Q*	I^2
Total Scale	24	0.85	0.83	0.87	1481.074 *	99.04%
Student Cohesiveness	22	0.80	0.77	0.84	4705.848 *	99.58%
Teacher Support	23	0.87	0.85	0.90	1920.505 *	99.32%
Involvement	24	0.85	0.82	0.87	1280.051 *	99.1%
Investigation	16	0.86	0.83	0.89	1914.472 *	99.4%
Task Orientation	22	0.82	0.79	0.86	4439.097 *	99.55%
Cooperation	22	0.86	0.84	0.89	5675.091 *	99.51%
Equity	22	0.88	0.86	0.91	2314.499 *	99.47%

Notes. *n*, number of studies; LL, lower limit; UL, upper limit; *Q*, Cochran's heterogeneity *Q* statistic; I^2, heterogeneity index. * $p < 0.001$.

Heterogeneity among reliability coefficients was examined by calculating the Cochran's heterogeneity (*Q*) test and the heterogeneity index (I^2) and constructing a forest plot. Table 5 presents high heterogeneity among the included articles ($p < 0.001$) and large I^2 indices (>99%) for the total score and the subscales. Figure 2 presents a forest plot of alpha coefficients for WIHIC total score in each study. Therefore, it can be seen that there was a substantial heterogeneity, Q (23) = 1481.074, $p < 0.001$, $I^2 = 99.04\%$, $\tau^2 = 0.0027$. To address potential publication bias, a funnel plot was produced with a follow-up of the Egger's test. Funnel plot asymmetry can be suggested by Egger's test producing a *p*-value less than 0.001 (see Figure 3).

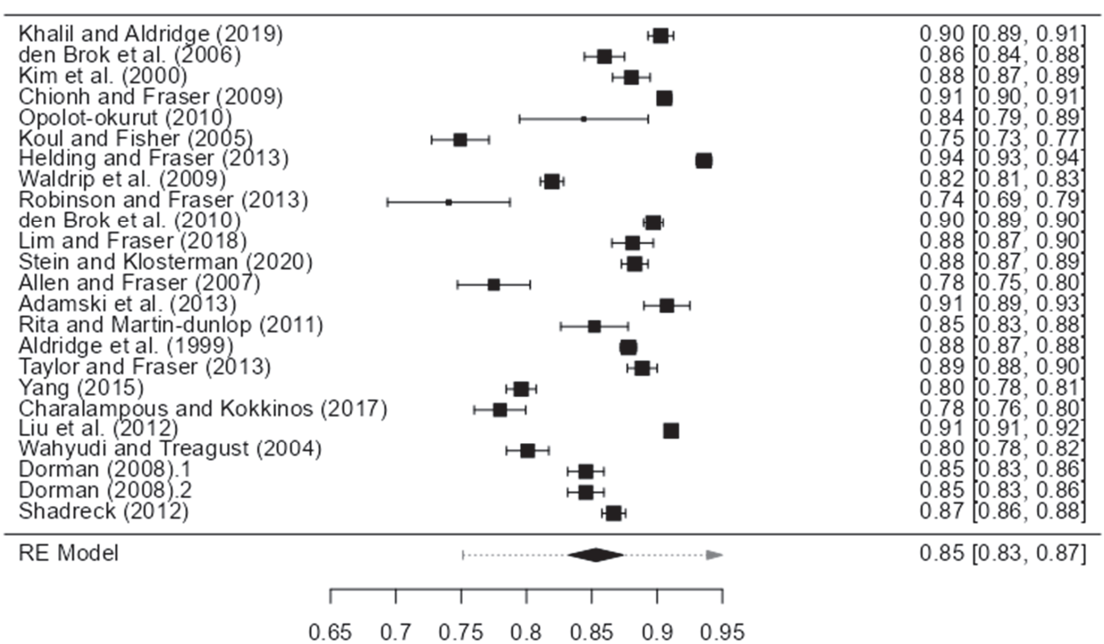

Figure 2. Forest plot for the reliability generalization of WIHIC.

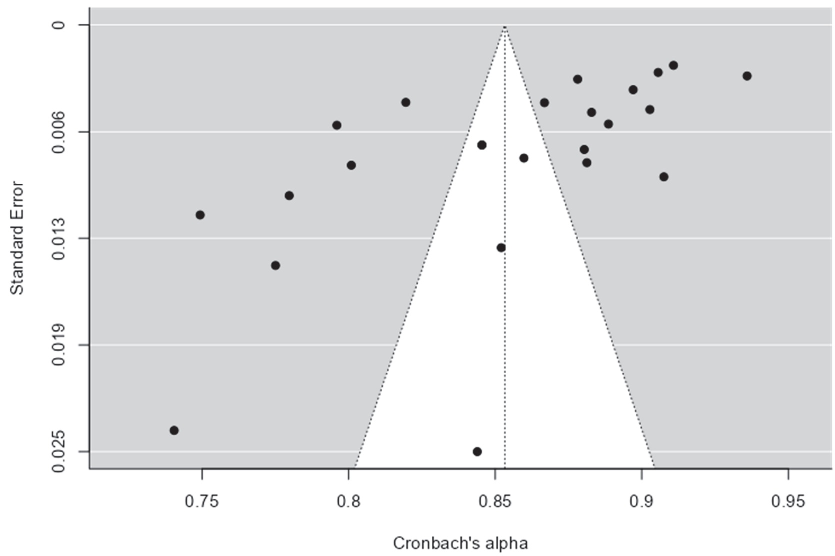

Figure 3. Funnel plot of alpha coefficient for the WIHIC scale.

3.3. Analysis of Moderator Variables

Mixed-model analysis was conducted using year, country, research design, school context, original/translated version of the questionnaire, and number of subscales as the moderators. It would be of benefit to examine the potential impact of these demographic factors was used. Among these factors, this study found that school context has significant effect on the overall estimate (z = 2.72, $p < 0.01$, 95% CI [0.028; 0.173], R^2 = 18.74%). No significant effect was seen with year (z = 0.026, $p > 0.01$, 95% CI [−0.164; 0.169], R^2 = 0%), country (z = 0.596, $p > 0.01$, 95% CI [−0.055; 0.103], R^2 = 0%), research design (z = −0.877, $p > 0.01$, 95% CI [−0.071; 0.027], R^2 = 0%), original/translated version (z = 0.434, $p > 0.01$, 95% CI [−0.035; 0.054], R^2 = 0%), and number of subscales (z = 0.419, $p > 0.01$, 95% CI [−0.058; 0.089], R^2 = 0%).

Separate analyses were conducted for each of the subscales. As presented above, school context has significant effect on the total scale ($p < 0.01$), and significant effect was also found for the subscales including teacher support ($p = 0.020$), involvement ($p < 0.001$), cooperation ($p = 0.036$), equity ($p < 0.001$), and investigation ($p = 0.006$). For the research design as the moderator, the total score of the reliability estimate showed a non-significant *p*-value ($p = 0.38$), but there was statistically significant value for the equity subscale ($p = 0.005$). Similarly, in terms of original/translated version of the questionnaire as the moderator, although there was no significant value for the total scale ($p = 0.665$), a significant effect was found for the task orientation subscale ($p = 0.030$). It can be concluded that the reliability of the total scale and subscales excluding student cohesiveness and task orientation were influenced by school context. Furthermore, the equity subscale was influenced by research design of the included studies, and the task orientation subscale was influenced by original/translated version of the questionnaire.

4. Discussion and Conclusions

We focused on the alpha coefficient, which is a commonly reported method in indicating internal consistency of an instrument and usually varies in administration of the instrument. Reliability generalization is used in our study in order to calculate the cumulative reliability estimates of the WIHIC questionnaire and identify study characteristics associated to the variability among the reliability coefficients.

Through the analysis of 24 included studies, the RG estimate of Cronbach's alpha for the WIHIC total score showed a high reliability value (0.85) even after accounting for potential publication bias. According to [41], the Cronbach's alpha value is acceptable when it is >0.70. Each subscale of WIHIC also showed high reliability value, and the minimum reliability value is also greater than 0.70 [19,32]. This suggests that the questionnaire can be used with confidence in whole or in part. However, high heterogeneity was seen in our RG analysis of the alpha coefficient, so the results must be interpreted with caution.

Among the demographic factors of the studies, school context (primary, secondary, and mixed) has significant effect on the total scale and subscales including teacher support, involvement, investigation, cooperation, and equity. In our study, we limited the school context into school level, as most WIHIC studies were conducted at university level, as can be seen in the literature [8–10]. Further research should be undertaken to include the university level in investigating the RG analysis of WIHIC inventory. In addition, among the subscales, research design (qualitative, quantitative, and mixed method) has significant effect on the equity subscale, and original/translated version of the questionnaire has significant effect on the task orientation.

This paper has its limitations, like most research. Unpublished literature and articles published in non-English were excluded. Further studies should extend the data sources to verify the claims that have been presented. In addition, most papers did not report the Cronbach's alpha value, and some provided only limited information. The reliability estimates of WIHIC questionnaire should be provided whenever the questionnaire is used. In general, the RG analysis of pooling reliability estimates helps in understanding the psychometric properties of the WIHIC inventory in diverse populations. The analysis also helps in understanding the source of variation across studies.

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education sciences

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Review

How Constructivist Environment Changes Perception of Learning: Physics Is Fun

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Abstract: The global availability of information makes its selection difficult, but at the same time it allows for the construction of teaching without the particular prior knowledge of students. However, it requires teachers to learn new abilities, such as developing a much broader coverage of the subject, explanations of illy solutions, and knowledge of different ways of thinking and the mental needs of pupils (pedagogical knowledge contents). We show examples of such teaching in physics in several quite different environments: from school classes to workshops for 3–4-year-old children, interactive lectures for children's universities, ad hoc explanations in science museums for secondary school students, to public lectures in didactics at international congresses. Every specific environment requires different approaches, but the contents may remain similar: innovative, constructivist, and interactive approaches assure a successful outcome in any didactical situation.

Keywords: learning environments; learning sciences; teacher education; constructivist approach; cognitivism

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1. Introduction

Motivation: "Physics Was Not My Favorite Subject"

In spite of technological progress, contemporary schools face new, demanding requirements; this is not the transmission of knowledge, but rather the forming of complex competencies. They include, first of all, reasoning and the ability to select and evaluate the available information, but also meta-competences, as capacities of organising collaborations, presenting one's own knowledge, etc., i.e., both social and personal competences. This has been precisely worded by Sheer et al. [1]:

> The mandate of schools is to unfold the personality of every student and to build a strong character with a sense of responsibility for democracy and community. This implies developing skills of reflection, interpretation of different information and other complex meta-competences.

Physics played a crucial role in the formation of both ancient and modern science. Four "elements" specified by Empedocles (and recalled by Aristotle in Metaphysics 988a, 26) are still taught as such in today's schools. The nature of time and space, being the main contents of Aristotle's Physics, is still the point of departure for popular science bestsellers, such as The order of time by Carlo Rovelli [2] (and similar books by Roger Penrose and Stephen Hawking [3], Chris Ransford [4], etc.). Galileo, in his discussion on accelerated motion (Dialogo dei Massimi Sistemi [5]) put forward the basis for what we call modern science: a repeatable experiment and its mathematical description (see the English Wikipedia for adjectives assigned to Galileo as a founder of modern science). Newton not only formulated mathematical laws of nature but, as stated by Robert Crease, made the world rational:

> The arrival of the Newtonian universe, was attractive, liberating and even comforting to many of those in the 17th and 18th centuries; it promised that the world

> was not the chaotic, confusing and threatening place it seemed to be—ruled by occult powers and full of enigmatic events—but was simple, elegant and intelligible. Newton's work helped human beings to understand in a new way the basic issues that human beings seek: what they could know, how they should act and what they might hope for. [6]

This cultural change was much more important than what we teach traditionally about Newton in school. Not in regard to the impact of modern physics, the "principle of relativity" and "uncertainty" (indeterminazione in Italian) became an integral part of contemporary philosophy. Despite its historical and cultural role (or perhaps because of it), physics in school is not an easy subject, and its traditional teaching does not seem to fit the postulates of Sheer et al. [1]. A common opinion is "physics was not my favorite subject at school". This subjective statement is supported by educational studies. Osborne [7], in England, showed, in a sample of approximately 3.5 thousand students attending middle schools, that as far as their interest in geography, biology, and English remained high (it changed from "like very much" to "like much") between the third and fifth form, it dropped drastically (from "like" to "dislike") in physics. A bigger drop (from "like much" to "dislike") was reported only for chemistry (and for French, it changed between "dislike much" and "dislike"); see Figure 3 in [7]. A study by the European Union (so-called the Rocard Report [8]) warned of the drastic fall (by 50% between 1995 and 2005) of the number of university graduates in the subjects of physics and engineering in France, Germany, and the Netherlands. A slighter fall was seen in the USA, and none was detected in the Republic of Korea.

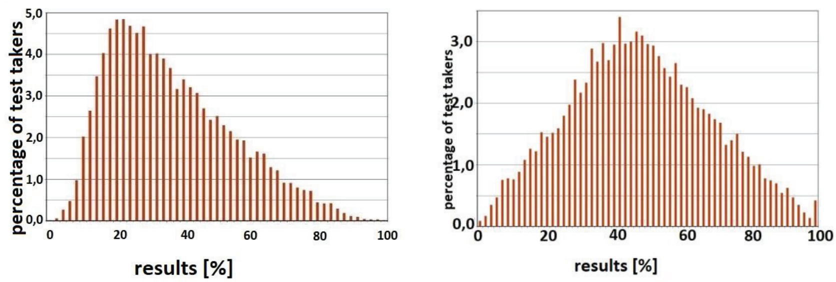
In Poland, physics is an obligatory subject in elementary and secondary school. In the recent (published in January 2023) study of the Polish Physical Society [9], performed on a sample of 350 scientists and teachers, 73% of the responders postulated changes in teaching physics to make it attractive at university level. A similar percentage confirms a negative image of physics in society. In the same study, as many as 82% of the responders indicated the capacity of analysing facts and drawing conclusions as the main feature of physicists.

The teaching of physics in Poland suffered from the recent (started in 2015 and fully operative only in 2021) reform of the national system. The system had been already changed in 1999, with the perspective of entering Poland into the EU, and resembled mixed Italian/French solutions: 5 years of elementary school (starting at the age of 7), 3 years of middle school (junior high school), and 3 years of Lyceum (senior high school, or vocational school). Physics was taught for three years in middle school and two years in Lyceum. However, the "Law on School Education" act of 2016 re-introduced the system which was in place before the EU adhesion, i.e., 8 years of elementary plus 4 years of Lyceum.

The main shock for teaching physics came from the lack of teachers at the elementary level: textbooks were prepared in a rush without didactical testing and in many schools, teachers of mathematics were swapped over to teaching physics. So far, this recent "reform" still lacks a quantitative evaluation: Figure 1 shows the latest published (2014) national score in the mature exam (the UK A-level equivalent) in physics.

As seen in Figure 1, the results were pitiful in the group that chose physics as an additional (i.e., not main) subject; the distribution of votes is Poisson's-like, meaning a good score (and even the sufficiency) was "a rare event". Teaching physics in Poland is efficient only for a small group of students who are particularly interested in this subject, so they choose an extended form of the exam (Figure 1b). This contrasts with the presumed role of physics as forma mentis, i.e., with its cultural influence in society. Actions must be taken, not to train scientific experts, but to increase the positive image of physics in general.

The reasons for the low "popularity "of physics as a school subject are three-fold. The first is the very structure of physics as a science, which requires necessarily both the theory and the experiment. This is not the case, say, for philosophy or biology: the former rarely appeals to experiments and in the latter, the role of theories (such as "conservation laws") is not as dominant as it is in physics. The second reason is the didactics of physics: teaching requires both humanistic (verbal communication) as well as mathematical capacities. The problems in physics start from a (verbal) description of the situation, possibly existing in nature, then requires a mathematical formulation, solving the equations, accepting results that are feasible, and, again, the verbal formulation of the answer. The third most important reason for the poor performance of students in physics (particularly in Poland, as we have witnessed) is the traditional, transmission-like way of teaching, with few experiments, almost no multimedia, and lacking any interdisciplinary connections [11,12].



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

Figure 1. Matura exams in Poland in Physics in 2014. (**a**) Standard level—the results resemble Poisson's distribution: high scores are rare events. The dominant statistic is at 21% of the possible score; (**b**) Augmented level: the results are distributed into a Gaussian, but the majority still stays below the sufficiency level. The substantial difference between the two distributions indicates that the requirements for the maturity exam were incoherent with the notions and competences transmitted in schools. Source: Report of Polish Ministry of Education [10], reprinted with permission.

The difficulties in teaching physics were detected around half a century ago, so physicists, teachers, and scientists undertook a whole range of actions to make their subject more attractive. Already in the 1960s, the first institutions for science divulgation, such as the Exploratorium in San Francisco, were founded [13,14]. These centres gather huge numbers of visitors (such as the "Kopernik Science Centre", which opened in Warsaw in 2010 and was visited by 1 million people in the first year of activity), and physics is the main leading thread there [14]. However, in spite of that, school groups are the main target; the impact on the ways of teaching (and learning) physics is still, in Poland, marginal. Teachers are not prepared to deliver lessons inside the centres, and the staff employed there have no specific competence in didactics.

The second strategy to attempt to make the didactics of physics easier would be new and affordable approaches to teaching. We mention here the master Feynman's Lectures in Physics, the Conceptual Physics by Paul Hewitt with its thirteen editions (also in Poland, under the name "Physics around us"), or the recent series by Leonard Susskind and Art Friedman, for example, their Quantum Physics, published in Italy with the subtitle "The necessary minimum to practice (good) physics" [15]. The common denominator of these books is the step-by-step illustrative and narrative didactics. However, the target group of these books remains, essentially, university students.

The third "line of attack/defence" by physicists are books for the general public that explain big philosophical questions. Apart from the already mentioned writers, we add such authors as Piergiorgio Odifreddi (mathematician) and Antonino Zichichi (experimental nuclear physicist at CERN) [16] in Italy, John Barrow (professor in mathematical physics) and John Tipler (experimental physicist) [17] in the UK, Michał Heller (priest and professor of cosmology) in Poland [18], and many others. Their books have gained popularity thanks to their interdisciplinary (and philosophical) approach.

As an expression of efforts to revitalise the teaching of physics, a global-range network, Groupe International de Recherche sur l'Enseignement de la Physique (GIREP), has been created; its congresses gather hundreds of specialists in didactics each year. GIREP is an important forum for the exchange of innovative ideas. However, the path from the didactical idea to its successful implementation is not straightforward in practice: high-level scientific concepts of modern physics rarely find a way to enter the school curricula; see, for ex., refs. [19–21].

In the present paper, we review a series of actions undertaken by us over approximately twenty years in order to increase the attractiveness of physics as a school subject (and, in consequence, also the number of university students in this discipline). The research question is: can we translate high-level principles of physics, as (i) an interdisciplinary science, (ii) based on experiments, but (iii) working on abstract concepts, to the cognitive level of children and teenagers? Which forms and contents should be developed to retain the durable interest of the audience/school class/general public? Is this interest profitable in terms of the knowledge of physics, apart from a mere phenomenology? We experimented in many ways, and the answer is complex, but in general, it is "yes!".

2. Need for New Approaches

Transferring knowledge in an encyclopaedic way can result in oblivion. The rapidly progressing developments of civilisational require a new approach to teaching to be developed. From observing pupils in school, we realise that memorising rules or definitions is pointless nowadays. Increasing the student's motivation for further work can only be done by asking questions and independently constructing knowledge based on their own experiences, which in turn will lead to understanding the discussed phenomena or physical concepts.

The overarching goal in the teaching process should be to equip students with skills that will allow them to apply their acquired knowledge in new situations in a rapidly developing world. Deepening curiosity for discovering and understanding the surrounding world and developing a willingness to use skills for human needs should take place through interdisciplinary teaching. Depicting physics as a field of science which is inseparable from other subjects will lead to a better understanding of the nature which surrounds us and, consequently, to the more effective use of acquired knowledge in everyday life. Physics is particularly suitable for searching scientific laws in objects that surround us; for example, see our virtual and real exhibitions under the nickname "Physics and Toys" [22]. On average, these pages attract a thousand visitors a day.

Students who can independently construct knowledge during lessons learn faster and are more involved in the teaching–learning process because they ask themselves more questions and pose possible hypotheses. The introduction of changes in the teaching process is inevitable and should be supported by the knowledge and application of the latest trends in pedagogy and general psychology, and, above all, by understanding the teaching and learning processes in the cognitive–constructivist approach.

There are many noteworthy publications on the methodology of teaching physics, but the observation of the present study shows that, quite often, teachers treat the education process as strict in guiding the child's development, replacing the process of the self-learning of the pupil with a mere transmission of notions, which in turn leads to the acquisition of a collection of information, instead of creating conditions for the child to construct their knowledge and use their own life experiences. A manifestation of development is a method for the child's improved functioning in the world, coping with its complexity thanks to their acquired skills and adopted attitudes towards the immediate environment [23].

There is a general agreement that the didactical process should undergo substantial changes. The old, traditional teaching model should be abandoned in favour of a constructivist model, with a variety of methods, means, and approaches. "Students like 'hands-on', 'inquiry-based' learning, laboratory experiments, and learning environments that encouraged independent thinking"; see [24] and the references therein.

2.1. Hyper-Constructivism

The term "constructivism" was developed in the 1930s from Jean Piaget's observation of how newly born children, day by day, construct their image of the world. Piaget assumes that Man constantly constructs his knowledge, as result of new experiences, in accordance with the principles of assimilation and accommodation. According to Piaget, children construct their knowledge about the world on their own, as they become integrated into the environment, and their cognitive schemas are their independent constructions resulting from constant exploration. In order to know objects, the subject must have active contact with them.

Piaget's theory was not only ground-breaking for thinking about cognitive and social development, but it also provided inspiration for the theory and practice of education, especially those directions in which the importance of constructing knowledge is emphasised. The foundation of teaching, he believed, was a discovery:

> To understand is to discover, or reconstruct by rediscovery, and such conditions must be complied with if in the future individuals are to be formed who are capable of production and creativity and not simply repetition. [25]

Jerome Bruner, the creator of the theory of mental development, who strongly emphasised the role of social interactions, can be considered a continuator of Piaget's research. Author of original didactic concepts, he paid particular attention to the role and conditions of stimulating the cognitive activity of children and youths and the development of positive motivation. In the 1950s, the term "cognitive science" appeared. Jerome Bruner, with the advent of early computers, joined psychology, cybernetics, and linguistics into a unique science, exploring the view of the external world in the human mind [26].

Lee Shulman is to be considered the third founder of innovative didactics. He introduced the concept of pedagogical content knowledge (PCK) [27], stressing that the range of abilities and competencies of the teacher must go far beyond the mere competencies of the subject he/she teaches. Teachers' masteries must include the psychology, pedagogy, and history of his/her matter.

We add to these competencies a principle called "9:1": the teacher must know not only a single, correct answer, but also nine possible wrong answers and, moreover, must know why the pupil provides a particular illy answer [28]. In other words, the teacher must be able to "dig up" the pupil's way of thinking, in his/her previous knowledge, in the (junk) external information, i.e., the reasons for the didactical failure.

Wide applications of constructivism, cognitivism, and PCK to teaching science dates to the beginning of the XXI century. However, it was only a moderate success; no educational revolution happened. One of the reasons is that the new didactics require much more advanced skills of teachers. He/she must be able to correctly guide the ways of thinking of pupils, ensuring their knowledge is not too tight and not too loose. John Nesbit and Liu Quing stated [29]:

> The effectiveness of inquiry-based learning depends on the guidance provided by teachers. An unguided or minimally guided inquiry may not work for students who have less previous knowledge or ability in the subject area. When the demands of the learning activities exceed students' abilities, their learning is blocked and they may develop misunderstandings about the topic.

Further, the teacher must also accept losing the role of a "guru", i.e., of the expert who never fails. Obviously, in an authoritarian school system, it would erode the position of the teacher. Even in the UK, Paul Newton et al. described it as follows [30]:

> We do have average and below average teachers who actually don' t have the skills to run discussion groups. I think that it is quite a high level skill for teachers. [. . .] Teachers need to be confident enough to accept that they may not know the answers, this may [. . .] discourage some teachers from allowing the situation to occur in the first place.

The eroding of the authority of the teacher may be avoided if we change the approach from ex-cathedral teaching to a constructivist-like dialogue. Then, the teacher needs not show his/her intellectual supremacy but instead become a partner in the common search for the scientific truth. As far as teachers, say, in Poland, declare the will to use the constructivist approach, they miss practical examples. Keith Taber, resuming the current situation with the implementation of new didactics, postulates “re-energising constructivist work by suggesting new perspectives and approaches” [31].

We propose, first of all as a practical application, in different environments, a new approach that combines the three fundaments: constructivism, cognitivism, and PCK. The name we use for this new methodology [28,32–34] is “hyper-constructivism” (H-C). Briefly, it consists of a guided, collective discovery of the law/phenomena/facts, with the aim to form the correct understanding in the mind of every single student. Out of nine science-specific pedagogical content approaches in teaching sciences, which include, among others, a flat transmission of notions, academically rigorous teaching, developing skills, activity-driven orientation, discovery orientation, etc. [35], our methodology is closest to a guided inquiry that “constitutes a community of learners”.

The starting point in our methodology is critical thinking, i.e., Cartesian’s basis to modern scientific methodology, used also by the OECD (Organisation for Economic Co-operation and Development) in the AHELO (Assessment of Learning Outcomes in Higher Education) evaluation of university systems [36]. So, the unit of teaching (a lesson, a workshop, or an interactive lecture in a great hall) starts by triggering critical thinking. This is independently if we speak to 3–4-year-old children or adult teachers, as noticed by Knigth et al. [37], who found that even in early childhood, collaborative thinking is the key to critical thinking. So, we invite an open discussion, addressing the whole audience: “Why do objects fall?”, at the beginning of our lesson on mechanics. It is not important who the audience is. With small children, such a lesson would finish with free playtime with wooden toys (which are easy to bring within carry-on luggage); for selected, advanced students in Korea, the lesson ends with the General Relativity Theory of Einstein (see further in this paper).

Constructivism for us is a practical teaching methodology, not a theory. However, we go beyond Piaget’s idea of the individual construction of knowledge and beyond an alternative understanding of this term, as a social process of “negotiating” knowledge [38]. Further, students become the main actors in the process of active discovery [39]. Keeping in mind all these constraints, we practice (and theorise [32–34]) a blended approach, in which the knowledge of students is formed in an interactive process, within the vivid interaction with the group (a school class, audience at public lectures, children at workshops, etc.), but the teacher precisely monitors the cognitive ideas which appear during the lesson/lecture in the minds of the participants. For this reason, we apply the term “hyper-constructivism”.

Nowadays, the baggage of notions in the possession of even small children is so vast, we simply must choose the best information, fitting our didactical goal, rather than assisting in the Socrates-like “midwifery” way. Using publicly available sources of knowledge, e.g., on the Internet, we can use these in the joint creation of knowledge in any subject, at any level or in any environment. This (collective) knowledge is the basis of interactive narration in the H-C method. Here, the role of the teacher is extremely important as a wise cicerone, knowing in advance which of the (hidden for pupils) paths leads to erroneous arrival points. The teacher, allowing an open discussion, thanks to his PCK skills, leads (in a delicate way) the thinking of the students, to make them follow (one of the possible) correct paths, and to provide them with the opportunity to perform their own, individual (and almost autonomous) learning.

In the H-C method, the knowledge becomes constructed in a spontaneous way. The teacher is responsible for setting the right path for the students to follow. The teacher is to some extent just an observer, a coordinator, and offers help if the students need it. Constructing knowledge can be based on the collection of information that students possess, and, if needed, referring to their own sources (textbooks, other printed materials, or the Internet).

The teacher's role is no longer to organise and systematise knowledge but to conduct analytical group reasoning. The point is to choose the one that is the most convincing, logically and scientifically correct from all available cognitive paths leading to the set goal.

The hyper-constructivist lesson is necessarily based on the interaction within the class. No experiment will be shown until the class expresses their opinion on its outcome. It does not matter much whether the answer is right or wrong; we need a working hypothesis to start the process of step-by-step deducing and verifying. As noticed in the case of demonstrations during university lectures in physics [40], if no prediction of the outcome of the experiment had been asked, the level of correct responses is low (0.58), and it increases to 0.8–0.85 if the students made some predictions (even if they were wrong).

Our approach, which appeals to the pre-existing knowledge of the audience, is, by force, interdisciplinary. We search in the minds of pupils for any relation/remembrance/connection to phenomena which could be useful in constructing knowledge, and this is the goal of the lesson. This process stimulates a brainstorm in the group, which is an important methodological competence on one hand, and on the other hand, rectifies the knowledge of pupils. Again, it is not important if the construction takes place in an elementary school or with an audience of university students. Moreover, the younger the pupils are, the more "strange" the ideas that they have are and the more flexible they are in an open discussion. The goal is to "clarify concepts and enable to link scientific ideas with other ideas" [41].

The next essential point in hyper-constructivist teaching is the need for a step-by-step consensus. As we apply group reasoning, every member of the group must be (pretty) convinced that he/she con-divides the outcome for the reasoning; otherwise, she/he would be alienated from the next steps. Newton et al. [30] summarised it as follows:

> It is not enough for students just to hear explanations from experts (e.g., teachers, books, films, computers); they also need to practice using the ideas for themselves. 'The' answers to 'the' questions need to become 'their' answers to 'their' questions.

2.2. Neo-Realism: Objects and Multimedia

The hyper-constructivist method, as previously mentioned, is based on the knowledge already possessed by students/pupils. However, what happens if this knowledge is insufficient? With the Internet, Google, Wikipedia, and YouTube we have "at hand" an infinity of educational resources. Their advantage is the immediate availability of resources; however, all of them belong to the "virtual" world, which in the language of physics, means possibly, but not necessarily, observable.

Therefore, we prefer real teaching, which aids both the experimental stands prepared in advance and ad hoc objects, such as balls taken from the pocket or cables of the computer used to draw an ellipsis on the blackboard or to show a reflection of a wave travelling in one dimension.

Taking into account the virtualisation of life (especially after the period of distance learning), it is important in creating knowledge and building correct interpersonal relationships to "touch" real exhibits. Real objects provide students with a full sensorial experience—with their weight, colour, and sound—when splashing. Real experiments yield not only expected experience but also a myriad of "failed" results. All these unsuccessful results become an opportunity to explain that in the real world (physical, chemical), many factors, not only those predicted, affect the result of the experiment. Additionally, according to the already cited "1:9" didactical principle, combined with Paul Newton's et al. [30] allowance for the teacher's fallibility, the real experience induces authentic educational joy [42].

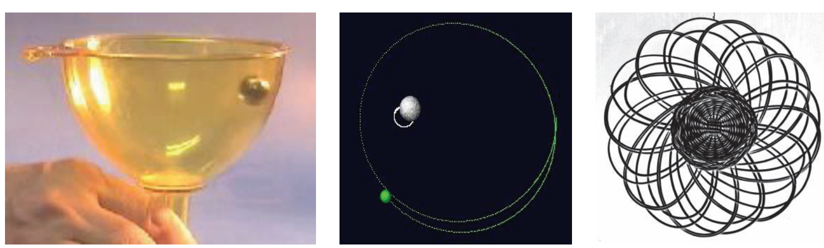
Objects that can be found in everyday situations, table-top Newton's cradle, plasma lamps, and balancing toys (see our virtual collection [22]), are particularly attractive for students. They can be also easily adopted by teachers. A statement by pupils "I have already seen it" is the confirmation that the constructivist path can be applied. This holds for all sciences; appeal to the "palpable" knowledge of students as a starting point and discuss their concepts about the subject. In teaching biology, Rebecca Garcia et al. [43] explained it as follows:

> We anticipated that this prior exposure would motivate students to apply existing information and expand on their perceived knowledge. In addition, we sought to dispel existing misconceptions through class discussion and evaluation of previously held concepts. [. . .] Students are more receptive to learning science when they can directly relate the material to real-life situations and events.

Following this lead, our first recommendation is to base the didactics on real objects. As this happens in a time dominated by the virtual world, we call this approach neo-realism (N-R). The objects used in the lesson are familiar to students; usually, they are simple, small objects that do not distract them from the discussed laws and physical phenomena. For example, two similar-in-size balls, but of different masses (caoutchouc and ping-pong, or just two different nuts) are dropped from the same height, and they fall at (almost, but with the difference invisible) the same time. In this way, it is possible to show the independence of the gravitational acceleration from the mass, or to explain the exchange of energy between two falling balls as a result of a collision (see our multimedia clips [44]).

Then, in the constructivist scenario, we complicate the experiment. We divide a piece of paper into two identical halves and we make one of them fall as a crumpled ball and another as a kind of parachute; here we show how air resistance affects the fall of bodies. The lesson is completed either by an experiment with a coin and a feather falling in a glass tube without air inside and/or when do not have the vacuum pump, by the clip of Galileo's experiment performed by Apollo 15 astronauts on the Moon [45]. The didactical potential of everyday objects can be a starting point and encourage teachers to create their own scenarios.

Another example of N-R is a gravity funnel illustrating Kepler's three laws [22], and a kitchen funnel that illustrates deviations from these laws, in particular due to the General Relativity, see Figure 2.The conceptual analogies used in teaching, correlated with everyday objects, stimulate the imagination and cause the formation of new associations, thanks to which they are more easily absorbed by the listeners.



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

Figure 2. Neo-realism—any object is useful in explaining physics: (**a**) kitchen funnel as an illustration of general relativity; (**b**) open orbits for non-Newtonian potential, a simple computer simulation; (**c**) ethnographic artefact in wicker showing an open orbit of Mercury (collection GK). Reprinted from ref. [14] with permission, author GK.

Real objects can also prove themselves useful in the explanation of modern physics. Physical modelling can be used to explain guesswork in modern physics, e.g., Planck's blackbody modelling with a box with a small hole, mirror lasers with translucent sunglasses, and mass spectrometers with shaking containers of different-sized balls. Each model can be extended with more advanced experiments (measurement or computer-aided). The above examples of using simple, intangible objects are the idea of neo-realism. Their main goal is to illustrate often complex and abstract physical laws in the simplest possible way.

Together with objects, computer models, photos, descriptions, and video clips, it makes up the pedagogical idea of neorealism: everything that a student can touch or see should be touched, and even if objects are scientifically impossible to visualise, such as quarks or electrons, they should also be able to touch them (Figure 3). Unfortunately, practice often shows that teachers only occasionally use the benefits of the surrounding objects, what may be due to their insufficient didactic preparation and/or lack of imagination.

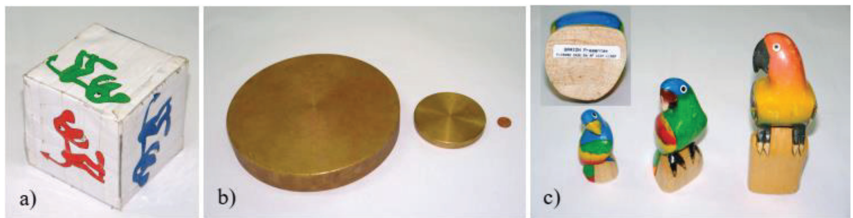


Figure 3. Neo-realism extrapolated beyond the limits of imagination. Typically, atoms, electrons, and neutrons are shown as small points, but similarly to Earth seen from space, also neutron (**a**), made of two quarks down and one up has its own structure; (**b**) assuming 1 euro-cent (Greek: lepton) as an electron, the mu and tau-leptons scale as bigger copper disks; (**c**) alternatively, we can imagine a neutron, proton, and the heavier hyperon lambda as three-colour parrots (collection GK, acquired in "Baryon" shop at San Paolo airport, 2005). Photos reproduced from ref. [14] with permission, (C) GK.

The use of experiments, obviously, is not new in teaching physics; it is the basis of many methodologies as stand-alone laboratories or as a part of the lesson in a class. For an example, see [46,47]. Additionally, demonstrations in the lecture hall have been proven to be a significant factor in triggering an interest in physics [48]. However, our experiments form a didactical sequence. It is often in our approach that such a sequence should reproduce the historical development of a physical concept. Let us say, the lesson on gravity starts from Aristotle's "teleological" statement, then we pass to the experiment, which is first qualitative, repeatable, but also abstracted from details ("close your eyes and listen to the ball bouncing, please!"), then to the measurement ("look and check, please"), then to the confuting of the simplified results ("now the two balls will fall from much higher altitude"), leaving the listener with heuristic anxiety. From Newton, we take the clear condemnation of any "spirituality": "There are some people who say that the objects may be moved just by thinking. They call it telekinesis. Let us try if it is real!". Further, following the warning of the Polish pedagogue, Kazimierz Sośnicki that too much exemplification leads to childness, we never repeat experiments unless with a clear scope to show additional didactical aspects.

In our practical applications, the two approaches, H-C and N-R, serve to obtain a cognitive goal that is not a mere knowledge of the notions of physics, but rather acquiring the ability to think. Students/pupils/teachers are invited to follow a line of reasoning, where at the beginning we do not reveal a clear point of arrival, such as "the law of gravity". Therefore, we use a variety of ways, not disregarding any a priori. So, using falling balls, we start from Aristotle's (wrong) statements, to make pupils arrive step-by-step but autonomously to the correct formulations. Further, we concentrate more on the complexity of phenomena, forming lessons on "the electricity sources" rather than on traditional subjects, such as electrostatics or electromagnetic induction. In this way, we avoid oversimplifications when students are not able to understand "a real nature"; they do not need this to remain fascinated by physics. In the following, we review some of our activities.

3. Teaching Environments

Taking our two general didactical principles, hyper-constructivism and neo-realism, we applied them in different environments, from primary school to university lessons, for active teachers.

3.1. Primary School: States of Matter and Electricity

We (KW) practiced H-C teaching first in primary school, within the official, national curriculum in the first grade (8 years old) by conducting lessons about electricity. However, we resigned from the typical organisation of the class, instead running a kind of workshop, in which children may touch (only if they are safe) all objects (Figure 4). The experiments for these lessons included everyday objects, such as plastic tubes, pieces of metals, lamps, batteries, etc.

(**a**)

(**b**)

Figure 4. An interactive lesson with students aged 8. (**a**) Teaching aids (traditional, interactive, multimedia) have been selected in such a way as to be able to refer to the knowledge that students at this age already have and those that helped to deepen this knowledge. We used batteries, fruits, a solar panel, a dynamo, balloons, straws, and many more; (**b**) working with solar cells in small toys. We show that a traditional lamp (i.e., producing also infrared radiation, and, therefore, resembling the solar spectrum) is more efficient than the "new", i.e., LED and fluorescent lamps with similar luminosity. Teacher: KW, (C) for photos: KW.

The lesson was easy and amusing, stimulated by ordinary objects that the pupils knew from everyday life. Together with the teacher, they were searching for answers to simple questions: "Can you comb your hair with a plastic ruler? What is it like? What would happen if . . . ? Can you separate pepper from salt?" (Cinderella's story). Properly thought-out experiments allow children to become acquainted with the research method from the early years of their education; it also plants a seed which can be used in later life.

It is clearly visible that teaching in the constructivist approach exposes itself primarily in the active attitude of the student, which is stimulated by the teacher using the appropriate aids. Then, the student is an independent and active subject who constructs his knowledge system, analyses, tracks his successes and failures, and draws conclusions from them. The teacher's role is mainly to create a situation of cooperation, stimulate the use of students' experiences, and facilitate the creation of new knowledge by asking questions. Therefore, language and vivid narration play an important role at the very beginning of learning.

Carefully planned experiments allow for conducting a lesson (Figure 4) on electricity (difficult in terms of didactics for the age of 8 yrs.) in a way that enables one to achieve the assumed didactic goal. Students are active participants in the lesson at each stage. They observe, experience, ask questions, and provide answers. Brainstorming between students leads to surprising results; the role of the teacher is merely to select correct conclusions, in accordance with the H-C didactical principles.

The achievements of the cognitive–constructivist theory point to the teaching methods that increase effectiveness. According to this approach, teaching is effective when the student's activity is stimulated; he/she uses previously acquired knowledge, anticipates, draws conclusions, and independently formulates solutions. These activities take place when the student is the constructor of his knowledge in the mind. The pupils asked other teachers in the school: "When will we have lesson with Mrs. Kasia?", and this is the best evaluation that the pupils enjoyed our didactical approach.

The lesson on the states of matter was scheduled for the 5th form. At the beginning (Figure 5a), the pupils attempted to recognise presented liquids based on smell, colour, and viscosity. Then, they made a drawing (first attempt at making a hypothesis) of the supposed order the liquids would be arranged in when poured consecutively. Afterwards, they proceeded to the experiment. Students were invited to the teacher's table to pour the liquids. Next, they verify their hypothesis by comparing the result of the experiment with the previously made drawing. They experienced a huge surprise when the oil was a layer above the water. The outcome of the experiment (the oil layer on the top) came as a completely unpredicted solution.

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

Figure 5. Fun with density: a group of 8-year-old pupils playing with Archimedes' law, making different fruits float in freshwater (**a**), then they check (**b**) that the buoyancy force depends on the density of the liquid (salty water, honey). Photo (C) KW.

Older students (Figure 5b) prepared four beakers with the same amount of water but with different amounts of sugar. The water had been coloured with water pigments (or, even better, with pigments that in some countries, such as Poland and Germany, are used for preparing Easter eggs). Then, they slowly poured it into the test tube, starting with the water with the most sugar. The students very quickly drew conclusions about what influences such an arrangement of layers. The more sugar there is, the higher the density will be. They found out why maple syrup is so thick. The aim of this sequence was to show that the division into (three) states of matter is somewhat artificial; the atomic structure is the key concept.

The main assumption of the lesson was to arouse the children's curiosity, which will strengthen their desire to explore the world of science and discover their own passions. The use of materials that children can find at home (different fruits, syrup, and colourants for Easter eggs) makes them "ambassadors" of further teaching at home.

3.2. Physics as a Playground

In elementary school, pupils already possess some cognitive tools to construct, with the help of the teacher, the correct notions: they read, they use smartphones, and they watch educational TV channels. A real challenge is to use the H-C methodology at the pre-school age, showing that the phenomena which children already observed follows some rules (that in further education, we will call the "laws of physics"). According to

Trumper [49], "a constructivist approach seen as a process in which pupils are actively involved in constructing the scientific concept should be presented as early as possible".

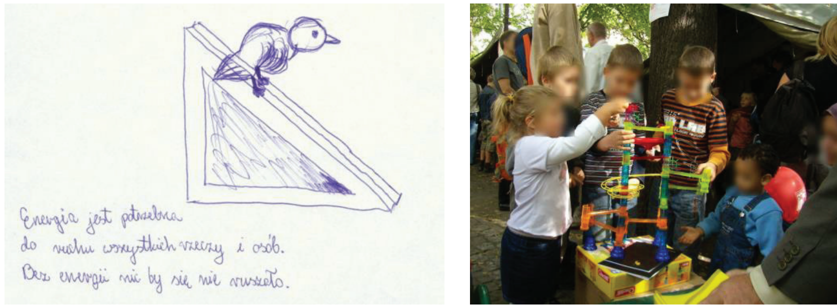
The same subject of electricity, that in elementary school we present with the commercial set of experiments (Volta's electrophorus, the electroscope, Wimshurst's electrostatic machine), see Figure 4, can be taught almost with "nothing", even merely a plastic tube and a piece of cloth (Figure 6a). Moreover, the same effect of rising hair can be detected due to the electrostatic charges one observes after sliding whilst wearing synthetic-fibre trousers on a long plastic slope (Figure 6b). What the (hyper-constructivist) teacher must do is spot the didactically interesting situation in the surrounding environment.

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

Figure 6. Showing electrostatics to children. (**a**) A plastic tube electrised by rubbing with a woollen pullover generates voltage up to a few keV. It is easier to demonstrate this on a girl with thin, blond hair. Photo Maria Karwasz; (**b**) Natalia Wyborska (age 4) and her first experience with static electricity in the playground: sliding in synthetic trousers on a long plastic "castle" generates electrical potential of tens of kV. Photo KW.

For children, experiments with movement are particularly attractive, for example, those involving balls, carts, and puppets. However, the very basis of the H-C lesson is a narrative story. One of our preferred (and also preferred by the public) lessons is entitled "Why do objects fall?". The standard answer, "Because of gravity", does not reveal much information; gravity is Earth's attraction and Earth's attraction is gravity. This is a perfect tautology; it is correct, but does not provide much information. So, we propose an alternative explanation dating to Aristotle: "objects fall because they are heavy, and the natural place of heavy objects is the centre of the Earth". So, we experiment whether objects fall to the centre of the Earth by placing a jacket (to avoid jumping) on a table, then on a chair (and not any further, to avoid sliding down to a mere phenomenology).

Narrative H-C teaching needs to be taught permanently in order to retain pupils' attention. So, the next immediate question is if the ball may jump up by itself. The answer is obviously not, unless we use a half-ball which if inverted (and posed on the table), jumps up, making it appear spontaneous [22]. So, Aristotle's explanation is not exhaustive enough. The keyword here is "energy". Children understand it perfectly; see Figure 7a. This picture is made by a 12-year-old girl, but the same story allows children aged 3–4 to equally enjoy the experiments; see Figure 7b. Note that we present a different way of arriving at the concept of energy from that which is practised in the literature, even if it is in a constructivist manner; compare [49,50]. Details of our scenario are provided in refs. [32,34].



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

Figure 7. Towards the evaluation of the efficiency of H-C teaching. (**a**) Picture by a 12-year-old girl drawn six months after the interactive lesson "Why do objects fall?" The sentence says: "The energy moves all things". (Brzeg, Poland, March 2014); (**b**) pre-school children queuing to conduct experiments on balls sliding down (Warsaw, 2012). Lessons GK, photo Maria Karwasz.

3.3. Interactive Lectures for Schools

What is more demanding are lessons for the general public: it is difficult to keep attention of listeners if they have much diversified knowledge of science. We have practiced such lessons with constant success for around 15 years. In Figure 8, we present two implementations of chasing carts in two different scenarios: for a secondary school in the Republic of Korea and for elementary school children in Poland (at complementary teaching within a so-called children's university). The scenario was born from the observation by Galileo that stones of different masses fall with the same "velocity" (one should speak about the acceleration, but from the cognitive point of view, this would be an unnecessary complication). What makes the whole subject intriguing is the constructivist play; we pose the question of which cart, the heavier or lighter cart, is quicker.

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

Figure 8. Galileo's experiment: which cart, heavier or lighter, is faster on the inclined plane? (**a**) Preparing the scenario. Lesson by GK as a public lecture in Gunsan (Republic of Korea, 2016); (**b**) autonomous trials, university for kids, Gorzów, Poland 2012. Photos by Maria Karwasz.

First, a pupil with closed eyes identifies which one is heavier. Then, the audience votes, similarly to in a parliament, on the two alternative working hypotheses. Only at that point the scenario (Figure 8a), "Ann starts with the lighter cart. When it arrives at the end of the first slope, Betty launches the heavier one. If the heavier is quicker, it should reach the lighter by the end of the last slope, should not it?", "No? Probably we made an error. Let us try again!", "So, let us check the alternative hypothesis". The whole series of 2 + 1 launches lasts for little more than a minute, but it triggers such an interest that after the lesson, everybody, regardless of their age, "wants to try it on his/her own, please!"; see Figure 8b.

3.4. Working with Teachers

Surprisingly, working with teachers is not easier than working with children. Teachers are stubborn about their methodologies. The OECD TALIS study [11] showed that, in particular, Italians prefer traditional teaching (based on textbooks) to constructivist approaches. Poles, in the same ranking, are in the middle, between Iceland, Austria, and Australia on one (constructivist) side, and Bulgaria, Malaysia, and Italy on the other.

However, practising the H-C approach in Italy, we noticed that being accustomed to traditional teaching makes Italian teachers much more perceptive than their colleagues in Poland. As seen in Figure 9, they react with enthusiasm to the novel methodologies, both in the form of interactive lectures as well as free-hand workshops. Teachers are very creative, and their long-term involvement in the innovative didactics remains high, even several years after lessons, as we observed from their constant scientific activity [19,20].

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

Figure 9. Triggering heuristic interest among teachers: (**a**) "Why do objects fall?"—an interactive lecture for secondary-school teachers at the University of Macerata, Italy, 2014; (**b**) free-hand experiments with magnets for teachers at the University of Udine, Italy, 2009. Lessons GK, photo Maria Karwasz.

This interest is confirmed by continuous invitations from different didactical entities (primary and secondary schools, universities) all over Italy (Milano, Bolzano, Udine, Trento, Cagliari, Reggio Emilia, etc.). What is appreciated by teachers (in Italy, and in general in different countries, as we observed in GIREP congresses) is the interdisciplinary character of our approach: mixing portable, interactive experiments with concepts deriving from the history and philosophy of science. To quote some opinions (from the 2022/23 courses for Italian teachers), "Thank you Professore for your precious advices" (Giuseppina), "The work by the teacher is like a sculptor" (Luigina), "Thanks a thousand for the opportunity to participate" (Alice), "Thank you for having divided with us your immense culture" (Maria), and "Lessons wonderful, never boring, reach with many interesting reflections" (Francesca).

In Poland, we have developed a constant forum of contacts with teachers via a yearly organised seminar (held in December, at the name-day of Copernicus). This initiative is divided equally into current progresses in science (physics, astronomy, biology, geography) with lectures held by active scientists, and workshops run by teachers. The seminar gathers each year around 50–70 participants, many of whom are returning participants. It became, with its 15th edition in 2022, not only the channel of scientific and methodological updates for teachers and researchers, but also a forum for social engagement.

3.5. Lessons for Wide Public

A real challenge for presenting physics (but on the other hand, an opportunity) is conducting meetings with the general public that include not only pupils, students, their parents, and teachers, but also persons from local administration, authorities, and enthusiasts of science. We practice such events mainly via science festivals, which are organised by local authorities in collaboration with a school that assure logistics. The members of the public in such meetings are vast; they make up a few hundred people. It is challenging to prepare different subjects every year that are also interesting to people with various interests. Such general subjects are, for example, "An industrious PhD (she) student" (about Marie Curie), "It sounds good"—about sounds and different, strange instruments, "Far, far away", a study on the different landscapes on Earth, as well as subjects such as the practically of international scientific collaborations, and so on. These initiatives last for years, proving that the educational messages transmitted and the ways we present them receive a long-standing acceptance. Note that the best place for meeting the general public are small- and middle-sized towns that are rather peripheral from big cities.

Conducting lessons for the general public is tiring, but a fast and fluent narration interlaced properly with experiments allows also for such an environment to trigger interest, and at the end, also involve the audience; see Figure 10b. Obviously, scenarios must be within reach and must offer non-trivial experiments. The members of the public amount up to several hundreds of people at such lectures; a measure of the lectures' success is not only the attention attracted but also the (frequent) wish of teenagers to take a photo with the professor.

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

Figure 10. Lessons for wide public—Regional Science Festival in Nadroz, Poland. (**a**) A 2011 lecture with experiments on modern physics; (**b**) 2010 "It sounds good!", an interactive lecture on acoustics, sound, and music: the director of the school playing organ tubes with his students. Lecture GK, photos Maria Karwasz.

3.6. Projecting Scientific Exhibitions

Science centres date back to 1960s ("Exploratorium" in San Francisco created by Oppenheimer). In Poland, the very idea was absent until around twenty years ago. In 1998, we (GK) organised, in collaboration with Trento University (Italy), the first exhibition of small interactive objects, "Physics and Toys" [22], which was presented at the national congress of the Polish Physical Society. This boosted the demand for such an exhibition, and also for science centres.

In 2009, the "Hevelianum" (named after the XVII century astronomer) Science Centre was created in Gdańsk and, a year later, the "Kopernik" Centre was founded in Warsaw. The former encompasses around 250,000 visitors each year, and the latter about a million. These numbers are close to the population of the two cities; the visitors are mainly scholars from the centres' surroundings. Physics is the core theme of these centres. In the "Hevelianum Centre", the same elements that were interactive objects at the "Galileo inclined plane" didactical tunnel are used with different arrangements; this is an example of more fun, less direct didactics (Figure 11a).

(**a**)

(**b**)

Figure 11. (**a**) Ad hoc hyper-constructivist lesson at the Hevelianum Science Centre, Gdańsk, for the secondary (pedagogical) school from Trento, Italy: a series of interactive experiments performed with the "death-loop" (at the bottom of the photo) allows to explain the concepts of the centrifugal force, of the potential and kinetic energy, the independence of the mathematical solution from the mass of objects but dependence on their inertia moments. An object is only an "excuse" for constructivist teaching; (**b**) "Fiat Lux—playing with light", an interactive exhibition, with 20 editions all over Poland (2007–2012): colours, geometrical optics, interference, diffraction, arts, history of science, etc. Grouping of objects into "nests" and very short explanations make different subjects self-explanatory. Authors: GK and Michał Kłosiński (Museum Toruń). Photos: Maria Karwasz.

We conducted experiments in different forms of interactive exhibitions:

- On movement and energy at "Hevelianum Center" (2009), as previously mentioned;
- An interactive exhibition on physics and the history of optics "Fiat Lux—playing with light. From Vitelo to optical tomograph" with 20 editions all over Poland and 100,000 visitors (2009–2012);
- Exhibitions on sounds (at the national congress of the Polish Physical Society in 2003, and a remake in 2023), and so on.

These exhibitions are not mere accumulations of objects; there is always a (hidden, hyper-constructivist) idea behind them. For the "Going downhill" experiment, the full tittle was "Everything on the inclined plane of Galileo, in other words, how the potential energy converts to the kinetic one, and how one may have fun with it". The sequential series of inclined planes with object rolling, falling, and sliding down served to introduce step-by-step notions on kinematics and dynamics. The exhibition on optics was multi-faced; it included the topics of physics, history, and arts of optics (Vitelo, Kepler, Newton, up to impressionists and Picasso, etc.).

We monitored the reaction of the public by the "book of visitors". Generally, the notes in this book were enthusiastic: "I am in the 5th [elementary] class and I think that the exhibition is great. I liked the most that one could touch everything.", "After having visited the upper part with paintings and arts, my son was pleased but tired. When we went down the world of [optical] illusion he revived and was astonished with all these novelties." (Mother of Max 11 yrs. old.), and "I live in Ireland—here is cool!" (Olivia). The shortest comment was by made by a beggar who came upon the exhibition by accident: "Sir! How it is interesting. Eyes turning around!". In view of frequently heard opinions that physics is unattractive and difficult, this was a great success, considering also that we are not professionals of scientific exhibitions.

The point is that when the ideas behind a given exhibition are known, it is easy to construct lessons ad hoc. Say, the exhibition on optics allowed us to run narrations (illustrated by experiments) on geometrical (Newton's) optics, on the diffraction, on the emission spectra in atomic physics, and so on, depending on the inventiveness of the teacher. A "visible" outcome of ad hoc lessons at science centres, see Figure 11a, is the increased interest of students, seen not only in their reactions but also in a durable change in their attitudes towards science, seen by students of the pedagogical lyceum choosing the profession of teachers of mathematics or the carrier of the theoretical nuclear physicists at CERN. More details on our scientific exhibitions are provided in ref. [14].

3.7. Constructivistic Text-Books

The idea of presenting physics by "touchable" objects and concentrating on the main features and not on the details was applied to a series of our books, which include "*Astronomy for kids*", "*Mechanics*" [51] for the first year of lower secondary school, and "*Modern physics*" for the first year of higher secondary school. We entitle these works as "tex-books", to underline that they are not traditional textbooks, but rather "handy books" (play on words in Polish). A detailed study of the didactical efficacy was performed (by M. Sadowska and KW) for "*Mechanics*" [52]. Two schools in a middle-sized town (Kalisz) and a village (Dąbrowa Biskupia), respectively, comprised together about 200 students.

The "Toruń physics tex-book. *Mechanics*", which appeared on the market in 2010, was primarily aimed at increasing students' interest in physics and astronomy, but it also included elements of the structure of matter and chemistry (Figure 12). The book provides information "from the scratch", starting from defining systems of reference (for example, the radial system for a spider in its net) and the rules for the evaluation of approximated numbers in mathematics, physics, the economy, and pharmacy.

Figure 12. Hyper-constructivist tex-book (not "textbook") [51]: touching the dimensions of an atom, by dividing the crystal of quartz (**a**); into sand by one thousand times (**b**), and again by one thousand times ((**b**), upper right corner) into a polishing liquid. Photo (**c**): picture of silicon crystal seen by atomic force microscope, 6x6 nm^2, Omicron. Text and photo GK. Reproduced from ref. [51] with permission.

What distinguishes our tex-book from other textbooks available on the market is the way of narration. The questions asked in the text help the student to explain the laws of physics by combining common knowledge with scientific knowledge. We introduce students to the elements of mathematics that are essential in the study of physics. Authors cite the example of the European Union budget, from which the student learns for what purpose approximations should be used and learn the rules governing rounding numbers. It is also worth noting that the concepts new to the students are set in real, practical contexts. An interdisciplinary approach is used, making reference to other fields of science and everyday phenomena, to some extent, in a similar way as done by Paul Hewitt in Conceptual Physics.

When introducing new notions, we select the most important, avoiding the information which is not essential for further narration. For example, we do not start from the traditional, Empedocles-like states of matter, but we rather introduce first to the concept of atoms, see Figure 12, and only then do we distinguish solids, liquids, gases, and plasma as different organisations of atoms.

Obviously, our tex-books do not start from "null". The very basis is the excellent five-volume "*Physics for Inquiring Minds*" [53] by E.M. Rogers, dating back to 1960, that considers about physics, history, and philosophy; the narrative, illustrative, and modelled notions on kinematics were inspired by the interactive CD by the Italian nuclear physicist Ugo Amaldi [54].

We tested two subjects from "*Mechanics*" [51]: (i) energy, work, and power and (ii) kinematics and compared the results with another Polish textbook [55] of a well-established publisher, officially approved for national-wide teaching. Questions were divided into three categories: knowledge, understanding, and abilities to use in typical and problematic situations. The synthetic results are shown in Figure 13. In the experimental group, the percentage of positive results of the test was 81% (and the mean score was 2.31 out of 5.0, which was the maximum), it was only 56% (1.75) using the traditional textbook. A particularly high rise in efficiency was obtained in the knowledge and use of knowledge in problematic situations (an almost 50% rise in positive answers). An even better result, almost 100% positive answers (and a mean score of 3.54) were obtained for the subject of kinematics (the mean score in the control group was 2.43); Figure 13b.

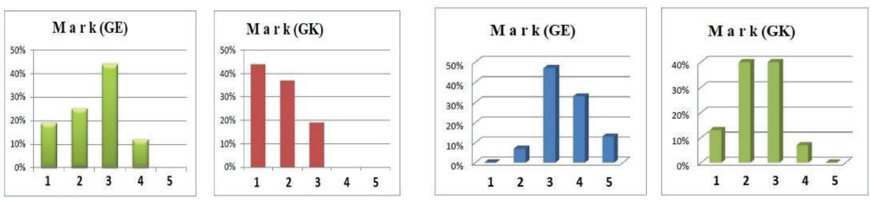


Figure 13. Comparison of experimental (GE) group using "Toruń tex-book" with a control group (GK) using a traditional textbook: the scores in GE groups are significantly higher than in GK, and with much uniform distribution. Left panel—test on energy; right panel—kinematics [52].

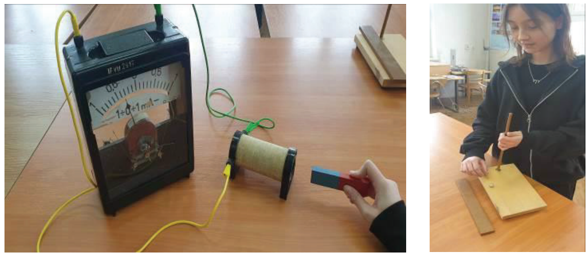
The most significant effects on the learning outcomes between our textbook and the standard one were noted in problematic situations, where the results in understanding and applying knowledge were included. While the experimental group of the program had an average score of 57%, the control group obtained 39%.

In the subject of energy, our tex-book assured a better understanding of the very concept, apart from a classification of the types of energy (kinematic, potential, etc.), as there is in traditional teaching. Faced with the alternative between the H-C tex-book and the traditional one, 94% of the students preferred the former for work within school (and 72% for homework). The tex-book is useful for reaffirming students' understanding (83%), repeating notions before an exam (94%), obtaining interesting information (94%), and learning numerical exercises (89%).

4. Discussion

The H-C method develops scientific thinking based on asking questions, planning the research process, and drawing conclusions from the conducted experiments. The goal is the learning process itself rather than the final concept; in the lesson on falling objects, we arrive at the concept of "energy" rather than the statement that "objects fall due to gravity". This is the first difficulty in the quantitative comparison of H-C with traditional teaching.

What differentiates our scenarios from simple "hands-on experiments" or the SPEE (situation–prevision–experiment–explanation) is the grade of interactivity and students' creativity. Depending on the teaching environment, for the same subject, we can dose differently the surprise, the unknown, the predictable, etc. In the typical SPEE situation, say on electromagnetic induction, see Figure 14a, one presents an experimental set-up: a coil, a magnet, a current meter, and wires. It is clear that wires should connect the coil with the meter, and that the magnet should be inserted into the coil; there is little to be invented. Therefore, traditional textbooks concentrate on the very formal question: "Which is the direction of the electric current induced?". This requires very little imagination or real discovery, making physics boring.



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

Figure 14. Traditional and H-C experiments on electromagnetic induction. (**a**) Introducing a magnet into a coil creates an electric current; (**b**) magnets, in general, interact with external magnetic fields (similarly to Earth's field, when rolling down on a wooden plate) and with electric currents (for example, induced in a copper bar when sliding on it). Photo KW, featuring Ewa Wyborska.

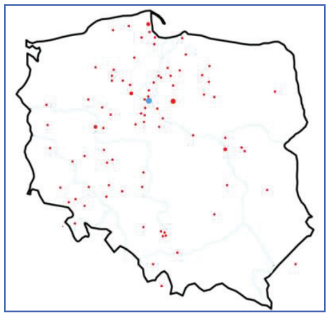
Instead, in the subject of electromagnetic induction, one can propose a whole series of simple experiments of magnets falling inside copper tubes or sliding (with a constant velocity) on a thick copper bar; see Figure 14b. Recently, we have applied such setups to modernise the rather traditional teaching for students in engineering at Kazakh National University. Simple experiments, such as that depicted in Figure 14b, were augmented with virtual means, i.e., internet descriptions and video clips. Additionally, in that environment, we observed a significant rise in interest and of the didactical outcome: all students expressed an opinion on the usefulness of such blended methods, and knowledge tests showed a rise in the correct answers, by 100% in some questions; while with traditional methods, this rise was modest (20%) (see ref. [56]).

Our hyper-constructivist, experiment-based teaching should be compared with two similar, but somewhat alternative, methodologies: the Socratic heuristic (maieutic) method, as invented by Socrates, and narrative, metaphor teaching. The Socratic method is still a masterpiece of arguing and debating, to the same extent in mathematics and in law [57,58], but physics is a practical, everyday science, now with centuries of experiments behind it. Using the N-R methodology, we need not to base only on the pupils' mere reasoning, but in any moment of didactical difficulty, we can recall an "ocular" experience: an experiment "from my pocket", or the experience already seen by pupils, or a video clip from the internet (such as objects falling in a huge vacuum chamber).

Second, our interactive, constructivist teaching is more than merely narrative; these approaches are complementary. The narrative teaching (of physics) in early childhood stimulates the imagination [59,60], probably to a greater extent than our experiments, but the free-hand reports of pupils some months after our lessons, such as those depicted in Figure 7a, prove that the H-C teaching leaves a durable "imprinting".

As already mentioned, the standard evaluation of the didactical efficiency of the H-C approach is a hard task. If we declare at the beginning of the interactive adventure on discovering the concept of energy "Today we will define the potential and kinetic energy", the whole possible heuristic path disappears before we have even started it. Additionally, in traditional teaching, we should declare that "Today we will speak about gravity, and we will also learn about the potential and kinetic energy". The two ways of teaching are to some extent incompatible. The H-C approach is more fascinating, but the formal aspects of the knowledge may be compromised; we are aware of this difficulty. For example, we do not explain that the electrical current is a flow of electrons [61] (that is not the full truth, as in semiconductors we speak also about "holes" and in liquids and plasma, about ions). Without such (simplified) notions, our pupils would probably be less successful in school tests, but they will certainly be much more creative than a "control" group. In a similar way, we do not fight the so-called misconceptions of pupils [62]; instead, we use such preliminary knowledge as a starting point for the H-C path. In our teaching, there are no wrong answers.

A clear indicator of the didactical success is the continuous request for our lectures, both in Poland and abroad. In Poland, in the last 12 years, the UMK team (5 researchers in total), using the H-C methodology, concluded approximately 300 interactive lectures, lessons, and workshops; see Figure 15a. Additionally, a real reward for the lecturer is the interest of the audience after the lesson, regardless of whether they are preschool pupils, see Figure 15b, or university researchers.



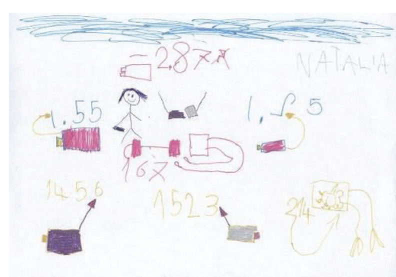
(**a**)

(**b**)

Figure 15. Evaluating the H-C teaching of physics in different environments: (**a**) The geographic distribution of lessons in the period 2009–2019. The size of the points is proportional to the number of events. Source: own work, database http://dydaktyka.fizyka.umk.pl/nowa_strona/?q=node/523 (accessed on 8 January 2023; (**b**) the deep emotional involvement of young students after the lesson on electricity. Zielona Góra, October 2010, Source: own work, photo Maria Karwasz.

However, the real success is not in the mere number of lessons, but rather the flexibility of the "Physics is Fun" methodology to involve an audience of all ages, and also to induce social competencies, such as group collaboration, see Figure 16a, or practical abilities, similarly to written reporting, as in Figure 16b. The narrative approach also allows us to make teaching inclusive [23]; see, for ex., in photo 8b, the child autonomously performing "Galileo's" experiment by rolling down carts.

(**a**)



(**b**)

Figure 16. (**a**) Pedagogical spin-off results of H-C teaching: autonomous division of tasks in measurements with a voltmeter: girls (10 yrs. old) plan, boys perform measurements and write the report. Głogów, Poland, 2014; (**b**) Natalia (7 yrs.) still hardly writes (note the inverted "2" number), but measured (and reported) correctly (even if without the decimal point) the voltage from new and exhausted piles and a vegetable (Al/Cu) battery (right lower angle). Świdnica, Poland, 2013. Workshops by GK, photo Maria Karwasz.

Compared with similar activities, such as open lectures organised by other Polish universities, in lectures and workshops at Science Centres ("Kopernik", "Hevelianum") and interactive theatres (“Physics on Stage” at CERN [63], “Mysteries of Light” by Marco Giliberti in Milan [64], etc.), we observe a constant high degree of interest for our “Physics is Fun” activities. Notably, we run them without specific external support and the activity is continuous; practically all of the windows available in the great lecture hall at the Faculty are filled with our lessons, even if dissemination is not our main institutional task.

5. Conclusions

The present paper, initially conceived as a presentation of teaching methodologies, developed into a review of these methods and their applications in various didactical environments. Both neo-realism and hyper-constructivism methods began as our practical activity; the former started as university didactics, under the Bologna process in Trento (1993–1994), then developed into interactive exhibitions in Italy (1994) and in Poland (1998), which subsequently led, in a few years, to the formation of science centres (in Gdańsk in 2009 and in Warsaw in 2010). The was H-C developed mainly as a teaching method at children’s universities (starting from 2009) and in interactive exhibitions (from 2008). Now, thanks to “tex-books”, we have expanded the N-R and H-C didactics to school curricula. This continuous growth of activities testifies the success of both approaches.

In the period of September–December 2022, we delivered interactive lectures on university premises, under the title “Energy, part II Thermodynamic”, for approximately 1000 students of primary and secondary schools; lectures and workshops on astronomy in Poznań for 100 children within a university for children; and lectures for around 300 students at the Science Festival in Kwidzyń, amongst others. The invitations for collaboration (a series of lessons for teachers on interdisciplinary didactics) arrived in 2022 from Italy and Kazakhstan, apart from the already mentioned contacts with the Republic of Korea. Work towards this is in progress.

We continue publishing H-C books. A book on science and philosophy [65] was published in 2019 in Rome and is now available on all major Internet vendor platforms, “*Modern Physics*” was re-published in 2021 by our University Editor, and “*Astronomy for Kids*” [66] arrived in 2023 as a reprint of the second edition. This proves the need for a somewhat humanistic approach to sciences, contrary to what had been shown by great masters in the past [2–5].

On the other hand, we have observed convergence with recent tendencies in science divulgation at the European level. A Spanish editor launched a series of multi-disciplinary and multi-sectorial (science, arts, engineering) books, comprising mathematics [67] physics, cosmology [68], and philosophy. Additionally, these series use simple language, a narrative approach, and numerous transversal references, but at the same time are based on the most recent scientific research.

New approaches to the didactics of physics, based on simple, possibly interactive experiments and an interrogative narration with the public, assured the success of a didactical approach in all different environments, both in schools and extracurricular teaching. This success is based on vast resources of both objects and scenarios. However, the hyper-constructivist implementations require the didactical capacities of teachers, lecturers, technicians, etc., to be advanced. Therefore, the long-term training of teachers is essential. The success of our recent (2022/2023) online lessons for Italian teachers of primary and secondary schools, on i) interdisciplinary, ii) multimedia, and iii) inclusive didactics proves this point.

In conclusion, physics needs not be boring or unpopular, but we must change the ways of teaching the subject to achieve this, particularly by adapting to specific learning environments whilst maintaining the essential characteristics of physics as a science which is experimental (Galileo), rational (Newton), and philosophical simultaneously. Teaching must involve learners in a constructivist way and respect their pedagogical needs. These conditions are hard to fulfil, but, in our opinion, necessary to keep the teaching of physics not only alive, but also fun.

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Data Availability Statement: Additional data on this study can be obtained at internet page: http://dydaktyka.fizyka.umk.pl/nowa_strona/?q=node/1009. (accessed on 2 February 2023).

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education sciences

Review

The Evolution of the Field of Learning Environments Research

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Abstract: This article reviews half a century of remarkable expansion and internationalisation in the field of learning environments research, including milestones such as the creation of the American Educational Research Association's Special Interest Group on Learning Environments and Springer's Learning Environments Research: An International Journal. Several widely used, extensively validated and economical questionnaires for assessing learning environments (e.g., What Is Happening In this Class? WIHIC) are discussed. A review of research identifies how learning environment researchers have generated robust knowledge about how to improve student outcomes through creating positive learning environments; demonstrated the value of including learning environment dimensions as process criteria of effectiveness when evaluating educational programmes and teaching methods; and provided teachers with straightforward approaches to use in action research aimed at improving their students' learning environments. To facilitate and motivate future research and practical applications, the 56-item WIHIC is included in an appendix, and some newer and emerging lines of research are identified (e.g., cross-national studies; the physical environments of educational buildings and learning spaces; and advances in methods of statistical analysis for learning environment studies).

Keywords: learning environments; historical perspectives; questionnaires; associations with outcomes; improving environments

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1. Introduction

For this special issue of *Education Sciences* devoted to the topic of the effects of learning environments on students' outcomes, I was asked to provide a historical perspective on the birth of the field and its subsequent evolution. In this article, discussion is structured under four headings of historical beginnings and milestones (Section 2), assessment of learning environments (Section 3), types of research on learning environments (Section 4) and discussion (Section 5).

2. Historical Beginnings and Milestones

My first introduction to the field of learning environments was in the early 1970s when I was undertaking research for my Ph.D. involving an evaluation of Australia's first national curriculum project, namely, the Australian Science Education Project [1]. This research was guided and inspired by Herbert Walberg's evaluation of Harvard Project Physics in the 1960s in the USA [2,3]. These two evaluations shared a common design involving a comparison of new and traditional curricula in terms of changes between pretest and post-test on a broad range of valued student outcomes (e.g., achievement, attitudes, inquiry skills, understanding of the nature of science).

Walberg's evaluation of Harvard Project Physics was pioneering in that, in addition to the wide range of student outcomes, criteria of curricular effectiveness included the classroom learning environment. Subsequently, I included student perceptions of classroom environment in my evaluation of the Australian Science Education Project. This approach to assessing classroom processes through high-inference questionnaires responded to by participants was methodologically innovative at the time when the dominant approach involved low-inference classroom observations conducted by external observers.

A fascinating pattern in the evaluations of both Harvard Project Physics and the Australian Science Education Project was that the new and traditional curricula could not be distinguished in terms of student outcomes, but they could be differentiated in terms of the classroom learning environment created. Apparently, innovations in curricula and teaching methods initially have an impact on improving classroom environment and that it is only subsequently that these more positive environments lead to improved student outcomes.

I undertook a five-month sabbatical with Walberg at the University of Illinois in Chicago during the blizzard of 1979. During that year, I was introduced to the annual meeting of the American Educational Research Association (AERA), the world's largest educational research conference. Soon, I became a regular participant in annual AERA conferences, which seemed to provide an excellent opportunity to disseminate my own research on learning environments, meet other learning environment researchers from around the world, and generally provide a catalyst for the spread of learning environment ideas and research around the world.

Although the AERA has over 100 Special Interest Groups (SIGs) on research on a very wide variety of topics, with each SIG being allocated its own program space/slots at AERA annual meetings, no AERA SIG at that time had learning environments research as a central focus. Therefore, in 1984, a major milestone in the evolution of the learning environment field was when Walberg and I (together with another colleague, Chad Ellett) decided to make an application to AERA to create a new AERA SIG called Learning Environments. When this application was successful, the SIG Learning Environments in 1985 started its own program at each AERA annual meeting with its own invited speaker, best paper award and opportunity to publish presentations in an annual refereed SIG-sponsored monograph. Today, this highly successful and international SIG has led to each AERA annual meeting program having over 100 presentations listed in the index under the heading 'learning environments'. Wubbels [4] describes how attending AERA conferences nearly every year for him was "an inspiring event in my professional and personal life" and that the SIG Learning Environments "has been of the utmost importance in developing the program of research of our research group... and the dissemination of its results worldwide" (p. 20).

The annual monographs published by the SIG Learning Environments provided the basis upon which I was able to approach Kluwer Academic Publishers with the idea of starting up the field's first journal. So, the next landmark in the evolution of the field of learning environments occurred in 1998 when the first volume of *Learning Environments Research: An International Journal* was published by Kluwer (now Springer Nature) (www.springer.com/journal/10984, accessed on 15 December 2022). In 2002, this journal was in its 25th volume, is rated in Scimago Quadrant 1 in multiple fields including Education, and is included in the Web of Science. Although I have served as an Editor-in-Chief of this journal since its inception, the journal's international reach has been enhanced by always having one or more Regional Editors for each of North America, Europe and Australia/Asia.

The next landmark occurred in 2008, a decade after the birth of the journal, when I established the book series entitled Advances in Learning Environments Research published by Sense Publishers (now Brill), which I co-edited initially with Jeffrey Dorman and now with David Zandvliet. The first volume in this series was *Outcome-focused Education: Determinants and Effects* [5], several volumes have focused on physical environments [6], and the recent *Thirty Years of Learning Environments: Looking Back and Looking Forward* [7] provides celebratory reflections on the accomplishments of the AERA SIG Learning Environments during its first 30 years.

3. Assessment of Learning Environments

There is a wide range of research methods used to assess and investigate learning environments, including direct observations, interviews, questionnaire surveys, and case studies [8]. Tobin and Fraser [9] advocate mixed-methods approaches which combine qualitative and quantitative methods, and Aldridge et al. [10] provide a useful example of this combination in a cross-national study of learning environments in two countries. However, undoubtedly, the most frequently used way of assessing learning environments in prior research has been to use 'high inference' questionnaires that tap students' and teachers' perceptions and therefore characterise settings through the eyes of the participants themselves.

One of these questionnaires is the What Is Happening In this Class? (WIHIC) [10], which is currently the most frequently used learning environment questionnaire worldwide. The nature of the WIHIC is clarified in Table 1 which lists the names of its seven scales together with a scale description and sample item for each scale. Items are answered using a five-point frequency response scale ranging from Almost Never (scored 1) to Very Often (scored 5). All of the WIHIC's 56 items are listed in Appendix A.

Table 1. Scale Description and Sample Item for each WIHIC Scale.

Scale	Scale Description Extent to Which	Sample Item
Student Cohesiveness	students know, help and are supportive of one another.	1 make friendships among students in this class.
Teacher Support	the teacher helps, befriends, trusts and shows interest in students.	The teacher talks with me.
Involvement	students have attentive interest, participate in discussion, perform additional work and enjoy the class.	I give my opinions during class discussions.
Investigation	there is emphasis on the skills and processes of inquiry and their use in problem solving and investigation.	I explain the meaning of statements, diagrams and graphs.
Task Orientation	it is important to complete activities planned and to stay on the subject matter.	I know the goals of this class.
Cooperation	students cooperate with one another on learning tasks.	I work with other students on projects in this class.
Equity	students are treated equally by the teacher.	I get the same opportunities to answer questions as other students.

Items are scored 1, 2, 3, 4 and 5, respectively, for the responses of Almost Never, Seldom, Sometimes, Often and Very Often.

The WIHIC's wide usage for many purposes around the world is illustrated by Fraser's [11] tabulation of 21 studies in 12 languages and in 13 countries (including the USA, UAE, Australia, Greece, India, Singapore, Indonesia, China, Korea and South Africa). This table captures major applications and selected results from the extensive research with the WIHIC, including a cross-national study of classroom environments in Taiwan and Australia [10]. More recently, Hanke and Fraser [12] compared middle-school students' mathematics classroom environments in the USA and Hong Kong, whereas Long et al. [13] compared American preservice teachers' perceptions of their learning environments before and after pandemic-related course disruption.

Significant research has been undertaken to modify the WIHIC for suitability for use in the contexts and languages of China and Greece. In China, the WIHIC was modified to form the NWIHIC (New What Is Happening in This Class?) and validated among 2280 grade 5–9 students from nine schools by Cai and colleagues [14]. The NWIHIC has six scales from the original WIHIC (Student Cohesiveness, Teacher Support, Involvement, Task Orientation, Cooperation and Equity) as well as the two new scales of Differentiated Instruction and Ongoing Assessment. Principal Component Analysis (PCA), Confirmatory Factor Analysis (CFA) and reliability analysis confirmed the NWIHIC's validity. In Greece, Charalampous and Kokkinos [15] rigorously developed and validated a new elementary-school version of the WIHIC in the Greek language (the G-EWIHIC).

The WIHIC's scales were included in the Constructivist-Oriented Learning Environment Survey (COLES), which was designed to provide feedback as a basis for reflection in teacher action research [16]. The COLES also includes the scales of Differentiation, Young Adult Ethos, Formative Assessment (extent to which students feel that their assessment tasks make a positive contribution to their learning) and Assessment Criteria (extent to which assessment criteria are explicit so that the basis for judgements is clear and public. For a sample of 2043 grade 11 and 12 students from 147 classes in nine Australian schools in Western Australia, the COLES displayed sound factorial validity and internal consistency reliability. The COLES was used successfully with teachers in conjunction with classroom observations and teacher collaboration in a whole-school professional learning initiative in Western Australia [17].

Researchers have modified and expanded existing learning environment questionnaire to better accommodate specific educational settings, such as computer-assisted classrooms [18] and science laboratories [19]. The Science Laboratory Environment Inventory (SLEI) includes unique dimensions such as integration, which focuses on the extent to which theory and laboratory instruction are integrated and which has been shown to be strongly linked with student outcomes. The SLEI was initially validated with 5477 high-school and university students in 269 classes in six countries, namely, Australia, the UK, USA, Nigeria, Canada and Israel [19].

Subsequently, the SLEI has been cross-validated and used in research in numerous countries. Lee et al. [20] validated a Chinese version of the SLEI in Taiwan and reported relationships between student self-efficacy and the levels of classroom Open-endedness and Rule Clarity. The SLEI also has been successfully validated and used in Korea [21], Israel [22] and Spain [23].

An extensive program of learning environment research that originated in the Netherlands involves the Questionnaire on Teacher Interaction (QTI), which assesses eight aspects of teacher behaviour based on the dimensions of influence (dominance–cooperation) and proximity (opposition–cooperation): Leadership, Helping/friendly, Understanding, Student responsibility/freedom, Uncertain, Dissatisfied, Admonishing, and Strict behaviour. In addition to the use of the QTI in the Netherlands [4,24,25], it also has been used in research in Brunei [26] and Indonesia [27].

The QTI has been adapted and used extensively among Chinese-speaking students. Sivan and colleagues [28] developed a Chinese version of the QTI (the C-QTI) and psychometrically validated it with students in Hong Kong. Using 'smallest space analysis', Sivan and Cohen [29] with 612 secondary students in Hong Kong demonstrated that C-QTI fits its underlying circumplex model for interpersonal teacher behaviour. An exceptionally rigorous development and validation of another Chinese version of the QTI involved 2000 secondary-school students from mainland China [30].

4. Types of Learning Environment Research

Section 4 describes three important types of learning environment research, namely, associations between the learning environment and student outcomes (Section 4.1), evaluation of educational programmes (Section 4.2), and improving learning environments (Section 4.3). Additionally, the discussion in Section 5 briefly identifies some emerging lines of learning environment research.

4.1. Associations between Learning Environment and Student Outcomes

A very strong tradition in learning environment research has involved investigating relationships between a range of student outcomes and the nature of the learning environment. This research has revealed consistent, strong and positive associations between the quality of students' learning environments and their cognitive and affective outcomes. This line of research began using data collected as part of the previously mentioned evaluations of Harvard Project Physics [2,3] and the Australian Science Education Project [1]. A comprehensive meta-analysis involving 17,805 students revealed more-favourable student outcomes in learning environments with more cohesiveness, satisfaction and goal direction and less disorganisation and friction [31]. In a study of 1121 undergraduate students in

Ethiopian universities, Tadesse and colleagues [32] found that students' perceptions of constructivist learning environments (especially personal relevance) were associated with learning outcomes. When Wan [33] investigated the joint influence of classroom and family environments on critical thinking among 2189 secondary students in Hong Kong, classroom environment was a stronger predictor than family environment.

In order to obtain very large and high-quality data for research on outcome–environment relationships, some researchers have conducted secondary analysis (i.e., analysis for new purposes of existing data that were collected previously for different purposes). For example, Khine, Fraser and Afari [34] analysed PISA (Programme for International Student Assessment) data from 14,167 students in the United Arab Emirates to explore associations between three learning environment characteristics (cooperation, teacher support, investigation) and three non-cognitive student outcomes (epistemological beliefs, self-efficacy, attitudes). Using structural equation modelling, statistically significant associations were found between each learning environment scale and each non-cognitive outcome.

Fraser and Kahle [35] conducted secondary analysis of data collected from 7000 students in 200 schools as part of a Statewide Systemic Initiatives in Ohio. The study was unusual in that it encompassed three different types of environments (classroom, home, peer) and both achievement and attitude outcomes. Each of the three environments accounted for statistically significant amounts of unique variance in student attitudes, but only the class environment accounted for statistically significant amounts of variance in student achievement.

4.2. Evaluation of Educational Programmes

As noted in Section 2, Walberg's historically important evaluation of Harvard Project Physics included learning environment dimensions among its criteria of effectiveness, thereby pioneering the use of learning environments assessments in many subsequent evaluations. For example, in Texas, Long et al. [13] traced changes in the learning environment among 230 preservice teacher education students during the switch to remote learning associated with the COVID-19 pandemic. These students perceived a statistically significant decline in student cohesiveness, teacher support, involvement, task orientation, and equity during the change to online learning, with the largest decline of 0.56 standard deviations occurring for student cohesiveness.

Flipped classroom instruction has been evaluated in terms of its effect on the classroom environment in Turkey [36] and the USA [37]. This American study revealed that flipped instruction was associated with greater cooperation and innovation but less task orientation, while the Turkish study suggested that flipped instruction was associated with higher student satisfaction and general belongingness.

Aldridge et al. [38] evaluated a national curriculum reform involving outcomes-based education (OBE) in South Africa using a school-level learning environment questionnaire with 403 teachers. It was found that teachers who had been involved with OBE perceived their school environments as having significantly more familiarity with OBE and work pressure.

It can be argued that the litmus test of the success of any professional development program for teachers is the extent of changes in teaching behaviours and ultimately student outcomes. In an evaluation of a two-year mentoring program for beginning elementary teachers in Florida, Pickett and Fraser [39] assessed teachers' teaching behaviour in terms of their 573 students' perceptions of classroom environment. The effectiveness of the mentoring program was supported by improvements over time in the learning environment, students' attitudes and students' achievement.

4.3. Improving Learning Environments

It is important not only that researchers conduct the sorts of learning environment studies reviewed in Sections 4.1 and 4.2 but also that teachers draw on learning environment concepts and methods to improve their students' learning environments. Teachers have successfully used feedback information based on assessments of their students' perceptions of their actual and preferred learning environments to guide practical improvements in their classrooms. Earlier, these improvement attempts involved the simple steps of: *assessment*; *feedback*; *reflection and discussion*; *intervention*; and *reassessment* [40]. Over time, these simple steps have evolved and been expanded to: *assessment and feedback*; *reflection and focusing*; *planning*; *implementing and refining*; and *reassessment* [41]. Some case studies of teachers' successful application of these change strategies in improving learning environments are reported below.

In South Africa, teachers applied these techniques for improving their classroom learning environments based on feedback from actual and preferred versions of the WIHIC. In the KwaZulu-Natal Province, 31 inservice teachers in a distance-education programme administered a primary-school version of the WIHIC in the IsiZulu language to 1077 grade 4–7 students [42]. Different teachers used feedback from the WIHIC with different levels of success in improving their classroom environments.

In New Zealand, when Taylor [43] used co-constructive learning strategies to reshape lessons, grade 9 science students perceived greater personal relevance and shared control in their classroom environments. In one South Australian school, a teacher of Italian used the COLES in her attempt to include her grade 8 and 10 students in co-construction [44]. Improvements in COLES scores over time, together with qualitative insights from interviews and narratives, supported the value of students co-constructing the learning environments of their classes.

In Australia, the COLES has been used in numerous action research studies involving teachers' attempts to improve their learning environments. The first study established the validity of the COLES with a sample of 2043 grade 11 and 12 students in 147 classes in nine schools as well as using qualitative methods in case studies of how eight teachers used the questionnaire feedback [14]. Bell and Aldridge's book [41] reported small but significant pretest–post-test changes over three years for a sample of 6107 students in 562 classes whose teachers implemented the approach to improving classroom environments. When Henderson and Loh [15] used the COLES in one school to guide teachers' professional learning among 25 teachers and their 500 students each year, teachers highly valued this type of feedback.

5. Conclusions

During the half of a century since I first encountered the field of learning environments during my PhD research, this field has undergone remarkable expansion and internationalisation. Learning environment researchers have: developed and validated economical questionnaires that have been used extensively around the world; generated robust knowledge about how to improve student outcomes through creating positive learning environments; demonstrated the value of including learning environments dimensions as process criteria of effectiveness when evaluating educational programmes and teaching methods; and provided teachers with straightforward approaches to use in action research aimed at improving their students' learning environments.

To facilitate and motivate future research and practical applications, this article has provided in Section 4 information about the world's most widely used learning environment questionnaire, namely, the What Is Happening In this Class? (WIHIC), as well as listing its 56 items in Appendix A. This article also has described major applications of learning environment assessments in investigating associations between student outcomes and the learning environment (Section 4.1), in evaluating educational programmes (Section 4.2), and in teachers' practical attempts to improve their learning environments (Section 4.3).

In seeking new insights, some researchers have conducted learning environment studies that cross international boundaries. For example, Hanke and Fraser [12] involved a large sample of 1309 grade 7 and 8 mathematics students in the USA and Hong Kong in responding to four learning environment scales (teacher support, involvement, cooperation, equity) and some attitude scales. Students in the USA perceived their learning environments significantly more positively than did Hong Kong students, but Hong Kong students enjoyed their classes more than American students. Interestingly, Aldridge et al. [10] reported the same pattern of results in their study of junior high-school science students in Australia (n = 1081) and Taiwan (n = 1879): although Australian students perceived their classroom environments more positively than Taiwanese students, Taiwanese students enjoyed their science classes more than Australian students.

Recently, there has been a resurgence in interest in the physical environment of educational buildings and learning spaces [6] in contrast to the psychosocial characteristics of learning environments reviewed in the present article. For example, researchers have focused on flexible furniture in the USA [45], a 'deskless' school in Finland [46], LED lighting in a pre-K child development laboratory in the USA [47], and a comparison of round-shaped and crescent-shaped seating arrangements in Japan [48]. However, it is disappointing to observe that although new designs or redesigns of learning spaces usually aim to change the psychosocial learning environment in specific ways, it has been rare to evaluate their effectiveness in terms of changes in psychosocial characteristics.

Based on a comparative ethnographical approach, Kokko and Hirsto in Finland investigated processes by which physical spaces can be transformed into learning environments [49]. Baars and colleagues [50] proposed a model for understanding and investigating the supportiveness of physical environments to innovative pedagogies, stressing the need for a psychosocial–physical relational approach to designing new learning environments.

Over the past decade, learning environment research methods have undergone impressive changes to more explanatory, predictive and model-testing approaches according to den Brok et al. [51]. These advances include approaches to statistical analysis such as confirmatory factor analysis, multilevel analysis, structural equation modelling and Rasch scaling. Recently, Kuzle [52] proposed a novel approach to obtaining elementary-school children's insights into psychosocial aspects of their classroom environments via qualitative content analysis of their drawings.

As this paper demonstrates, the learning environments field had experienced impressive expansion and diversification during the previous half century. Two major catalysts for this expansion have been the American Educational Research Association SIG (Special Interest Group) on Learning Environments and *Learning Environments Research*: *An International Journal*. As this special issue of *Education Sciences* on the topic of learning environments research illustrates, the field is ripe for further exciting new developments in the coming decades.

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Appendix A

Table A1. Items in the What Is Happening In this Class? (WIHIC) Questionnaire.

Student Cohesiveness	
1.	I make friendships among students in this class.
2.	I know other students in this class.
3.	I am friendly to members of this class.
4.	Members of the class are my friends.
5.	I work well with other class members.
6.	I help other class members who are having trouble with their work.
7.	Students in this class like me.
8.	In this class, I get help from other students.

Table A1. *Cont.*

Teacher Support	
9.	The teacher takes a personal interest in me.
10.	The teacher goes out of his/her way to help me.
11.	The teacher considers my feelings.
12.	The teacher helps me when I have trouble with the work.
13.	The teacher talks with me.
14.	The teacher is interested in my problems.
15.	The teacher moves about the class to talk with me.
16.	The teacher's questions help me to understand.
Involvement	
17.	I discuss ideas in class.
18.	I give my opinions during class discussions.
19.	The teacher asks me questions.
20.	My ideas and suggestions are used during classroom discussions.
21.	I ask the teacher questions.
22.	I explain my ideas to other students.
23.	Students discuss with me how to go about solving problems.
24.	I am asked to explain how I solve problems.
Investigation	
25.	I carry out investigations to test my ideas.
26.	I am asked to think about the evidence for statements.
27.	I carry out investigations to answer questions coming from discussions.
28.	I explain the meaning of statements, diagrams, and graphs.
29.	I carry out investigations to answer questions that puzzle me.
30.	I carry out investigations to answer the teacher's questions.
31.	I find out answers to questions by doing investigations.
32.	I solve problems by using information obtained from my own investigations.
Task Orientation	
33.	Getting a certain amount of work done is important to me.
34.	I do as much as I set out to do.
35.	I know the goals for this class.
36.	I am ready to start this class on time.
37.	I know what I am trying to accomplish in this class.
38.	I pay attention during this class.
39.	I try to understand the work in this class.
40.	I know how much work I have to do.
Cooperation	
41.	I cooperate with other students when doing assignment work.
42.	I share my books and resources with other students when doing assignments.
43.	When I work in groups in this class, there is teamwork.
44.	I work with other students on projects in this class.
45.	I learn from other students in this class.
46.	I work with other students in this class.
47.	I cooperate with other students on class activities.
48.	Students work with me to achieve class goals.
Equity	
49.	The teacher gives as much attention to my questions as to other students' questions.
50.	I get the same amount of help from the teacher as do other students.
51.	I have the same amount of say in this class as other students.
52.	I am treated the same as other students in this class.
53.	I receive the same encouragement from the teacher as other students do.
54.	I get the same opportunities to contribute to class discussions as other students.
55.	My work receives as much praise as other students' work.
56.	I get the same opportunities to answer questions as other students.

Items are scored 1, 2, 3, 4, and 5, respectively, for the responses *Almost Never*, *Seldom*, *Sometimes*, *Often*, and *Almost Always.*

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Article

How do Facilitating Conditions Influence Student-to-Student Interaction within an Online Learning Platform? A New Typology of the Serial Mediation Model

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Abstract: This study investigates factors affecting university student-to-student interaction within online learning platforms. A new model was proposed based on the United Theory of Acceptance and Use of Technology (UTAUT). The single-stage cluster-sampling method was employed, and 113 university students in Hong Kong were respondents. It was found that Information Quality, Social Influence, and Facilitating Conditions affect students' intention to interact with each other. A quasi-full mediation model was established of the mechanism from Facilitating Conditions to students' interaction behavior. The direct effect of Facilitating Conditions on students' interaction and the effect of System Quality on the intention of student interaction were not significant. A fast network, computing facilities, and mobile-friendly software are possible candidates of the virtual environment conditions affecting the intention of student-interaction behavior within online learning platforms.

Keywords: online learning; student-to-student interaction; serial mediation model; United Theory of Acceptance and Use of Technology

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1. Introduction

During the pandemic period, instructor–student interactions were emphasized, and student–student interactions were ignored [1]. Learning outcomes of almost all social science and business courses include student engagement and discussion of subject content. Doing group projects is one of the ways that students learn how to collaborate with each other. It makes students not only to ask the teacher when they do not understand the course materials, but also, students are encouraged to discuss among themselves and to learn from each other. It is especially important when some of the university teaching is in a large class format and when there is no compulsory attendance requirement. Students have to use different ways to communicate with each other. It is beneficial if the university can assist students' discussions through an e-learning platform. Students have meaningful development through collaborative e-learning [2].

There are advantages in using an online discussion forum rather than a face-to-face meeting. Students do not need to be in the same location and can communicate asynchronously at a time convenient to them. University online forums usually have better security, so that third parties find it difficult to hack those systems. If there is a pandemic like COVID-19, the tutorial function, which normally requires discussion among teachers and students, could be replaced. There are some disadvantages, such as that the students cannot have physical contact, they usually cannot see each other, and they might need some technical support. Teachers might be required to work outside normal class hours to reply to some student postings [3].

However, academic discussions among students have yet to be explored for an underlying mechanism on an e-learning platform. Colleges put a lot of physical and manpower resources into information technology support. We aim for student-to-student interaction as an output measurement. Thus, it is worthwhile to examine the process in detail.

There are four research objectives in the paper, and they are listed as follows:

(a) propose a new model of factors affecting the intention of university student-to-student interaction using e-learning platforms;
(b) propose a new typology of the serial mediation decision tree;
(c) investigate the underlying mechanism between facilitating conditions and the use behaviour of student-to-student interaction; and
(d) provide recommendations to the college management for the development of using an e-learning platform

2. Literature Review

E-learning is defined as making use of hardware and software for teaching and learning through the World Wide Web [4]. Scholars provide an explanation for the term e-learning: any form of electronic education technology, including computer-based learning, computer-assisted instruction, internet-based learning, web-based learning, online education, and virtual collaboration [5]. Their definition of e-learning is used in the study. Having said that, online learning might require learners to use the internet to connect to each other or access course material. Today almost every electronic device can connect to the internet using a public or private connection. Thus, e-learning and online learning are used interchangeably.

E-learning platforms have been used in universities for decades, and their functions have been much improved [6]. From uploading materials by teachers and downloading materials by students, almost all the platforms now provide messaging, discussion forum, testing and marking functions [6].

There are several electronic learning environments that people are using. They can be classified into four categories. The first one is the university electronic learning system including Blackboard and Moodle. The second type is communication software, for example, electronic email and skype. The third type is social media websites, such as Facebook and Google+. The fourth type is application software on mobile devices, including Whatsapp, Wechat, and short message systems [7]. The last type could be conference call software like Google Meet, Microsoft Teams, and Zoom.

During the online lesson, teachers deliver the course content to students. Students can ask questions in a chat room. Sometimes, using a microphone is not a popular choice, since there are a lot of students in a virtual classroom. Previous research on online learning has focused on teacher-to-student interaction, with less attention on student-to-student interaction [1]. This study fills in the literature gap by proposing a new model on factors affecting the intention of university student-to-student interactions using online learning platforms.

2.1. UTAUT

The United Theory of Acceptance and Use of Technology consists of four independent variables (performance expectancy, effort expectancy, social influence, and facilitating conditions) and four moderating variables (gender, age, experience, and voluntariness of use) [8].

2.2. Facilitating Conditions

This refers to the education training in using a new technology, which a company offers for people when it wants them to use that technology [9]. For example, due to the pandemic situation, teachers have had to learn how to use new software, such as Zoom, Microsoft Teams, or Google Meet, to teach their students. Schools are going to offer training support to teachers. Constructive feedback given by lecturers and setting clear expectations can increase the effectiveness and student interactions in a discussion forum [10].

2.3. Social Influence

Social influence is how the opinions of friends, peers, classmates, and family members affect the perception of a person. It has been found that social influence positively associates with the intention to do something [11].

2.4. Association between Facilitating Conditions and Social Influence

We should have information technology support that could be affected by others. This is because the support alone is not enough to drive the person's intention to do something. That is not contradictory with the original UTUAT model. In the model, several factors, including facilitating conditions and social influence, contribute to behavioral intention.

The UTAUT model and the Delone and McLean Information system success model, with 'System Quality' and 'Information Quality' constructs, were combined (Figure 1). The selection of the model was justified by an integrative approach and was to be verified by a focus group and empirical study later. The proposed framework that will be tested in this study is appended below (Figure 1).

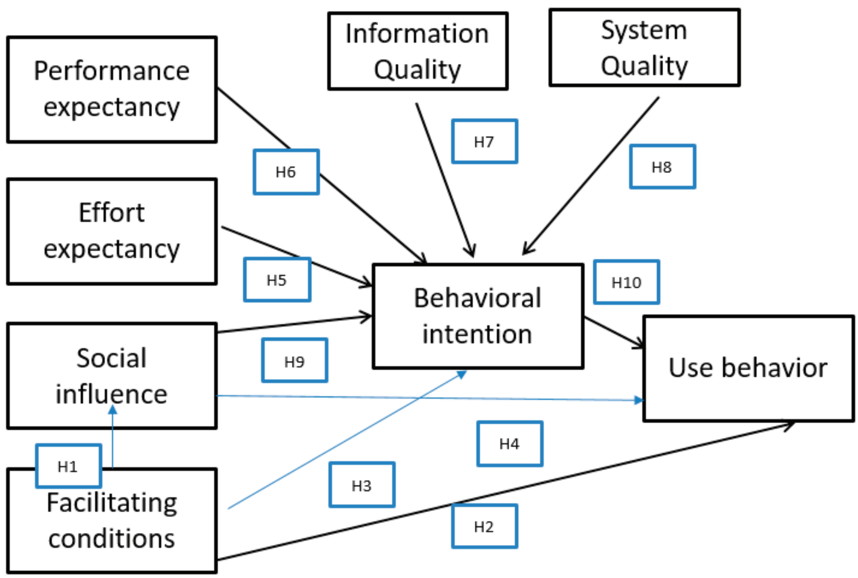

Figure 1. Research framework of student-to-student interaction (Source: authors).

Thus, we have hypotheses oneto four, nine and ten for serial mediation. Hypotheses five to eight are other independent variables linking to the intention of student-to-student interaction.

There are hardware and software for online learning platforms available so that students interact more with his or her fellow classmates. Social and peer pressure could also be motivating factors.

H1. *Facilitating Conditions have a positive association with Social Influence.*

H2. *Facilitating Conditions have a positive association with the behavior of student-to-student interaction.*

H3. *Facilitating Conditions have a positive association with the intention of student-to-student interaction.*

H4. *Social Influence has a positive association with the behavior of student-to-student interaction.*

Effort Expectancy comes from the scale of the "perceived ease of use" of the Technology Acceptance Model (TAM). Students that find it easier to use the platform might have more interaction with his or her classmates.

H5. *Effort Expectancy has a positive association with the intention of student-to-student interaction.*

Performance Expectancy comes from the scale of "perceived usefulness" of the Technology Acceptance Model (TAM). Students find that the platform is useful; thus, they use it for their interaction with their classmates.

H6. *Performance Expectancy has a positive association with the intention of student-to-student interaction.*

Students find more relevant information available when they have a higher intention of student-to-student interaction.

H7. *Information Quality has a positive association with the intention of student-to-student interaction.*

A more reliable system could lead to a higher intention of student-to-student interaction.

H8. *System Quality has a positive association with intention of student-to-student interaction.*

H9. *Social Influence has a positive association with the intention of student-to-student interaction.*

H10. *The intention of student-to-student interaction has a positive association with the behavior of student-to-student interaction.*

2.5. Mediation

There are two types of Multiple mediation effects: in parallel or in series (Figures 2 and 3). Scholars discuss the multiple mediation model with more than one mediator [12].

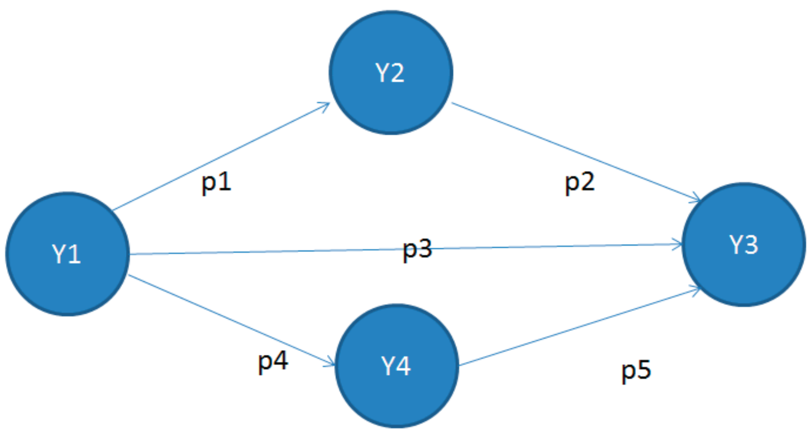

Figure 2. Parallel mediation model [Source: authors].

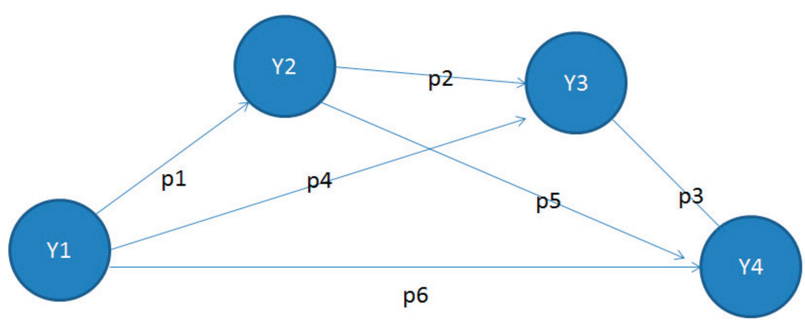

Figure 3. Serial mediation model. (Source: authors).

In the parallel mediation model, we aim to compare the effects of more than one mediator. As a result, we know which mediator has a larger mediating effect. The overall mechanism or linkage between the antecedent and consequence are basically the same. In the serial mediation model, the focus is on the process of the mechanism. The effect of the antecedent passes through a mediator one-by-one before reaching the dependent variable.

Regarding a definition of a mediator, "it accounts for the relationship between the predicator and the criterion [13] (p. 1176)." To test the mediating effect, the three-step method was used. Three regression equations should be established:

1. The mediating variable is regressed on the independent variable;
2. The dependent variable is regressed on the independent variable; and
3. The dependent variable is regressed on the independent variable and the mediating variable. [13] (p. 1177).

"To establish mediation, the following conditions must hold: firstly, the independent variable must affect the mediator in the first equation; secondly, the independent variable must be shown to affect the dependent variable in the second equation; and thirdly, the mediator must affect the dependent variable in the third equation. If these conditions all hold in the predicted direction, then the effect of the independent on the dependent variable must be less in the third equation than in the second equation. Perfect mediation holds if the independent variable has no effect when the mediator is controlled" [13] (p. 1177).

Mediation lets us know more about the mechanism of the relationship among variables [13]. A new mediation analytic framework was proposed [14]. Five types of mediation were presented: complementary, competitive, indirect-only, direct-only, and no-effect mediation. Complementary mediation is Baron and Kenny's partial mediation. Indirect-only mediation is, in fact, Baron and Kenny's full mediation type. There is no need to test the association between the dependent variable and independent variable as there could be a competitive mediation [14].

A similar situation applies to serial mediation.

3. Methodology

The research methodology consisted of two stages. The first stage consisted of a focus group, which was qualitative in nature, and the second stage was a survey. A focus group of 10 students was conducted. The recruitment method was purposive sampling. In the purposive sampling method, the researcher deliberately identifies criteria for selecting the sample. Students that had some online learning experience and were willing to join the meeting were the criteria. Data collected from a focus group can contribute to the researcher's understanding of the research problem. A quantitative method with a cross-sectional approach was used in the second stage to examine the use of an electronic learning platform in a college so as to investigate the relationships between variables [15].

A factor analysis curtails a number of factors to a smaller number of factors for the framework design. Second, a correlation analysis was used to analyze the relationships among variables [15]. Finally, the partial least squares method was used to analyze the research framework, as one of the objectives of the thesis was testing the predictive power of the independent variables. In addition, sample size could be more flexible in the partial least squares analysis. A multiple regression analysis was also used to reconfirm the linkages among the dependent variable and some independent variables [16].

Most researches involved in e-learning platforms have used the positivist approach. The survey method is one of the most common forms of the positivist approach. It implies that a project is used to grasp information from a group of target respondents by using a survey [17]. A lot of respondents can be reached with a questionnaire. The Hawthorne effect may also occur in quantitative research using questionnaires. Although questionnaires can be anonymous, the researcher's identity and the aim of the research usually have to be shown to respondents. Reducing the level of personal interaction between the researcher and his or her subject may reduce this problem [18].

3.1. Research Design

Figure 4, below, captures an overview of the research design.

Figure 4. Research design of the study (Source: authors).

The purpose of the focus group was to help the researcher to design the questions and choices for answering parts on the survey. The survey was undertaken in two phases: a pilot study preceding the main survey. Both the pilot test and survey questions were in English. Students were asked to complete the questionnaire in English. All students were assumed to be proficient in English, because all the courses within their studies were conducted in English. They cannot complete their studies without an understanding of general English usage. Since the questionnaires were designed to be distributed during class with the presence of the researcher, in case of any question during the process, students could ask the researcher their question. The target population in the college at that time was the student population, which was 1000.

Cluster sampling was used in the study. It is a cost-effective method, because it is easy to operate [15]. Our target students were homogeneous generally and grouped naturally in their own classes' format. It would have been easy for us to randomly select some of the classes for our survey purpose. One minor problem was not of all the classes are the same size. A large class would have had higher chance of being in our sample because they have more students. The cluster sampling method has a similar accuracy when compared to simple random sampling [19].

There were four different programs in the four particular classes, selected randomly. The four undergraduate programms were "Bachelor of Arts in Marketing and Public Relations", "Bachelor of Arts in Applied and Media Arts", "Bachelor of Social Science", and "Bachelor of Arts in Retail and Service Management". They were all together for 13 weeks, and class meetings were conducted as a mixture of lectures, seminars, group discussions, and presentations. Students were assessed on the basis of a test, group project, class participation, and a final examination. Students had to pass both their coursework and final examination.

The focus group meeting lasted for an hour. In the first 10 min, the background of the study and focus group agenda were explained. There were 10 students that participated in the focus group. The students' names were Paul, Peter, Eva, Mary, Irving, Tony, Susan, Ruby, Irene, and Wilson. These were not their real names. An extra 10 minutes at the end of the meeting was used to make sure everybody could speak up and that any other related issues could be covered. The focus group findings provided researchers with hints for the survey, which was the main focus of the whole study.

3.2. Scales and Measurement

All scales were modified to suit the purpose of this study. Performance Expectancy, Effort Expectancy, and Use Behavior constructs were based on scales of the Technology Acceptance Model (TAM) [20]. Social Influence and Facilitating Conditions constructs were based on the scales of the Theory of Planned Behavior (TPB).

System Quality and Information Quality constructs were based on the variables used by the Information System Success model (ISS) [21].

Behavioral intention will have a positive impact on the use of a system [8] (p. 460). The construct comes from the scale "behavioral intention to use the system" of the Unified Theory of Acceptance and Use of Technology (UTAUT).

A table of survey instruments with modifications used is shown in Table 1.

Table 1. Modified survey items.

Construct Name and Abbreviation	Items
	Performance expectancy (PE), [8] (p. 447)
PE1	I would find the platform useful in my information accessing and processing
PE2	Using the platform enables me to accomplish tasks of information access and processing more quickly
PE3	Using the platform increases my productivity of information access and processing
PE4	If I use the platform, I will increase my ability to get timely information
	Effort expectancy (EE), [8] (p. 450)
EE1	My interaction with the platform would be clear and understandable
EE2	It would be easy for me to become skillful at using the platform
EE3	I would find the platform easy to use
EE4	Learning to operate the platform is easy to me
	Social Influence (IS), [8] (p. 451)
IS1	People who influence my behavior will think that I should use the platform
IS2	People who are important to me will think that I should use the platform
IS3	The seniors in my organization have been helpful in the use of the platform
IS4	In general, my organization has supported the use of the platform
	Facilitating conditions (FC), [8] (p. 453)
FC1	I have the resources necessary to use the platform
FC2	I have the knowledge necessary to use the platform
FC3	The platform is compatible with other systems I use
FC4	A specific person (group) is available for assistance with the platform's difficulties
	Behavioral intention (IB), [8] (p. 460)
IB1	I intend to use the platform in the future
IB2	I predict I would use the platform in the future
IB3	I plan to use the platform in the future
	Use Behavior (UB), [20] (p. 229)
UB1	How many times do you use the platform during a week, overall?
UB2	How many minutes do you use the platform every week, overall?
UB3	You use the platform often
	System Quality (SQ), [21]
SQ1	The platform provides me with a fast response time
SQ2	The platform is reliable
SQ3	The platform is easy to access
	Information Quality (IQ), [21]
IQ1	The platform provides me with accurate information
IQ2	The platform provides me with relevant information
IQ3	The platform's information is easy to understand
IQ4	The platform's information is up to date

A total of 120 students were approached, and a paper-based questionnaire was used. Aa total of 113 usable completed questionnaires were received, and the response rate was 94%. Single-stage cluster-sampling was used for the main survey. There are 13 programs in the school. We randomly picked four of them and asked all students in those program. A total of 58% of respondents were female, and 42% of respondents were male. Age ranged from 18 to 21.

4. Analysis

Focus Group

During the focus group, students were asked the frequency of online learning platform, Moodle, usage in their study. They used to access Moodle once per week to get material. However, some of students relied on the efforts of their classmates to download these for them. That is to say, they were less likely visit Moodle.

"Paul used to download notes for our project groups; thus, we do not need to visit the platform so often.", Eva said. Ruby, Irene, and Wilson agreed with Eva.

Students, including Paul, used Moodle to download their lecture notes, to submit their assignments, to ask questions, and to read course announcements. Five of them were not aware that there was a discussion forum on Moodle and never used it. They discussed their coursework through Facebook and other discussion forums, such as Skype. They could see the faces of each other, as well as sending documents at the same time. They would use the forum on Moodle only when there were marks allocated for their discussion and contribution.

"We share our ideas and answers to the exercises on Facebook, because School would not monitor our activities, unlike Moodle ... except some activities count participation marks ... you know ... we did it on Moodle's discussion forum." Mary said.

Another reason for them not using the discussion forum on Moodle was that they did not want their discussion open to the teacher and other students which were not in their peer group and project group. They preferred to discuss among their peer group so that they would not lose their 'face.' Keeping face is a very important consideration in Chinese people's culture.

Irving commented, "I want to keep my idea discussed within my group before submitting to the teacher. The idea could be naive and might not be correct."

Tony said that at the beginning of the project, they would use Skype (more personalized) for brain-storming. At the middle and final stage of project, she would use Facebook, which can deal with documents and comments. Whatsapp would be used to make an invitation to have a meeting and for the clarification of questions.

I would say that the use of different software depends on the purpose of the meeting. Brain-storming or discussion needs real-time interaction. Whatsapp deals with an established task for confirmation. Another reason for them not using the discussion forum on Moodle is that it requires a username and password for the login-screen for security reasons. However, for Facebook, they are already login in.

"I know it is for the security reason, but I have to wait a minute before I access the content. In contrast, my mobile phone has already gone through Facebook. I made a response with my fingers." Susan said.

One more reason for using Facebook was that they know the respondents are online. When they send something to their teammates, they expect the respondent will give them back a reply immediately. In contrast, email is not used normally among students as they do not check their email very often. In short, Email is asynchronous, and social networking sites are synchronous.

5. Main Study

The conceptual model in this study was examined using partial least-square structural equation modelling (PLS-SEM), with the SmartPLS 3.0 statistical software. PLS-SEM requires less stringent assumptions about normality, which is more suitable for model development in an exploratory study and for analyzing small sample sizes [12]. The minimum sample size of the study should be equal to or larger than "10-times the largest number of structural paths directed at a particular construct in the structural model" [12] (p. 20). In this study, because the largest number of structured paths used for the behavioral intention was 6, the minimum sample size should have been larger than 60. Using PLS-SEM is appropriate with a sample size of 113, as in this study.

5.1. Measurement Model

The validity and reliability of the measurement items were evaluated in the measurement model. The reliability, internal consistency, discriminant validity, and convergent validity were assessed using the following guidelines [22]:

1. The indicator loadings were examined through a reflective measurement model assessment. Loadings above 0.708 are recommended, as they can explain more than 50% of the indicator's variance and provide acceptable item reliability.
2. The measurement model possessed adequate internal consistency reliability, as the composite reliability and Cronbach's alpha of all constructs exceeded the 0.70 criteria. Composite reliability values between 0.825 and 0.970 are classified as good.
3. The convergent validity of each construct was measured to explain the variance of its items. The threshold level for AVE should be 0.50 or higher to explain at least 50% of the variances of its items [22]. The average variance extracted (AVE) of each construct was higher than 0.50, ranging from 0.616 to 0.914, demonstrating convergent validity [22].
4. The discriminant validity was assessed by the heterotrait–monotrait (HTMT) ratio of the correlations. The threshold value is 0.85 [23]. Table 2 shows the measurement model assessment, and Table 3 shows the discriminant validity of each construct. All constructs were demonstrated to be reliable and valid. Therefore, we could proceed to assess the structural model.

Table 2. Measurement Model Assessment.

Construct	Item	Loading	Cronbach's Alpha	Composite Reliability	AVE
Facilitating conditions (FC)	FC1 FC2 FC3	0.841 0.832 0.838	0.912	0.945	0.851
Social Influence (IS)	IS1 IS2 IS3	0.938 0.929 0.720	0.835	0.901	0.754
Behavioral Intention (IB)	IB1 IB2 IB3	0.947 0.961 0.960	0.953	0.970	0.914
Use Behavior (UB)	UB1 UB2 UB3	0.832 0.888 0.606	0.706	0.825	0.616
Performance Expectancy (PE)	PE1 PE2 PE3 PE4	0.844 0.891 0.790 0.782	0.848	0.897	0.685
Effort Expectancy (EE)	EE2 EE3 EE4	0.693 0.942 0.947	0.839	0.901	0.755
Information Quality (IQ)	Q21 Q22 Q23 Q24	0.758 0.748 0.867 0.819	0.821	0.876	0.639
System Quality (SQ)	Q18 Q19 Q20	0.856 0.793 0.890	0.807	0.884	0.718

Table 3. Assessing Discriminant Validity (HTMT).

Construct	BI	EE	FC	IQ	IS	PE	SQ	UB
BI								
EE	0.636							
FC	0.663	0.762						
IQ	0.616	0.526	0.465					
IS	0.652	0.628	0.542	0.459				
PE	0.596	0.773	0.580	0.648	0.626			
SQ	0.606	0.811	0.564	0.772	0.549	0.767		
UB	0.420	0.567	0.368	0.232	0.306	0.335	0.547	

The R-adjusted squares of Social Influence, Behavioral Intention, and Use Behavior were 0.231, 0.549 and 0.136, which indicates that 13.6% to 54.9% of the variances were explained. The Q-square is used to assess predictive relevance. All three Q-square values ranged from 0.071 to 0.482, indicating that the model had a small to large predictive relevance.

The path coefficients and t-statistics were evaluated by conducting a bootstrap analysis (with 5000 subsamples and 113 cases). Figure 5 shows the PLS model result. The analysis showed that all the proposed relationships were significant. Table 4 shows the results of hypothesis testing.

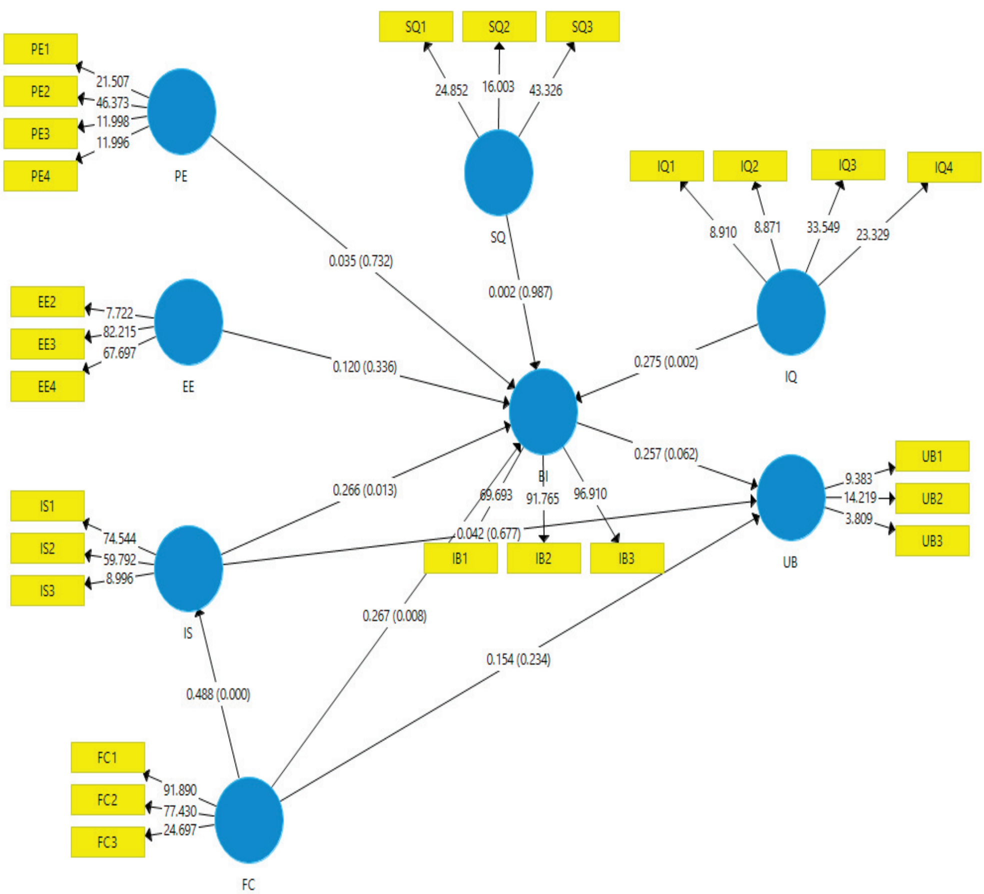

Figure 5. PLS model. (Source: authors).

Table 4. Results of Full Mediation Hypotheses Testing.

Hypothesis	Item	Path Coefficient	t-Value	p-Value	Result
Hypotheses 1, 9 & 10	FC >> IS >> BI >> UB	0.033	1.705	0.088 +	Supported
Hypothesis 2	FC >> UB	0.154	1.190	0.234	Unsupported
Hypothesis 3	FC >> BI	0.267	2.641	0.008 **	Supported
Hypothesis 4	IS >> UB	0.042	0.417	0.677	Unsupported

(Bootstrap samples = 5000, n = 113 cases); + $p < 0.1$; ** $p < 0.01$.

5.2. Hypothesis Testing

Hypotheses six and eight were unsupported. Effort efficiency was not associated with behavioral intention. Hypothesis five was not supported. This might have be due to the fact that the effect from social influence was so strong. Instead, hypothesis seven was supported (Table 5).

Table 5. Results of other Hypotheses Testing.

Hypothesis	Item	Path Coefficient	t-Value	p-Value	Result
Hypothesis 5	EE >> BI	0.120	0.963	0.336	Unsupported
Hypothesis 6	PE >> BI	0.035	0.342	0.732	Unsupported
Hypothesis 7	IQ >> BI	0.275	3.055	0.002 **	Supported
Hypothesis 8	SQ >> BI	0.002	0.017	0.987	Unsupported

(Bootstrap samples = 5000, n = 113 cases) ** $p < 0.01$.

6. Discussion

Facilitating Conditions, like a fast Wi-Fi speed, computing facilities, and mobile-friendly software, could lead to the intention of student-to-student interaction on an online platform. The findings of Hypothesis 3 of our study concurs with the previous result of researchers [9]. Given that the target respondents come from Hong Kong, a metropolitan city with good infrastructure, students are generally equipped with compatible hardware and software skills [24]. Thus, those "Facilitating Conditions" might not affect student-to-student interaction behavior (Hypothesis 2). The online platform system quality also cannot affect the intention of student-to-student interaction (Hypothesis 8). This is because students could use other means, like mobile phone applications and social media networking sites, to connect to each other. Instead, information quality can affect student-interaction intention (Hypothesis 7). If there is a new piece of information, like a model answer is uploaded by instructor, students are likely to share this piece of information to their classmates. Thus, quality information is a real driver of the intention of student-to-student interaction.

Our findings echo the results obtained from researchers [3]. We extend their result to the student-to-student interaction of online learning platforms. The influence from other people, like family members and peers, was found to be significant for the decision of young people. The findings of Hypothesis 1 of our study concur with the previous result of researchers [11]. Social influence is one of the mediators between the Facilitating Conditions and the student-to-student interaction behavior of online learning platforms. Social influence cannot affect student interaction behavior directly (Hypothesis 4), and a quasi-full mediation model was established.

The online platform is mature today, and students are used to making use of the platform regularly. Thus, the ease of using the platform (Hypothesis 5) and usefulness of the platform (Hypothesis 6) are not the determining factors affecting the intention of student-to-student interaction. Students' interaction is affected by other factors, like social influence [11]. In summary, Hypotheses 1, 3, 7, 9 and 10 were supported, and Hypotheses 2, 4, 5, 6, and 8 were not supported.

For parallel multiple mediation, a decision tree for single mediation can be applied [12,14]. Regarding serial multiple mediation, one more complication has to be considered. There are partial direct effects. For two mediators run in series, there are two partial direct effects in addition to one full direct effect. In our example, the Facilitating Conditions of Behavioral Intention and Social Influence of Use Behavior were two partial direct effects. We have to test whether these two effects were significant not or not before reaching the true full mediation. Otherwise, a multiple mediation may be named as a quasi-full mediation instead (See Figure 6).

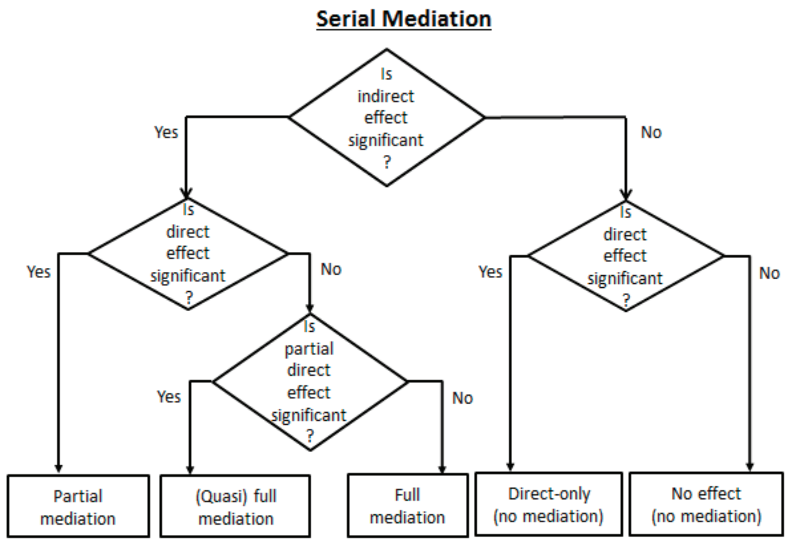

Figure 6. Serial Mediation decision tree (Source: authors).

Regarding the indirect effect from the Facilitating Conditions to the Use Behavior via Social Influence and Behavioral Intention, the *p*-value was found to be significant.

FC >> IS >> IB >> UB, t = 1.705, $p = 0.088 < 0.1$

Social Influence (IS) and Behavioral Intention (IB) were two mediators in a series manner.

There are three conditions for the true full mediation that we need to check.

First, we examine the effect of the initial independent variable on the final dependent variable, i.e., from the Facilitating Condition to the Use Behavior, directly. From facilitating conditions to Use behavior, FC >> UB, the *p*-value was 0.234, which is not significant (Table 4).

Second, we have to check the mid-way through effects. From the facilitating conditions to the behavioral intention, FC >> BI, the *p*-value was 0.008, which is significant. Finally, we need to check social influence to use behavior, IS >> UB. From IS >> UB, the *p*-value was 0.677, which is not significant.

Here, a quasi-full mediation is proposed, as the direct effect of FC >> UB was not significant, and FC >> BI was significant. Hypotheses one, nine and ten were supported, and hypotheses two and four were not supported, but hypothesis three was supported (Table 4).

It is worth mentioning that social influence and behavioral intention are subjective perceptions, while facilitation conditions and use behavior measure objective actions. Both the starting and ending constructs are visible variables. The two mediators are invisible constructs.

Facilitating conditions do not associate with use behavior directly but via social influence and behavioral intention. The resulting effect is significant at a *p*-value of less than 0.1, as the effect becomes weaker as it passes through more than one mediator.

7. Theoretical and Practical Implications

This study provides a new typology for serial mediation. Previously, there has been no distinction between a full serial mediation and a quasi-full serial mediation [25]. We propose that in order to be a full serial mediation, all of the partial direct effects should be non-significant. Otherwise, it should be a quasi-full serial mediation, as illustrated in the study.

The study provides an explanation of why facilitating conditions do not associate with use behavior in the UTAUT framework. Instead, Facilitating conditions, through social influence, affect the behavioral intention of student-to-student interaction. Furthermore, the underlying mechanism between facilitating conditions and student-to-student interaction behavior was uncovered. It is through the subjective perception of social influence and the behavioral intention of student-to-student interaction.

There are two implications for the design of e-learning platforms. First, the design of this technology should support the learning processes but not interfere with it. Second, computer technologies can have an influence on how young people think, study, and learn. The effectiveness of the design of the technology can be assessed by how it promotes young people to think, study, and learn [26]. A fast network, computing facilities, and mobile-friendly software are candidates for the virtual environment for student-to-student interaction on online platforms.

8. Conclusions

A new typology for serial mediation was proposed. The underlying mechanism between facilitating conditions and student-to-student interaction was uncovered (Hypotheses 1, 9 and 10).

Online learning has been developing for decades, and there have been some successes for internal (learning and teaching) and external (pandemic) reasons. Students not only need to communicate with the teacher, but also with their fellow classmates. Student interaction behavior is not affected by Facilitating Conditions and Social Influence (Hypotheses 2 and 4). Facilitating Conditions, Social Influence, and Information Quality are important factors affecting student-to-student interaction through online learning platform (Hypotheses 3 and 7). It enables learning to happen anytime and anywhere. The intention of student interaction behavior is not affected by Effort Expectancy, Performance Expectancy, and System Quality (Hypotheses 5, 6, and 8). It was found that students' participation rates in discussion forums varied a lot, and there were a lot of other communication tools, such as social media. Collaborative learning through student-to-student interaction and teacher-to-student interaction is also important. What college management should do is provide suitable infrastructure or an environment for students and teachers.

Researcher have time and money restrictions. Considerable information can be obtained from a population within certain time-period by the survey method [25]. The use of surveys assumes that respondents have enough recall of events and report this information accurately and completely. Other disadvantages of using the survey method are the unwillingness of respondents to provide the desired data and the ability of respondents to provide data. Furthermore, some respondents might be unwilling to tell the truth and answer personal questions [25].

The two major research designs in survey research are cross-sectional and longitudinal designs. In a cross-sectional design, a representative sample of the population is addressed at a specific moment. It is very useful for describing the status quo in a segment of the population, as in this study. However, the result of a cross-sectional survey may have a limited useful shelf-life, as variables change over time. Furthermore, it has limited application in examining the cause-and-effect relationship [26].

A longitudinal study is designed to observe and study phenomena over time. It allows researchers to track changes within particular individuals. A cause-and-effect study can be easily carried out, since it is generally agreed that cause must precede effect. However, it takes time and resources to conduct a large sample study, and lengthy studies suffer the problem of attrition. Attrition occurs when people drop out of a study before it has finished [26]. People with extreme scores have a natural tendency to become less extreme over time. A longitudinal design could be used in future studies because there is time gap between the intention of students' interaction and students' interaction behavior [26].

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Article

Learning through Digital Devices—Academic Risks and Responsibilities

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Abstract: The purpose of this study is to examine the risks of learning through digital technology and to design the individual and academic responsibilities. We propose answering the following research questions: Are higher education students and their families equipped with digital devices? What strategy do students use in their individual learning? How frequently do they get involved in various added digital activities (gaming, social media communication, surfing the Internet)? What are the risks of excess time spent online? A total of 2210 higher education students from five European countries, Romania, Slovakia, Hungary, Serbia, and Ukraine, participated in the quantitative study, the data being collected by the Center of Higher Education Research and Development at the University of Debrecen, Hungary in 2019. The analysis of the data is based on the advanced statistical test carried out with the SPSS program. The results indicated that most students come from families that possess essential digital devices (smartphone, PC, notebook) with an internet connection, regardless of the country of origin. The students' learning strategy is mixed: they use the virtual and real environment. More than half of the students declared that they never learn by watching tutorials or listening to audio recordings. Reflecting on themselves, more than a third of them stated that they generally spend too much time online. Daily surfing, gaming, and communicating on social networks are those added activities that significantly multiply their chance of spending too much time in a virtual environment. The binary logistic regression analysis proves that these students have a four times greater chance of developing a concentration crisis. In addition, it is characteristic for there to be a general time management crisis that implicitly contributes to the development of a deadline crisis in learning, and another risk is the duplication of intention to drop out of university.

Keywords: higher education students; academic learning; online time; risks

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1. Introduction

This explanatory study makes a diagnosis in a group of students in higher education who have learned in five European countries: Romania, Hungary, Slovakia, Serbia, and Ukraine. We examined their equipment, individual learning, and added activities through digital devices.

The presence of technology in the teaching-learning process is not a new phenomenon because laboratories, schools, or university workshops have existed for centuries. The seminar (laboratory) classes are an integral part of the curriculum and are aimed at making the connection between theoretical knowledge and its applicability and practical functionality, as well as practicing students in this demonstrative, innovative environment. Computer-assisted training is a didactic–learning method that capitalizes on the principles of modeling and cybernetic analysis of the training activity in the context of new information and communication technologies, characteristic of the post-industrial society. The process of the informatization of training reflects the huge progress made at the level of a cultural model that is gradually affirmed, on a social scale, through the development of information and communication technologies and the application of these technologies at the level of information services present in all spheres of human activity. The social trend of a massive endowment of people, the digitalization of modern formal learning, and the promotion of computer-assisted training as a new form of learning are being researched to establish their advantages and limits [1,2].

Several national and international social–political trends that focus on this topic have pointed out the economic, administrative, and social approaches of digitalization having a general, utilitarian prism of using technology, neglecting the individual dimension. One of the foundations of modern education in schools and universities is the principle of relevance. This refers to a requirement that education simultaneously responds to the personal development needs of beneficiaries and, at the same time, also adapts to social and economic needs. A question that arises, however, is how will the individual, human dimension function on the prism of the social and political goal of lifelong learning? Making a diagnosis to determine the needs of pupils and students focusing on learning through digital devices, establishing the existing individual and educational risks, is a requirement of the current society of the 21st century, centered on the education of the beneficiary [3–5].

In our era, the digital journey of the young generation starts during their socialization in their families in early childhood, and continues as students in schools and universities. Many parents provide digital technologies for education and learning purposes, and schools and universities use digital instruments in teaching. Students learning through these modern instruments is a new phenomenon, and many studies present the gaps in knowing the risks and the lack of critical thinking. The time spent online and the impact of digitalization on the young generation's development is a conflicted theme in the scientific articles. The literature exploring the lifestyle on digital use emphasizes a challenge for researchers, teachers, parents, and also youth, to determine where the limit is between the healthy and harmful use of the digital instruments and how much daily time spent online is too much [6–11].

Traditional learning is replaced by hybrid learning, which combines two learning environments: face-to-face and virtual. Their integration is a challenge for all actors involved in the learning process. The adaptation of the person to two environments, also synchronous and asynchronous, and the efficient management of time in both the real and the virtual environment is possible only by developing the skills and competencies necessary for this way of learning. Time and other personal resources management are to be learned. Connecting people and households to the Internet and equipping them with digital devices is a modern social goal, but the development of perception toward being reflexive, logical, and responsible for their activities is a condition of lifelong learning [12].

Lifelong learning means daily or weekly regularly learning and the continuous ability development of personal reflection and time management. "Personal, social and learning to learn competence is the ability to reflect upon oneself, effectively manage time and information, constructively work with others, remain resilient and manage one's own learning and career. It includes the ability to cope with uncertainty and complexity, learn to learn, support one's physical and emotional well-being, maintain physical and mental health, and to be able to lead a health-conscious, future-oriented life, empathize and manage conflict in an inclusive and supportive context." [13].

The first critical point of learning through technology is the inequality in equipping students with modern digital devices. Another critical point of the modern process is the individualization of modern learning. Digital technology allows for a high degree of individualization of formal learning, where students form their own rhythm of learning and particular strategies, but, at the same time, the danger of psychosocial isolation arises. Another critical point concerns the ever-changing web context. The online learning environment does not provide stability in time for young people but facilitates the continuous search for novelties [14–16]. In light of this, a question arises: how does the use of informal searching and other added virtual activities (gaming and communication on social platforms) affect students' individual learning time and concentration ability?

At the level of European countries, the general endowment of households with the Internet shows inequalities. The population of the countries in the former Soviet bloc with Internet access experienced exponential growth after the political changes of 1989 (Figure 1). In 2019, in Slovakia and Hungary, over 80% of the population was considered as individual Internet users, and, in Romania, over 70% [17].

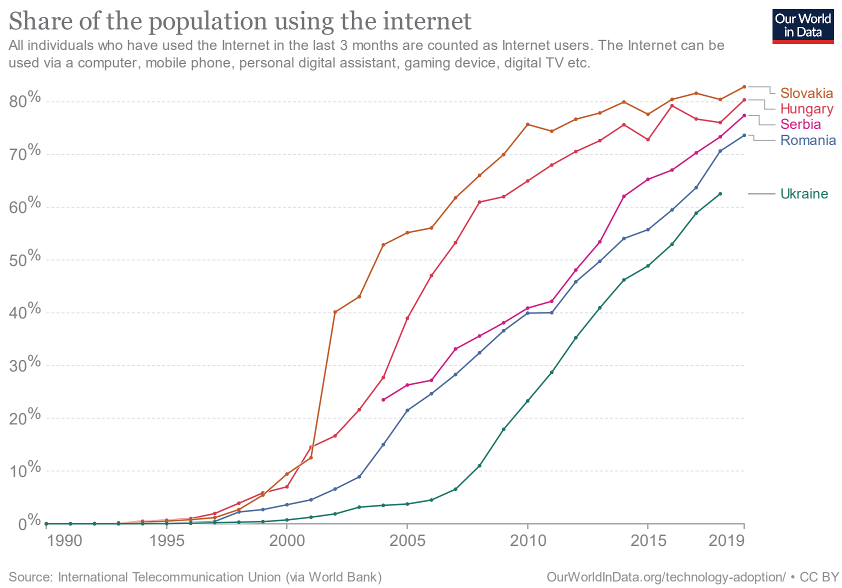


Figure 1. The percentage of the total population with access to the Internet. Source: https://ourworldindata.org/internet#internet-access, accessed on 15 April 2022.

This inequality is particularly evident in the assessment of digital skills. At the European policy level, the European Commission's Communication on the Digital Education Action Plan defines digital competence as "the confident, critical and responsible use of digital technologies, as well as their use for learning, in the workplace and for participation in society." [13]. Although such a large percentage of the population of European countries has been connected to the Internet in the last 30 years, through various digital devices, the group of people aged 16–74 who have basic digital skills was much narrower in 2021. In the EU countries targeted in this study, Slovakia, Hungary, and Romania, the biggest gap is in Romania. Out of the total population, over 70% use the Internet individually, but the percentage of those who have at least basic digital skills is below 30%. This gap is smaller for the young generation in Romania, aged between 16 and 24: approximately 50% of them have basic digital skills, but young people of the same age in Slovakia and Hungary are around 70% [18,19].

Following the analysis of these international statistics, it can be concluded that it is not enough to just increase the number of people with access to the Internet through various digital devices. Real inequalities can be reduced by educating these people and especially the younger generation in the confident, critical, and responsible use of digital technologies, as well as their use for learning, in the workplace, and participation in society.

2. Materials and Methods

The Center for Higher Educational Research and Development from the University of Debrecen, Hungary, CHERD–H (https://cherd.unideb.hu/en, accessed on 12 December 2019), based on contract No. 1908/23 November 2018, led international quantitative research, named PERSIST (http://www.persist.unideb.hu/en/palyazatrol, accessed on 12

December 2019), on the topic of university dropout. The questionnaire had items referring to the digital devices' dotation, virtual learning strategies, added online activities, and dropping out reasons (learning, concentration, and time management crisis). Students from different European universities completed this complex questionnaire. In 2019, the database was finalized and led to statistical analysis of the data. The database was completed by 2210 students from five European countries (Table 1). The partner university institutions that participated in this study were the following:

- From Romania: the Babeș–Bolyai University with 163 students, the Emanuel Univesity from Oradea with 112 students, the University of Oradea with 173 students, Sapientia Hungarian University of Transilvania with 135 students, the Partium Christian University from Oradea with 156 students.
- From Slovakia: the Selye János University (SK) with 98 students, Constantine the Philosopher University in Nitra with 31 students.
- From Hungary: the University of Debrecen with 805 students, the Debrecen Reformed Theological University with 100 students, the College of Nyíregyháza with 113 students, St. Athanasius Greek Catholic Theological Institute with 27 students.
- From Serbia: (SB) the University of Novi Sad 97 students.
- From Ukraine: the Ferenc Rákóczi II Transcarpathian Hungarian Institute with 105 students, the Mukachevo State University with 10 students, Uzhhorod National University with 74 students.

Table 1. Countries included in the study and the number of higher education students (N). (Source: PERSIST 2019).

Country	N
Romania	739
Hungary	1045
Slovakia	129
Ukraine	189
Serbia	97
Missing data	11
Total	2210

In this study, the answers to the following research questions were looked for: Are students and their families equipped with digital devices? What strategy do students use in their individual learning? How frequently do they get involved in various added digital activities (gaming, social media communication, surfing)? What are the risks of excess time spent online?

3. Results

This section is divided into five dimensions: at first, we will present the student sample and the demographic and academic characteristics of them. Secondly, the family background on digital equipment dotation and the subjective material situation of the students are presented. After that, we examine the individual learning strategy and student's reflection on time spent online. We will finish the presentation of the results connecting the excess time spending on the virtual environment and the risk of academic learning crisis.

3.1. Demographic and Academic Characteristics of the Student Sample

In this study, participants were 1494 females and 638 males, with an average age of 23 years. Most of them (83%) were in their second- or third-year bachelor's degree (B.A.), and the rest of the students were in their master's degree (M.A.), in the academic year

2018–2019. The following Table 2 presents the student sample by their academic field of study. The 20,210 respondents came from a broad spectrum of specializations: teacher education, arts, economic, medical, social and natural sciences, technical, IT, agricultural, law, and theology domains.

Table 2. Students' specialization fields (N = 2210). (Source: PERSIST 2019).

Country	**N**
Teacher education	489
Arts	324
Economic	282
Medical	202
Social sciences	186
Natural sciences	140
Engineers	126
Agricultural	116
Informatics	115
Art	75
Law	63
Theology	55
Other	37
Total	2210

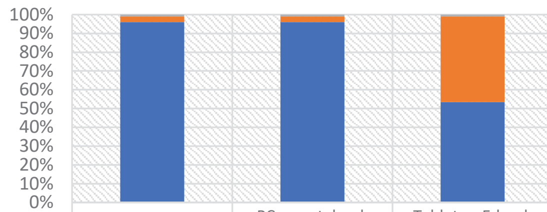
3.2. The Family Background of Students and the Digital Equipment of Them

A total of 28% lived in large cities (municipalities), 34% in small towns, and 38% in rural areas by the age of 14. Almost half of the students (49%) grew up in a family with two children, 21% have two more brothers or sisters, 11% grew up in a large family with four or more children, and 19% have no brothers or sisters. Their mother's educational level was 26% primary, 41% secondary, 32% higher education, and 1% never met their mother. Their father's educational level was 34% primary, 37% secondary, 27% higher education, and 2% never met their father. Most families (56%) had an approximately average material situation compared to the family peers. A total of 35% declared that their family is in a better or much better situation than their peers, and 9% were below the average level, according to the subjective perception of the students. A total of 10% of the students perceived negative changes regarding the material situation of the family during their academic studies.

In the next figures, it is noticed that most of the families of origin had in their possession a smartphone, mobile phone, personal computer (PC), or notebook, with access to the Internet. Moreover, more than half of the students had a tablet or e-book reader (Figure 2).

It can be stated that the families of students' essential digital equipment (smartphone, PC, notebook) were generally good, with access to the Internet (Figure 2). Most students came from families that own essential digital devices, regardless of their country of origin. Only a small percentage (3%) were deprived of these goods. These results show a higher dotation of the families compared with their countries' average [17].

Examining the individual material situation, a third of students (31%) declared that they have everything that they want and can spend significant sums, such as trips abroad or buying expensive things. The majority (62%) had everything that is necessary but could not afford large expenses. A minority group (7%) of the students (a total of 143) often experienced a lack of money for their daily needs. The relative digital equipment dotation shows that 56% of students could not afford a smartphone that was more expensive than others, 59% did not have a more expensive PC or notebook than others, and 70% did not own tablets or e-book readers. It is important to underline that, at the individual level of the total sample, 626 students possessed tablets or e-book readers, according to the country of origin: 335 from HU, 142 from RO, 48 from SK, 53 from the UA, 14 from SB. According to their material situation, most of them could buy, but the results indicate that these digital devices were not among the preferences of students.

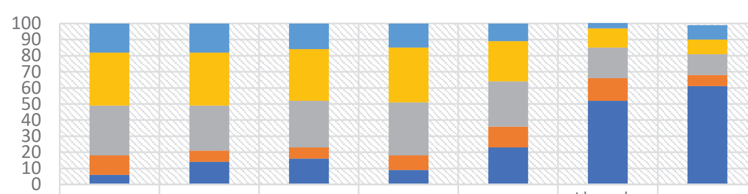


	SmartPhone	PC or notebook with internet acces	Tablet or E-book reader
Total	100%	100%	100%
No	3	3	46
Yes	97	97	54

Figure 2. Digital devices in the student's family (N = 2210) (%). (Source: PERSIST 2019).

3.3. Individual Academic Learning Strategies and the Use of Digital Technology

Examining students' learning strategies, we considered the next question: How frequently do you read bibliographies specific to your field of specialization (in traditional mode, reading books or through technology)? Approximately two-thirds of students (64%) regularly read specific literature (9% of students read daily, a quarter read weekly, and 29% monthly). At the same time, it is important to note that a third of students do not read bibliographies at all, or very rarely. In addition, there are many strategies for individual learning. The literature review suggested the mixed mode, which is the combination of the classic (make notes, figure, highlight important information, read the material loudly or silently) with the digital one (read slide show, watch videos, listen to audio recordings). Figure 3 presents the frequency (daily, weekly, monthly, rarely, or never) of students who preferred individual learning strategies in real and virtual environments.



	I make notes, figures when I learn	I highlight important information in the book	I learn by reading silently the material	I learn through ppts, illustrations	I learn by loud reading	I learn by watching videos, listening records	I use other strategies on learning
daily	18	18	16	15	11	4	9
weekly	33	33	32	34	25	12	9
monthly	31	28	29	33	28	19	13
rarely	12	7	7	9	13	14	7
never	6	14	16	9	23	52	61

Figure 3. What strategy do students have in the process of individual preparation and academic learning? (N = 2210) (%). (Source: PERSIST 2019).

Next, factorial analysis was performed on the main components based on five variables of the learning strategies. Three factors were extracted as a result of the orthogonal rotation of the factors, thus determining the factorial structure in Table 3, which represents 75% of the initial variance (the first factor 28%, the second 27%, the third 20%). The latent structure was connected to both the real and virtual environment: they mark information, read the material, listen to audio recordings, or watch tutorials. The following pattern emerged in Table 3: learning by marking, learning by reading, and learning by listening or watching.

Table 3. Structure analysis of learning strategies. (Source: PERSIST 2019).

	Learning by Marking	Learning by Reading	Learning by Listening or Watching
I make notes and figures	0.840		
I emphasize important information in the book	0.789		
I read silently the materials		0.877	
I learn through slide show, illustrations		0.717	
I watch tutorials or listen to audio recordings			0.980

3.4. Reflection on Added Digital Activities and the Time Spent on Virtual Environment

Several studies have been conducted researching added digital activities of the people and the risk generated [20–24]. We continue with the premise that students are usually involved in actions in the virtual environment, in addition to their academic learning duties: they communicate on social networks, surf the Internet, play games, and listen to music. The proportion of students with digital implications is included in Table 4: their more preferred daily activity is the communication on the social networks and they less prefer to listen to music when they learn.

Table 4. The frequencies of added digital activities of the students (N = 2210) (%). (Source: PERSIST 2019).

	Never	Rarely	Monthly	Weekly	Daily
I communicate with others on social networks	2	5	3	18	73
I surf the Internet or play games	10	12	5	29	45
I listen to music when I learn	40	9	18	20	14

The added digital activities (the communication on social networks, surf the Internet, or play games) increase the time that youths spend in an online environment [25–27]. More than a third of 2210 students declared ”all the time” or ”mostly yes” regarding whether they spend too much time online (Figure 4). The variable “I spend too much time online” was converted to a variable dichotomy: 0—no (never, mostly not), 1—often (all the time, mostly yes).

How do students spend their excess virtual time? Does time spent online mean learning (to read special bibliographies, slide show, illustrations, watch tutorials, listen to audio recordings) or include communication on social networks and carrying out other digital activities (gaming, surfing)? The Chi-square test analyzes the association between student’s excess time spent online and different virtual activities. The variable “I spend too much time online” was converted to a variable dichotomy: 0—no, 1—often. There is no significant association between the excess time spent online and the specific learning activities (Table 5). The significant association appears due to communication on social networks ($p = 0.000$), and surfing and playing games on the Internet ($p = 0.000$). These added activities significantly multiply the student’s time spent in the virtual environment. The time spent online nearly doubled in the student’s group who communicate daily on social networks (OR = 1.8) compared with the group who communicate rarely. The odds of spending too much time online were double the amount for the higher education students who surf the Internet or play games daily (OR = 2.3).

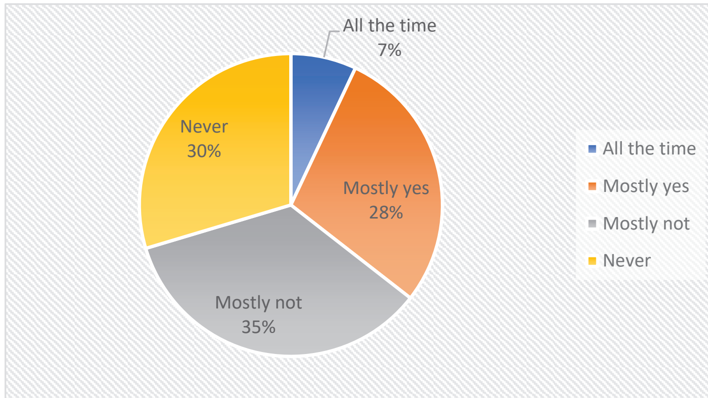


Figure 4. Is it characteristic of you to spend too much time online? (N = 2179) (%). (Source: PERSIST 2019).

Table 5. The association of added digital activities and time spending online (N = 2210) (%). (Source: PERSIST 2019).

I Spend Too Much Time Online	I Communicate on Social Networks		I Surf the Internet or Play Games		I Read Bibliography		I Learn by Slide show and Illustrations		I Watch Tutorials and Listen to Records	
	Daily	Not Daily	Daily	Not Daily	Often	Not Often	Often	Not Often	Often	Not Often
no	917	419	504	836	855	481	725	441	271	1042
often	592	148	425	308	472	271	387	259	150	577
N	2076		2073		2079		1812		2040	
OR	1.8		2.3		1		0.9		1	
Sign.	$p = 0.000$ ***		$p = 0.000$ ***		NS		NS		NS	

*** $p \leq 0.001$, p—level of significance.

3.5. This Self-Reported "Too Much Time Online" Can Lead to a Learning Crisis? The Crisis of Concentration in the Classroom, in Handling Deadlines, and the Danger of Dropout

Concentration and time management factors appear important in students' learning process: concentration in the classroom activities, sufficient time for individual preparation, and managing deadlines. The chi-square statistical test examination reveals the association between self-reported "too much time online" and students' learning problems. As we can see from data in Table 6, students who spend too much time online tend to have higher problems with their own concentration resources and managing time. The odds of concentration and time management crisis significantly multiplied for the students' group who spent too much time online, and their intention to abandon their university studies was nearly doubled.

The variable "I spend too much time online", converted to the variable dichotomy of 0—no, 1—often, was used as an independent variable in binary logistic regression analysis. We also included demographic factors (country of origin, sex, mother and father education level, the number of brothers and sisters, if students own expensive laptop or smartphone). Dependent variables are related to concentration in the lectures or to the situation where there are more interesting things to carry out, and, on the other side, with deadlines and general time crisis. Those who spend too much time online are four times more likely to develop concentration problems in the classroom. If they encounter new things, their chance of losing the ability to concentrate on learning doubles. The "too much time online" variable can generate crises of time and implicitly contributes to the development crises in the preparation of the written papers for seminars and exams. An expensive laptop can significantly reduce the deadline time crisis of students (p = 0.002, ExpB = 0.6), but not the general time crisis. Thus, the excess time spent online induced general crises of concentration and time (Table 7).

Table 6. The significant association between time spent online and learning crisis. (Source: PERSIST 2019).

I Spend Too Much Time Online	Concentration Crisis in Class		Concentration Crisis in Searching		General Time Crisis		Deadline Time Crisis		Abandon Intention	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Never
no	248	1147	985	406	426	966	1217	161	539	848
often	349	424	407	359	410	355	570	191	401	367
N	2168		2157		2157		2139		2155	
OR	3.8		2.1		2.6		2.5		1.7	
Sign.	p = 0.000 ***		p = 0.000 ***		p = 0.000 ***		p = 0.000 ***		p = 0.000 ***	

*** $p \leq 0.001$, p—level of significance.

Table 7. Too much time online is a predictor of the concentration and time crises. (Source: PERSIST 2019).

Independent Variables	Dependent Variables							
	Concentration Crisis in Class		Concentration Crisis in Searching		General Time Crisis		Deadline Time Crisis	
	Exp (B)	Sig.	Exp (B)	Sig.	Exp (B)	Sig.	Exp (B)	Sig.
I spend too much time online (0—no, 1—yes)	4	p = 0.000 ***	2	p = 0.000 ***	2.6	p = 0.000 ***	2.5	p = 0.000 ***
Brothers and sisters' number (0—many, 1—alone or one)	0.9	NS	0.9	NS	1.0	NS	0.9	NS
Country (0—other, 1—RO)	1	NS	0.7	NS	1.0	NS	0.8	NS
Sex (1—male, 0—female)	1	NS	1	NS	1.0	NS	1.5	p = 0.003 **
Expensive mobile phone (0—no, 1—yes)	0.9	NS	NS	1.2	1.0	NS	1.2	NS
Expensive laptop (0—no, 1—yes)	1	NS	1	NS	0.9	NS	0.6	p = 0.002 **
Mother education level	1.1	NS	0.9	NS	1.1	NS	0.9	NS
Father education level	1	NS	0.8	NS	0.8	NS	1	NS

*** $p \leq 0.001$, ** $p \leq 0.01$, p—level of significance.

Finally, we analyzed if it is possible for added online time to increase the chances of students intending to abandon their studies. The binary logistic regression analysis was conducted to answer this question: the answer was yes (Table 8). Was there a significant correlation (p = 0.000) between the independent variable: I spend too much time online and the dependent variable: Do you think of abandoning your studies? We also included demographic factors (country of origin, sex, mother and father education level, the number of brothers and sisters, if students own expensive laptop or smartphone). Regarding the student group who spends too much time in a virtual environment daily, their chance of abandoning higher education studies nearly doubled (ExpB = 1.7).

Table 8. Too much time online is a predictor of university drop out. (Source: PERSIST 2019).

Independent Variabile	Dependent Variable	
	Do You Think of Abandoning Your Studies?	
	Exp (B)	Sig.
I spend too much time online (0—no, 1—often)	1.7	$p = 0.000$ ***
Brothers and sisters' number (0—many, 1—alone or one)	1	NS
Country (0—other, 1—RO)	0.8	NS
Sex (1—male, 0—female)	1	NS
Expensive mobile phone (0—no, 1—yes)	1	NS
Expensive laptop (0—no, 1—yes)	1	NS
Mother education level	0.9	NS
Father education level	0.8	NS

*** $p \leq 0.001$, p—level of significance.

4. Discussion

In the process of the individual, family, community, and social spread of digital devices, the economic, administrative, and educational utilities are pronounced and the advantages of using these innovations are emphasized [28]. However, European statistical data show that, within the population aged 16–74, the digital skills necessary for lifelong learning, with an educational and professional purpose, have not been developed [19]. Learning to learn and work through these digital devices is a much more complex task than learning to use these innovative devices of the twenty-first century [29]. The results of this study show that 97% of the total of 2210 students who attended university studies in the academic year 2018–2019 in five European countries (Romania, Slovakia, Hungary, Serbia, and Ukraine) had access to the Internet in their family of origin. This is a much higher result compared to the general population of the countries involved in this study (Figure 1). Only 3% of the sample of students were deprived in 2019 of this innovation; they did not have these digital devices in their possession and did not have access to the Internet in their families of origin. When analyzing students' preferences regarding digital devices, 70% of the sample of students did not possess an individual e-book reader or tablets, which is a result that directs us to the next step of the study, in which, we approached their learning strategies. According to the specialized research, following the educational spread of these digital devices, in many educational institutions, they switched to a mixed method of teaching–learning [30]. This method is also confirmed by our results, where the individual learning and academic preparation of students is mixed: they make notes and schemes from the learned subject, mark important information on books, read the subject, and learn through slide show, illustrations, videos, and recordings. The statistical structure analysis has led us to three individual learning strategies: learning by marking, learning by reading, and learning by listening or watching. Of these three strategies, the least preferred is the last; that is, 66% of students never or very rarely watch tutorials or listen to recordings for learning purposes. In their individual learning, they regularly prefer the other strategies: 51% learn by marking, 49% through slide show or illustrations, and 48% learn by silently reading the material. A third of students use these popular methods with a monthly regularity. It is worth mentioning that 18 to 23% of students do not read the educational material regularly (not even monthly) and use these learning strategies very rarely (annually or never). Preparing materials for individual learning purposes, university institutions have the responsibility to know the student's preferences and to offer the possibilities of mixed learning in order to develop their competency in mixed academic learning from the first year of study. It is recommended that specializations elaborate for the first-year students a reference book of the theoretical and practical university training as a learning support in their individual and professional preparation. Equally, it is important for them to learn to use digital platforms and online resources of the university [31,32]. Students have a responsibility to choose and develop their own academic learning strategies, which they can regularly use in their preparation and individual learning.

In the second part of the study, we focused on the management of own resources—the time and concentration of students—because these are based on learning and working activities. Due to the fact that digital devices are useful not only for learning and working purposes, but also for communication, socialization, and leisure purposes, and since students did not know the danger and the risks, we asked students to reflect on the digital activities that they are involved in and the time spent online, in addition to their academic responsibilities. According to our results, the most preferred digital activity is communicating with other people through social networks. A total of 73% of the total of 2210 students use this digital mode of communication with others on a daily basis. A total of 74% frequently (daily or weekly) use their digital devices for surfing the Internet and gaming. Almost half of them (49%) never or very rarely listen to music during learning. According to the scientific literature [33], these digital leisure activities overlap with the other physical or virtual activities and responsibilities, where people most frequently use multiple tasks in both the real and virtual environment. They simultaneously engage in several tasks and activities. Operating efficiently in and between these two environments, in the long term, requires the development of special skills and competences. Learning by using the physical and virtual environment (or mixed learning), as well as simultaneous involvement in learning and digital leisure activities (communication on social networks, surfing on the Internet), are complex activities whose efficiency is researched, presenting many dilemmas [34,35]. One of these concerns is time management [36–38]. According to our results (Figure 5), the subjective excess time spent in the virtual environment is due to digital leisure activities (communication on social networks, surfing the Internet and gaming) and not due to learning tasks. These added digital activities require added virtual time, and the risk that the student will experience a general time crisis is 2.6 times higher compared to those who do not spend excess time in the virtual environment. In addition, an excess of virtual time has 2.5 times more of a chance of inducing a crisis of academic learning due to failure to keep to the deadlines (timely completion of academic assignments, essays required by the teacher). The chance of dropping out of the academic studies almost doubled for students who spent excess time in the virtual environment.

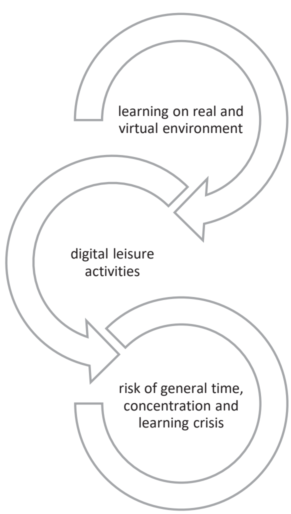


Figure 5. Simultaneous involvement in learning and digital leisure activities risks a learning crisis.

Another dilemma is the management of individual resources, under which, in this study, we understand the capacity of individual concentration, specific to the human brain, as very important in the learning process [39,40]. According to our results, students who spend too much time online have an almost four times higher chance of developing a crisis of concentration, which implicitly negatively influences individual or classroom academic learning (Figure 5).

These results were also supported by our advanced statistical tests, where the variables were controlled by the variables characteristic of the demographic situation.

5. Conclusions

The purpose of this study was to determine if higher education students were equipped with digital devices in 2019, to examine their individual learning strategies, and to design some risks and responsibilities in using this equipment. The study subjects were from five European countries: Romania, Slovakia, Hungary, Serbia, and Ukraine. Students reported their family digital equipment, their individual material situation, and their learning strategies in the real and virtual environment, and reflect on their added digital activities and their time spent online. We found that most of these families were equipped with essential digital devices (smartphone, PC, notebook) and 3–7% of them were deprived of these goods. These students had material risk in academic integration, and the responsibilities of the universities are to support these students in procuring digital devices for learning purposes and to develop digital skills. After analysing individual academic learning strategies and the use of digital technology, we found a latent structure of the learning strategies of students. We conclude that they were connected with the real and virtual environment in their individual preparation. The students' favorite mode of learning is to silently read the material on a traditional (book) or digital format and to mark important information. More than half (52%) of them declared that they never learn by watching videos (tutorials) or listening to records (audio recordings); they mostly prefer the summarized way of learning: watching or reading slide show and illustrations. The academic responsibilities of the universities are to support students' digital socialization in universities. Teachers have to prepare the academic materials on accessible (traditional and digital) formats, in a summarized way, to develop students' competency toward mixed learning. Students have the responsibilities to find the best individual strategies for learning and to practice through academic preparation. On the final part of this paper, we explored the student's subjective time management and concentration capacity. They learn by using the physical and virtual environment with mixed strategies, and, simultaneously, are involved in learning and digital leisure activities (communication on social networks, surfing and gaming daily on the Internet). It was found that the excess of time spent online can induce general crises of concentration and time. The added digital activities require added virtual time, and the risk that the student will experience a general time crisis has a 2.6 times higher chance compared to those who do not spend excess time in the virtual environment. In addition, the excess of virtual time has a 2.5 times greater chance of inducing a crisis of academic learning due to the failure to keep to the deadlines and to concentrate in order to learn, and the intention to abandon the university study was nearly duplicated.

The practical significance of these findings is that students need to be supported in digital socialization in higher education and in their individual academic learning, includ time and resources management in the same way.

The role of universities and teachers is to educate students on individual responsibility, develop critical thinking toward using digital devices, learn to structure time, and support the ability to concentrate in such a way as to avoid learning crises and academic dropout.

The pandemic period has accelerated the digital transformation of universities around the world, creating their own innovative, special experiences, which have a practical significance for the future [41–43].

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Doctoral School on Human Sciences, University of Debrecen, Hungary.

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education sciences

Article

Impact of Educational Gardens and Workshop Activities on 8th-Grade Student's Perception and Knowledge of Plant Biology

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Abstract: Educational gardens can be a significant resource in the promotion of environmental education, engaging both the school population and the general public. The main goal of the present study was to implement and assess a hands-on interventional program to promote knowledge and awareness of plant-related topics at a basic school level. We report on a hands-on educational project implemented with 8th-grade Portuguese students (mostly 13–14 years of age), associated with the establishment, on school grounds, of three educational gardens representing distinct Portuguese ecosystems. This was a collaborative project and encompassed several activities and subjects, including garden creation, plant propagation and plant care, plant identification, the study of form–function relationships, and lectures by plant researchers. A survey instrument with pre- and post-test assessments demonstrated the effectiveness of the program in raising student knowledge and awareness on topics centered around the native flora. Specifically, we noted that scores increased in all questions addressing different plant biology-related topics in the post-test assessment. This study supports the benefits of incorporating field/laboratory work and educational gardens in educational programs geared toward plant-oriented environmental education.

Keywords: educational gardens; environmental education; native flora; invasive species; plant biodiversity

1. Introduction

Environmental education within schools can be fundamental for intellectual growth. By presenting social alternatives and exposing their advantages and disadvantages, environmental education ultimately enhances awareness of environmental problems, promoting a change in student attitude [1]. Fostering connectedness to nature should be a goal for environmental education programs, and there is an increasing consensus within the scientific community that educational gardens play an important part in this effort. An educational garden is one that, in an appropriate context (e.g., on school grounds), is used mainly for educational purposes and should not be mistaken with other public sites (e.g., outdoor recreational spaces). Educational gardens can be themed toward different subjects, including awareness of the loss of biodiversity, climate change, the proliferation of invasive plant species, or a recognition of the interdependence of people and plants [2,3]. Gardens within the school context also engage students to cultivate an interest in science within a holistic and real-world context [4], but unlike remaining outdoor recreational spaces on school grounds, educational gardens typically cover a variety of subjects relevant to the school's curriculum. Gardens are particularly suited to foster plant-oriented environmental education, and we hypothesized that the implementation of a large educational program anchored on novel educational gardens would increase student knowledge on three plant-oriented topics (native vs. invasive species, plant species identification, and plant adaptability). The present study was motivated by a specific research hypothesis: are educational gardens focused on Portuguese native flora effective for increasing plant-oriented environmental knowledge and awareness when students are involved in field/experimental work on school grounds?

1.1. Benefits of Educational Gardens

At present, there is a strong theoretical framework to support the multiple advantages of educational gardens. Young students tend to define and visualize a good and healthy environment as being outside in a safe, clean, green, and inhabitable space [5]. Research has shown that environmental gardens may enhance student learning by incorporating a hands-on approach to experiential learning, impacting both personal and educational levels [6]. Additionally, these gardens can lead to improved performance and well-being as a result of student engagement [7,8]. Many educators are re-discovering the value of gardens as places for learning in educational institutions, including school and university communities [9–12]. Teachers trust that gardens encourage academic instruction, and it was demonstrated that school gardening can improve students' test scores and school behavior [13]. According to Strgar [14], when appropriate methods are used, teacher involvement can significantly increase the interest in less attractive subjects. The specialized knowledge, enthusiasm, and interest of the teacher or of an informal science educator can greatly enhance the student's interest. As such, the extent of teacher perception of the significance of educational gardens has also been recently studied [3]. Gardens are naturally suited toward the exploitation of plant-oriented topics, but their impact can be extended outside this scope. For instance, with didactic farms, children and young people come into contact with domesticated animals and perceive the reality behind the animals that provide various functions, such as clothing or food. Working with living organisms as a whole is an effective way to improve the quality of biological education since it provides information/experiences that are not accessible via reading, viewing pictures, or examining models [15,16]. Additionally, these gardens provide opportunities for field courses, which improve integrative learning, resulting in learning gains that are recognized and appreciated by students [17].

1.2. Plant-Oriented Environmental Education

As stated, the natural calling of educational gardens is the deployment of plant-oriented topics. We wished to amplify the existing body of literature regarding the interdependence of educational gardens and plant-oriented environmental education, favoring environmental rather than biological science education. We identified three topics around the concept of native flora that are of timely interest: native vs. invasive species, plant species identification, and plant adaptability to climatic variables. For theoretical support, it has been acknowledged that botanical gardens have become important settings for the development of educational programs that increase awareness of the interdependence of people and plants and promote an individual's willingness to protect the environment [18]. The fruition of an educational garden can promote motivation toward the protection of the environment. Gardens can address issues such as native plant species [2], and in this regard, we hypothesize that knowledge of the existing flora and the capacity to identify species can have a motivational role. However, due to the changes in vegetation in urban and peri-urban environments, it is often difficult for children and young people to have contact with forests dominated by native trees since the peripheral areas of large cities are dominated by forest plantations of exotic species that were introduced to areas from outside its native range [19]. As such, educational gardens have an added intrinsic value within the urban environment. This interconnects with the issue of non-native species. A work involving students aged 13 to 15 confirmed the effectiveness of a workshop on invasive plants to raise awareness of this matter [20]. In it, researchers emphasized the identification and management of invasive species and investigated the relationship between native/invasive species, clearly demonstrating the success of the strategy to raise students' knowledge and information retention [20]. The presence of exotic plants in ecosystems does not necessarily represent a significant problem unless these species display the potential for invasion, triggered by advantages such as the absence of pathogens, greater resistance/adaptation, or rapid growth [21]. Under these circumstances, invasive species can spread over large regions and at a considerable distance from the parental specimens [22]. Human beings are potential carriers regarding the introduction and spread of these species, and their deliberate or accidental introduction in ecosystems determines important changes, such as biodiversity reduction [2]. Pimentel and co-workers estimated that the economic cost associated with invasive species impact and control exceeds USD 120 billion per year in the United States, and in this sense, the most adequate strategy is to prevent their introduction [23,24]. According to the Portuguese legislation (Decreto-Lei nº 92/2019, Ministério do Ambiente, 2019), 200+ plants are considered invasive in Portugal. Almeida and Freitas [25] state that more than 15% of the Portuguese flora is composed of exotic plants. Given this reality, public awareness regarding the danger of exotic plants and the significance of Portuguese native flora is important. However, the majority of the population is not conscious of this problem, and in order to increase awareness, environmental/scientific education must be a priority.

1.3. Target Group and Methodology

Considering that educational programs targeting young people contribute to a future generation of scientifically literate and environmentally conscious citizens, the main driver of the present study was to implement and assess a hands-on interventional program to promote knowledge and awareness on plant-related topics at a basic school level (8th-grade, mostly 13–14 years of age). This target group was selected considering that the Portuguese 8th-grade biology teaching curriculum includes global issues such as ecosystem management, Earth's sustainability, and spatial planning. Further, 8th-grade students are still at a vital age where they are well attuned to becoming familiar with environmental education [26]. Additionally, we engaged all of the school community in the promotion of environmental protection. The project included socio-cultural and scientific activities that encouraged the presence of parents in the school and promoted interactions between students, parents, and teachers. We applied a pre-validated survey instrument before and after the activities to quantify the effectiveness of our approach to raising awareness of plant-based topics and used a control group from a different school to provide statistical support to our findings. Ultimately, we demonstrate the usefulness of educational gardens in increasing knowledge of different aspects of Portuguese native flora.

2. Materials and Methods

2.1. Research Design

The main objective of the present study was to address the following research question: can a multi-tier educational program on Portuguese native flora, anchored on the creation of educational gardens and fostering direct interplay with plant researchers, increase plant-oriented environmental knowledge and awareness in 8th-grade students? The research design (Figure 1) consisted of the implementation of a comprehensive educational program in one school anchored on the creation of educational gardens on school grounds. A second school was deprived of the educational program and served as the control ecosystem. The instrument chosen for the quantitative analysis of the program's effectiveness was a pre-validated questionnaire coupled with a pre- and post-test assessment strategy (Figure 1). The sampling strategy consisted of convenience sampling across eight 8th-grade classes. The questionnaire addressed three variables/topics, namely Invasive, exotic and native plant species (five items), Plant species identification (three items), and Plant adaptability to climatic variables (three items).

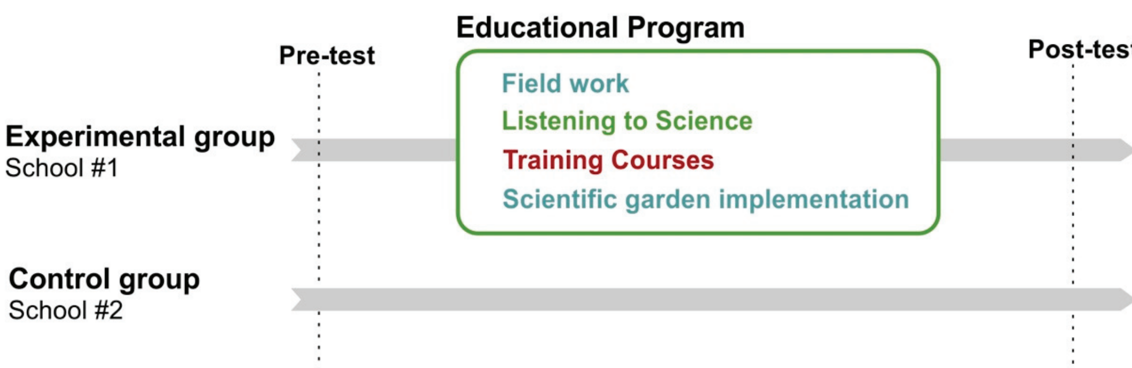

Figure 1. Research design of the study.

2.2. Participants

The activities took place between May 2013 and July 2014. This study involved two public schools: EB 2/3 D. Maria II (experimental group; n = 92) and Escola Básica Conde de Arnoso (control group; n = 58), both belonging to the School Cluster D. Maria II, V.N. Famalicão, in northern Portugal. The EB 2/3 D. Maria II School is located on the outskirts of the city of Vila Nova de Famalicão and Escola Básica Conde de Arnoso (Arnoso Sta. Maria) is located 6 km from the city of Vila Nova de Famalicão. For the present work, we used a convenience sample, detailed in Table 1. The participants consisted of students from eight 8th-grade classes of both these schools. The majority of the students were between 13 and 14 years of age, which is the standard for 8th-grade students in Portugal. Some students started school earlier and were 12, while others were held back one or more years and were 15 and 16 years old (Table 1). The control group was composed of students from Escola Básica Conde de Arnoso. This school was not subjected to any intervention or educational garden implementation; therefore, the students did not attend any of the activities. Even though the impact of demographic variables was not addressed in the present work, experimental and control groups share the same age and educational background (Table 1), come from schools of the same periurban area (distance between schools = 6 Km), and are expected to have comparable socio-demographic background, academic achievement, and science education experience.

Table 1. Depiction of the experimental and control groups.

Class	No. of Students	Age	Male	Female
Experimental group				
8ºA	19	12–15	7	12
8ºB	20	13–15	13	7
8ºC	18	13–14	14	4
8ºD	19	13–15	13	6
8ºE	16	13–15	11	5
Control group				
8ºF	20	13–14	9	11
8ºG	19	12–16	7	12
8ºH	19	13–16	6	13
Total	**150**	**12–16**	**80**	**70**

2.3. Educational Program

A team composed of plant biologists, teachers, the Parents Association (EB 2/3 D. Maria II School), and City officials (Vila Nova de Famalicão) implemented the project "Jardins com(s)Ciência" (word pun meaning both Gardens with Science and Gardens with a Conscience). Project development took place within the scope of a Ciência Viva/CONFAP call designated Pais com a Ciência. Ciência Viva is the Portuguese state agency for the promotion of scientific and technological culture (www.cienciaviva.pt). The project's activities encompassed various aspects of plant biology and included the establishment, on school grounds, of three educational gardens. Additionally, we engaged all of the school community in the promotion of plant-oriented environmental protection. The project included socio-cultural and scientific activities that encouraged the presence of parents in the school and promoted interactions between students, parents, and teachers.

2.3.1. Educational Garden Implementation

The focus of activities was the construction within the grounds of School EB 2/3 D. Maria II of the three educational gardens, each with an area of approximately 100 m^2 (Figure 2A). The gardens were designed to incorporate species that represent the Atlantic, Lowland Mediterranean and Mountain Mediterranean ecosystems, which are all typical of the Portuguese vegetation (Figure 2B–D; Supplementary Figure S1). The selection of the different climatic areas that determine the type of vegetation present in Portugal was based on the environmental, climatic stratification of Europe [27]. There are four main environmental zones in the Portuguese continental territory (Lusitanian, Mediterranean Mountains, Mediterranean North, and Mediterranean South). The environmental zone Mediterranean Mountains only occurs in a small part of northern Portugal, and the vegetation present there is similar to the Mediterranean North. For that reason, the Mountain Mediterranean garden represents both of these environments. The Atlantic garden represents the Lusitanian environmental zone, with its relatively humid Atlantic climate and Mediterranean-like distribution of precipitation. The Lowland Mediterranean garden represents the Mediterranean South environmental zone, which occupies plains and uplands in southern Mediterranean areas. Species choice involved two criteria, (1) representativeness of the species in each environmental zone and (2) greater ease in acquiring plant specimens in a nursery or by collection in nature. Figure 2B–D depicts the array and spatial distribution of the selected native species for each ecosystem. Teachers and plant biology researchers planned the garden design and chose and acquired the species introduced in the educational gardens. Students and parents conducted the landscaping effort that implemented the gardens on school grounds, with support from plant researchers. Specimen plantation implicated several landscaping activities, including delimiting of specimens with maritime pine bark, placing of plant label plates, and installation of fences to protect against unauthorized intrusion (Supplementary Figure S1A–D).

2.3.2. Additional Practical Activities

As part of a multi-tier plant-oriented program, students carried out a series of laboratory/practical activities, such as the creation of a plant nursery and different training courses addressing plant propagation, flora identification and the study of the relationship between form and function in plant organs (Figure 3A). One activity consisted of flora identification in the newly implemented educational gardens. The goal of this activity was to engage students in the identification of the species introduced in the educational gardens, and it involved the design of dichotomous keys specifically for each of these gardens (Supplementary Data S1–S3). According to the literature, dichotomous keys have long been considered the most important way of learning how to identify new species and were shown to develop differentiation skills such as diagnostic abilities [28]. The present, purposefully built dichotomous keys can now become a useful teaching tool in the forthcoming school years. A second activity saw the creation of a plant nursery within the school (Figure 3A). This activity involved: (a) workshops on plant propagation with the participation of students and their parents; (b) the creation of a plant nursery with native plants in the classroom; (c) transplanting the native plants, after growth for four months in the nursery, into the school gardens and subsequent monitoring of the setting in process; (d) teacher training in nursery implementation and plant propagation techniques. A third activity consisted of understanding form–function relationships in plant leaves. The goal of this activity was to complement ecological data by providing a more in-depth discussion on leaf morphology, form–function relationships, their importance for plant functioning, and their usefulness during plant species identification via a hands-on workshop and custom-generated PowerPoint presentations. An important feature of these activities was the presence of plant researchers within the project team (Figure 3B). This collaboration allowed the development of state-of-the-art scientific content, particularly concerning aspects that might elude schoolteachers, such as plant identification at species level, generation of dichotomous trees, hands-on plant manipulation, or study of plant form–function relationships. During the three activities, workshops and hands-on field work promoted practical knowledge, which is useful for day-to-day, easy-to-implement practices while simultaneously raising the standards of scientific knowledge (Figure 3B).

A final activity consisted of a set of 1-h lectures, evenly distributed throughout the project, discussing the work of the invited plant researchers (Figure 3A). The goal of this activity was to allow direct contact between students and plant specialists, followed by active discussion within an informal setting. Members from all of the educational community (school board, teachers, educational aids, and parents) attended and participated in these lectures. Here, students listened to topics that included landscaping, native, exotic and invasive plants, plant and fungal symbiotic relationships, and plant morphological and physiological diversity.

During all activities, both teachers and researchers guided the students by asking questions, pointing out interesting plant features, and encouraging students to reflect on what they saw and experienced. This study was a collaborative learning effort between teachers, researchers, parents, and students (Figure 3B). All participants were actively engaged in creative discussions that took into account their different backgrounds and knowledge base. Teacher's knowledge in conducting educational programs, the technical know-how of the researchers, the involvement of parents, and the development of a significant set of activities and contents around plants collectively led to the extensive exposure of 8th-grade students of the experimental group to various topics in plant biology (Figure 3B).

Figure 2. Design and construction of three educational gardens within the grounds of School EB 2/3 D. Maria II. (**A**) Aerial picture of the school grounds (dashed line), depicting the implementation site of the Atlantic (1), Mountain Mediterranean (2), and Lowland Mediterranean (3) gardens; image was retrieved from Maps (Apple). (**B**–**D**) Species spatial distribution in the Atlantic (**B**), Mountain Mediterranean (**C**), and Lowland Mediterranean (**D**) gardens. Am, *Armeria maritima*; Ap, *Acer pseudoplatanus*; Au, *Arbutus unedo*; Ba, *Betula alba*; Ca, *Corylus avellana*; Cm, *Crataegus monogyna*; Cp, *Cistus populifolius*; Cv, *Calluna vulgaris*; Da, *Dianthus lusitanicus*; Dc, *Daboecia cantábrica*; Dp, *Digitalis purpurea*; Dt, *Digitalis thapsi*; Ear, *Erica arborea*; Eau, *Erica australis*; Fv, *Fragaria vesca*; Hs, *Helichrysum stoechos*; Lp, *Lavandula pedunculata*; Np, *Narcissus pseudonarcissus*; Ov, *Origanum vulgare*; Po, *Polygonatum odoratum*; Qf, *Quercus faginea*; Qp, *Quercus pyrenaica*; Qrb, *Quercus robur*; Qro, *Quercus rotundifolia*; Qs, *Quercus suber*; Rc, *Rosa canina*; Tm, *Thymus mastichina;* Tp, *Thymus pulegioides*; Vr, *Viola riviniana*.

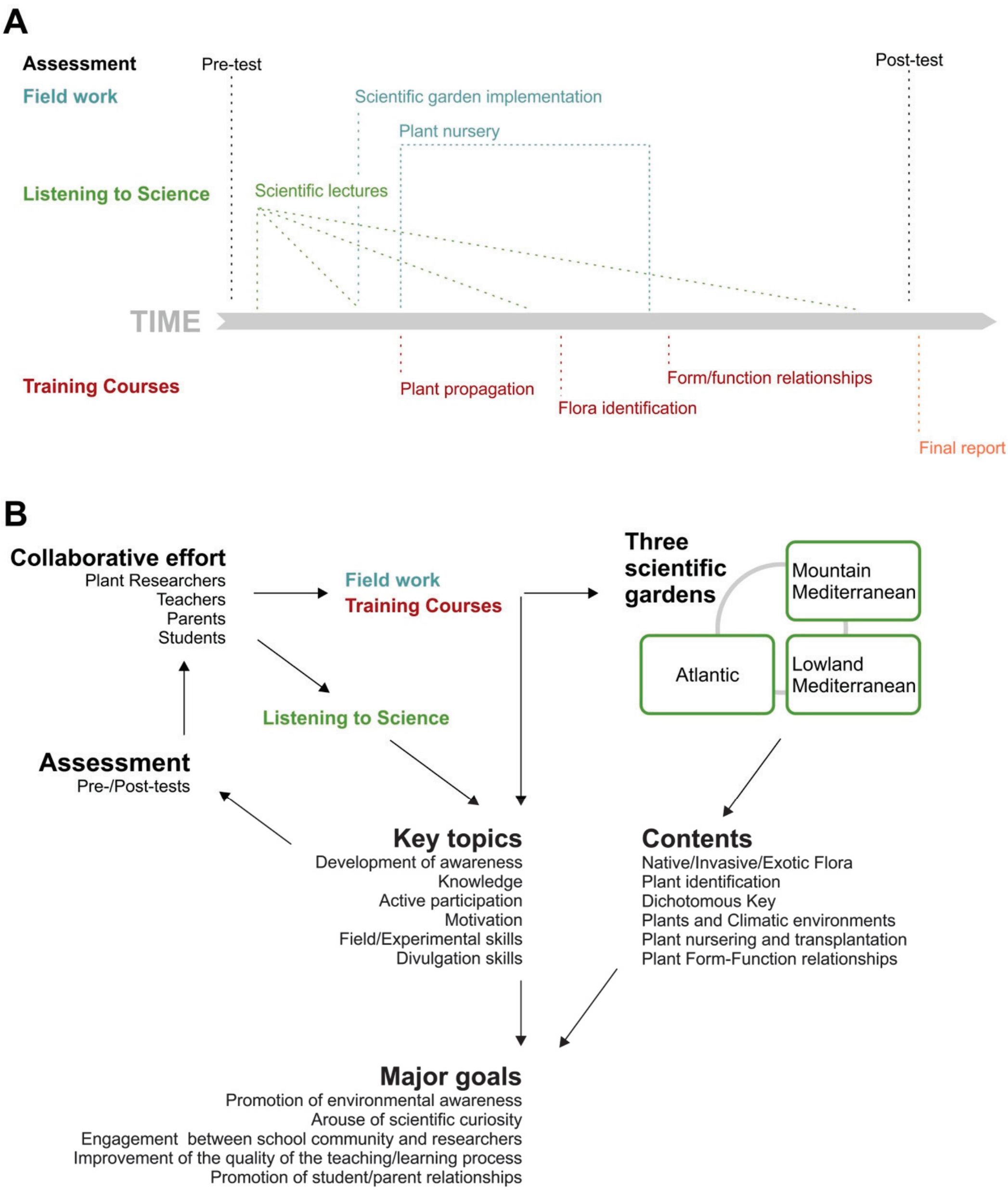

Figure 3. Timeline and outline of the project. (**A**) Timeline depicting the major events that took place during the project's duration. (**B**) Outline of the project, based on the creation of three scientific gardens, and including project intervenients, contents, key topics and major goals.

2.4. Instrument, Data Collection and Analysis

The instrument selected to quantify the effectiveness of the project's activities and assess students' knowledge gains consisted of a pre-validated questionnaire containing 11 informative items, given to students at the beginning and at the end of the intervention (pre- and post-test) (Figures 1 and 3A). The same procedure was implemented in the control school group, where no gardens or activities were developed (school Escola Básica Conde de Arnoso). The survey instrument was previously validated by a group of six students from the same grade belonging to the experimental group school. No doubts were raised during the process. The survey instrument emphasized Portuguese native flora and specifically three topics pertaining to student familiarity with the terms exotic, invasive, and autochthonous plants, identification of native species, and plant adaptability to climatic variables (Table 2). The native species included in the questionnaire were *Acer pseudoplatanus*, *Arbutus unedo*, *Crataegus monogyna*, *Pinus pinaster*, *Quercus rotundifolia*, *Quercus suber*, *Quercus robur*, *Quercus faginea*, and *Quercus pyrenaica*, and the exotic/invasive were *Acacia dealbata*, *Acacia longifolia*, *Carpobrotus edulis*, and *Eucalyptus globulus*. The time between the implementation of the first activity (implementation of the school gardens) and the application of the post-test was seven months. Supplementary Data S4 contains the full questionnaire, whereas Table 2 summarizes the items and topics. Students completed the questionnaire during the course of a regular natural sciences class, with a time limit of 40 min. Student participation was anonymous and voluntary. Teachers informed students that their participation and questionnaire performance would have no implication in their curricular evaluation. Data obtained in the pre- and post-tests from the experimental and control groups (matched case-control study) was statistically resolved through a McNemar's test, using GraphPad's web-based statistics platform (http://graphpad.com/quickcalcs/mcNemar2/; accessed on 10 July 2020) with significance set at $p < 0.05$.

Table 2. Items incorporated into the survey instrument, addressing three separate topics, and used to assess students' knowledge.

Invasive, Exotic, and Native Plant Species
Q5 Identification of synonyms within terms concerning native/invasive plants
Q6 Meaning of invasive plants
Q7 Typical features of invasive plants
Q8 Recognition of invasive species in Portugal
Q9 Species abundance in the region prior to human modification of the landscape
Plant species identification
Q10 Identification of the common name of several species given their scientific name and a representative picture
Q11 Identifying deciduous trees
Q12 Correct use of dichotomous key
Plant adaptability to climatic variables
Q13 Matching between species and climatic environments/forest ecosystems
Q14 Ideal time for the transplantation of plant species
Q15 Cautions with the transplantation of plant species

3. Results

This project Jardins com(s)Ciência consisted of a series of activities designed to promote environmental awareness toward plant biology and native plant protection in 8th-grade Portuguese students (Figure 3). The activities had a broad scope and included: (a) the implementation of three educational gardens representing different Portuguese forest ecosystems; (b) the creation of a plant nursery; (c) different training courses addressing plant propagation, flora identification, and the study of the relationship between form and function in plant organs; (d) scientific lectures by active plant researchers (Figure 3A). To estimate the impact of this project on students' plant-oriented environmental awareness, we used a survey instrument with pre- and post-test comparisons of the performance of both experimental and control groups. For statistical support, we tested the Chi-square and McNemar tests. Here, we observed that the McNemar test out-performed the Chi-square analysis of statistical differences (data not shown), with the latter providing biased (extremely low) *p*-values due to the fairly high number of test subjects, whereas the McNemar test provided a *p*-value resolution within the range of the *p*-value cut-off (0.05). The McNemar suits this form of paired comparison as it determines the statistical significance of the difference between two correlated proportions (2×2 contingency table), in this case, pre-test vs. post-test $\times$ control group vs. experimental group.

To assess performance, we developed 11 items associated with Portuguese native flora and centered around three topics: Invasive, exotic and native plant species; Plant species identification; Plant adaptability to climatic variables (Table 2). Figure 4 and Supplementary Data S5 reports the overall performance in the pre and post-tests of the experimental and control groups, displaying the percentage of correct answers and the statistical significance of results between tests, while Supplementary Data S6 contains the bulk data. The experimental group's scores increased in all questions when comparing the pre-test to the post-test (Figure 4A). Conversely, the control group often displayed marginal increases or even a decrease in scores, with only three questions showing a marked increase (Q5, Q7, Q13; Figure 4A). The average accuracy in the pre-test was similar between the experimental group (32.6 ± 18.9) and the control group (30.9 ± 20.6), highlighting the robustness of the study population (Figure 4B). Following the implementation of the educational program, average accuracy increased in the experimental group by over two-fold (71.2 ± 17.0) but not in the control group (34.3 ± 16.0). Figure 4C scrutinizes this information by depicting the variation in response success from the pre- to the post-test in both groups for each specific question. By far, the largest increase (94.5%) was observed in Q7, regarding the typical features of invasive plants. This was followed by three questions with improvements in the ~45% range, one within the same topic of invasive species (Q9) and two within the topic of Plant adaptability to climatic variables (Q14 and Q15). Broadly, the topic of Plant species identification was the worst performer in this analysis. We observed the existence of statistical support for these claims in every question present in the questionnaire (p-values < 0.05; Supplementary Data S5). Collectively, the results provide very strong support that the implementation of our educational program increased student awareness across all topics.

In each topic, we incorporated questions that involved knowledge of multiple forest species, with broadly positive results in the experimental group (Figure 5). For the topic of Invasive, exotic and native plant species, students were asked to recognize the name of invasive species (Q8). Here, a positive increase in the acknowledgment that *Acacia* sp. are invasive was observed in the experimental group (Figure 5A). For the topic of Plant species identification, students were asked to name a forest species common in the Portuguese flora based on a provided image (Q10; Figure 5B). Interestingly, for *Pinus pinaster* and *Eucalyptus globulus*, the most abundant forest species in Northwest Portugal, score variation was very low for both the control and experimental groups because initial (pre-test) results were high to begin with (Supplementary Data S6). Still, on this topic, a consistent improvement across all species was observed in Q11, which addressed the concept of deciduous species (Figure 5C), suggesting a generalized lack of knowledge and a beneficial effect of the educational program. Finally, with regards to Plant adaptability to climatic variables, students were asked to match a species to one of the three Portuguese climatic environments/forest ecosystems (Q13; Figure 5D). Here, the most effective progress was associated with two oaks species (*Q. robur* and *Q. rotundifolia*) and the strawberry tree (*Arbutus unedo*).

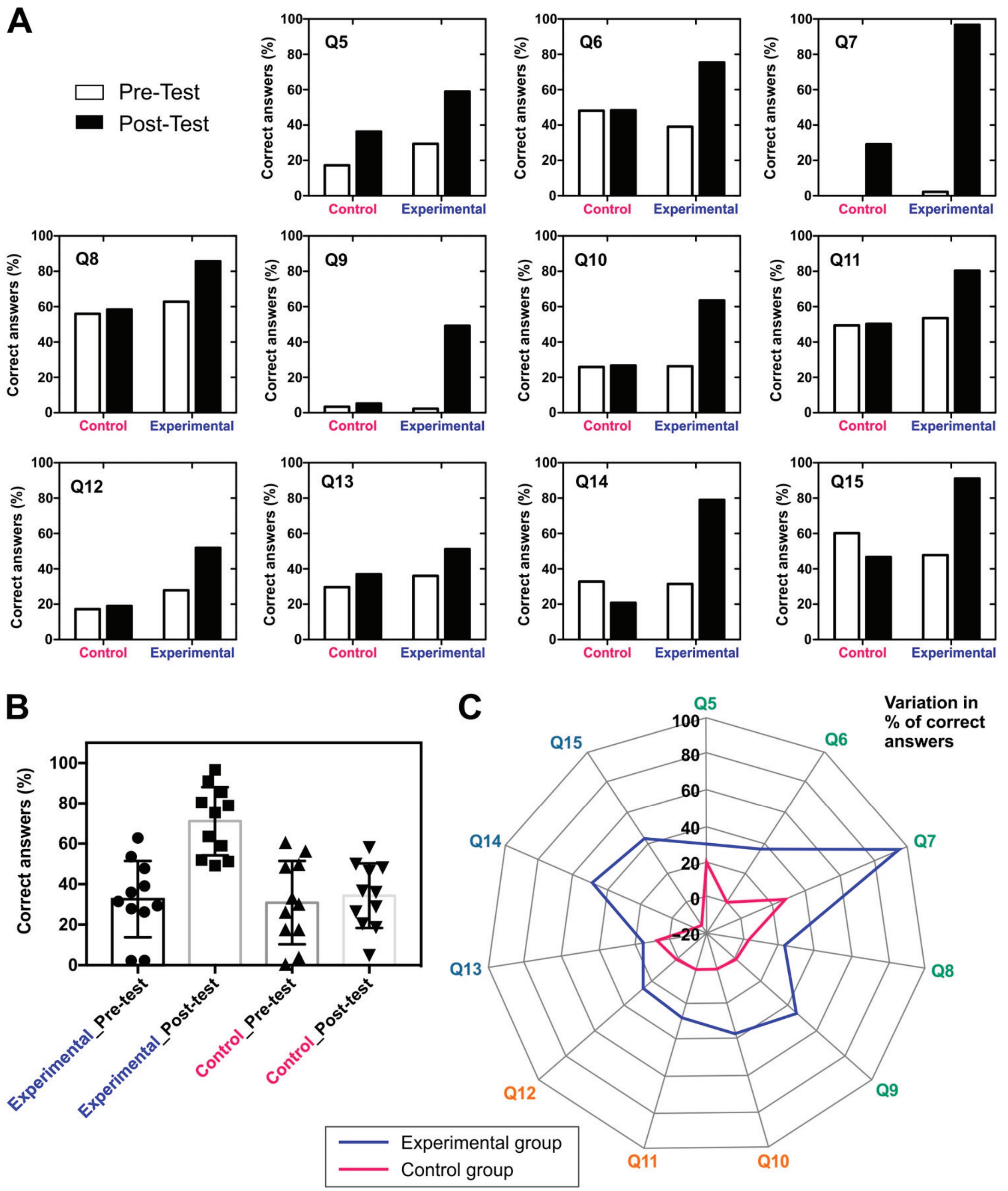

Figure 4. Results of the student questionnaire in the pre- and post-test assessment of the Experimental and Control groups. (**A**) Percentage of correct answers (accuracy) in each group for each question. (**B**) Variation in accuracy between the four different test populations. (**C**) Radar map showing the variation in the percentage of correct answers between pre- and post-test for the control and experimental groups.

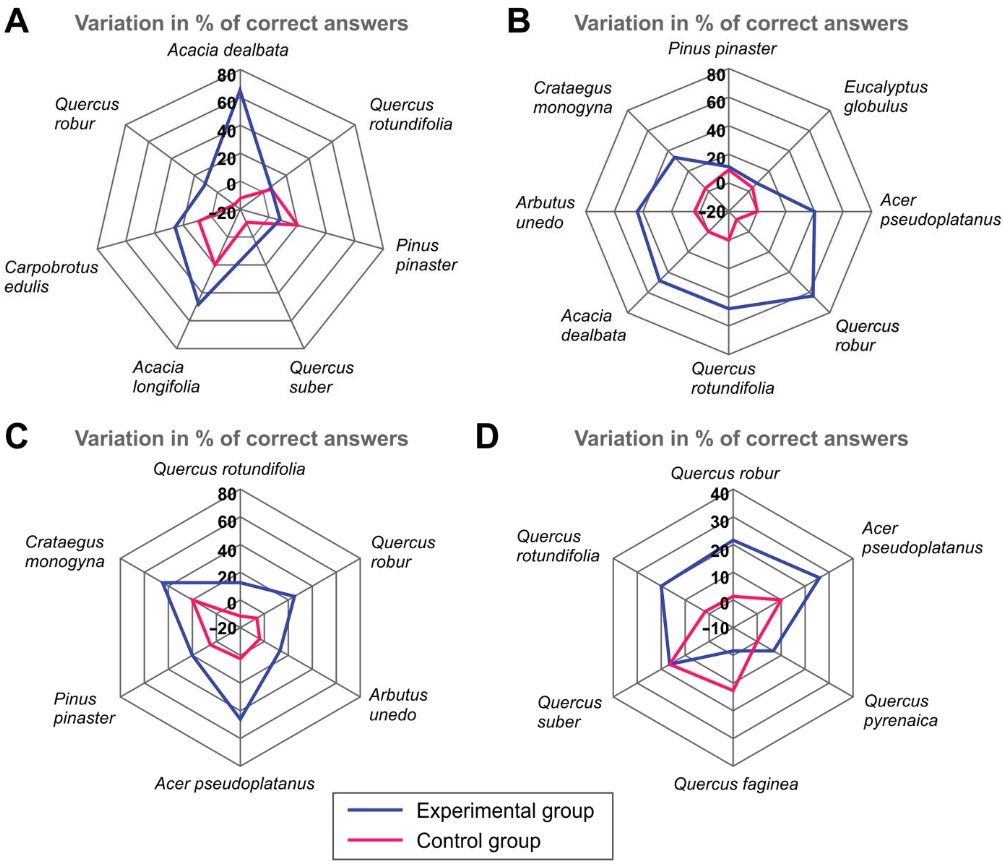

Figure 5. Radar map showing the variation in the accuracy, i.e., the percentage of correct answers between pre- and post-test, for the control and experimental groups, in questions tackling different species. Discrimination of answers at the species level for question 8 (**A**), question 10 (**B**), question 11 (**C**), and question 13 (**D**).

4. Discussion

Presently, there is an urgent need to educate people effectively so that current and future actions and decisions are made in educated and informed ways [3]. In this regard, outdoor education is considered an important tool for improving student attitudes and clearly influencing students' knowledge of plants [29]. In order to increase plant-oriented environmental awareness and scientific literacy in general, we designed a project named Jardins com(s)Ciência (Gardens with Science/Conscience). This environmental program is in line with recent strategies adopted by educators, which are re-discovering the value of gardens as spaces for learning in educational institutions [30]. It was also geared toward students at an age where they begin to lose environmental attitude and behavior [26]. Thus, we structured the program's contents vertically, ranging from organ structure/function to species to ecosystem levels. It was a hands-on program, including various field activities designed to enhance the participants' understanding of autochthonous/invasive plants, plant identification, plant features, the correct use of dichotomous keys, the relationship between species/climatic environment, and plant nurturing (germination, growth and transplantation).

With a 25 h/week contact time between students and teachers, Portuguese 8th-graders spend a significant part of their time at school (http://www.dge.mec.pt/matriz-curricular-do-3o-ciclo; accessed on 9 November 2021). We hypothesized that field and laboratory motivational activities within the school context could be an important additional recourse for academic success and most importantly, a good instrument to raise awareness to plant-related topics. In support, various studies have shown that intrinsic motivation is linked to active and engaged behaviors [31]. Further, hands-on, laboratory and out-of-class education activities improve students' interests, scientific inquiry skills, autonomy, and understanding of scientific concepts [15,32–34]. Finally, providing students with autonomy is an additional factor toward an increase in their motivation [35]. Results showed that the present work was successful in increasing student knowledge across a series of plant topics centered around the native Portuguese flora and its contrast with invasive species. For questions focused on invasive plants (Q5–8), there was an overall improvement. The student's preexisting knowledge was high for the definition of an invasive plant (Q6 ~50%) and identification of invasive plant species (Q8 ~60%). Improvements were more noticeable in the identification of the characteristics of invasive plants, where the variation in the experimental groups was close to 100% (Q7). The positive performance of the students on this subject may be related to the knowledge acquired during the lectures given by plant researchers on native, exotic, and invasive plants (where active discussions were promoted) and the fact that this topic was emphasized during garden implementation and flora identification activities. Likewise, this emphasis may explain why scores in the post-test increased significantly when addressing the identification of plant species (using both their common and scientific names) and the correct use of a dichotomous key. This hands-on approach also contributed to the knowledge increase observed in the more practical aspects of the questionnaire, which focused on plant transplantation (Q14 and Q15). In support, previous studies corroborate the positive impacts of gardening, leading to increased academic learning, environmental attitudes and interpersonal skills [8]. Garden-based learning experiences develop students' environmental knowledge, improve environmental attitudes, encourage their sense of environmental responsibility, and motivate related positive actions [30]. Teaching in school gardens has been shown to enhance student's academic learning and skills acquisition across the curriculum, as well as foster the development of students' social, affective, and physical skills [36]. Other studies have emphasized the importance of outdoor programs in significantly relieving 'plant blindness', making this biology topic more attractive to students [29].

In the past, environmental education researchers were encouraged to explore alternative models leading to responsible environmental behavior after the publication of Hungerford and Volk's work [37]. As a result, knowledge was no longer considered a unique factor that could lead to behavior change. One of the models that followed this line of thought, the Hines Model [38], is based on behavior change and environmental education literature. However, this model also focuses on additional conditions, including personality factors, knowledge of issues, and possession of skills for taking action. In the current work, the information and messages communicated to students were an important step toward the promotion of future environmentally friendly attitudes. According to the Hines Model, knowledge is a prerequisite to action: before an individual can intentionally act on a particular environmental problem, that individual must be conscious of the existence of that problem [38]. Here, we observed a significant increase in knowledge on various topics in students who participated in the project.

Research has demonstrated that teaching with and about plants is full of misconceptions and is considered a pedagogical challenge [39,40]. The present success in improving student awareness can foremost be attributed to teacher and plant researcher involvement. In support, teacher involvement was shown to increase student interest in subjects, such as plant biology, when appropriate motivational methods were used. Our results effectively add to existing studies, specifically demonstrating that planting trees within the school area in collaboration with experts may have a significant impact on student understanding of the role of plants in nature, building positive attitudes toward plants [29].

A key topic addressed by the present project concerned the issue of autochthonous vs. invasive plant species. Results obtained in the pre-test concerning this specific subject are in agreement with previous reports, indicating that only 1% of the Portuguese population considered invasive species to be the most important threat to biodiversity [41]. Studies have demonstrated the importance of public participation in both environmental conservation initiatives and the improvement of student knowledge of native and exotic plants [42]. Thus, our project's first lecture, open to all of the school community, was used to motivate students toward this issue within Portuguese ecosystems, and later activities in the educational gardens highlighted the native nature of the planted species. A workshop regarding invasive plant species performed at the Botanical Museum of Coimbra University, Portugal, clearly demonstrated the importance of practical and informal education activities similar to our own [20]. Reis and co-workers revealed the effectiveness of their activities in increasing public awareness regarding synonyms of native plants and the meaning of invasive plants, corroborating our results since the percentage of correct answers in both studies was similar [20]. Concerning the recognition of invasive species in Portugal vs. the number of invasive plant species reported in Portugal, the number of correct answers obtained in the post-test (86%) is higher than those registered by Reis and co-workers (39.7% of correct answers). This discrepancy could reside in the fact that the results from Reis and co-workers were obtained one year after the implementation of the activities [20]. In summation, our assessment demonstrates the effectiveness of public education efforts in raising awareness that may help prevent the propagation of invasive species in Portugal.

The results and their subsequent statistical treatment support that this project was successful in raising student knowledge and awareness of various plant biology topics. The results suggest that knowledge improvement is related to the effectiveness of the teaching methodology rather than to the existence of a priori student familiarity with specific topics. We administered the post-test seven months after the start of the field activities. In order to infer the long-term retention of knowledge, it would be interesting to re-apply the test after a longer period. Most significantly, we designed several of the activities and contents of this project to be sustainable and last beyond the project's initial duration. Globally, the developed contents will allow teachers to carry out most of the project's tasks in the upcoming years. This is significant because the consistency of educational messages is known to affect behavior [43].

The importance of motivating learners to physically maintain plants, plant trees, name plants, and identify them using dichotomous keys has already been suggested to improve awareness of the importance of plants in nature [29]. Outdoor programs can, therefore, be considered good supplements to conventional biology settings, providing a better knowledge of living organisms and promoting positive attitudes. Moreover, educational gardens can influence the well-being of the whole school community, including teachers, staff, and parents. Additionally, it is known that families bring valuable resources to informal learning. Building the capacity in families to organize and optimize learning opportunities wherever they arise, therefore, constitutes an important feature [44]. Overall, this project contributed to improving students' knowledge concerning plant biology, with emphasis on autochthones/invasive plants, species identification, ecosystem ecology, and form/function relationships in plant organs. The present garden designs and the dichotomous keys constitute promising tools that can be easily extended toward other school/educational programs within the Mediterranean ecological space. Finally, our findings reinforce the necessity of employing this type of approach to promote environmental education, as the targeting of students contributes to the engagement of future generations of citizens in having a more active and mindful attitude toward sustainable development.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci12090619/s1, Supplementary Data S1. Dichotomous key for the Atlantic garden; Supplementary Data S2. Dichotomous key for the Lowland Mediterranean garden; Supplementary Data S3. Dichotomous key for the Mountain Mediterranean garden; Supplementary Data S4. Full pre-validated questionnaire for quantitative assessment of student knowledge gain; Supplementary Data S5. Performance in each question of the experimental and control groups, in both the pre- and post-test questionnaires; Supplementary Data S6. Scores for the pre-test and post-test in both control and experimental groups; Supplementary Figure S1. Construction of three educational gardens within the grounds of School EB 2/3 D. Maria II.

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Institutional Review Board Statement: This study was approved by the School Board of the School EB 2/3 D. Maria II, V. N. Famalicão, after hearing the Pedagogic Council, since there is no ethics committee in the school. Student participation was anonymous and voluntary.

Informed Consent Statement: Informed consent was obtained verbally from the students' guardians on behalf of the students enrolled in our study. This was obtained during a regular meeting, in which the director of the class explained the aims of the project and requested authorization from parents for their children to participate. Verbal consent was the method agreed upon by the School Board, class director, and the students' guardians.

Data Availability Statement: The datasets for this study can be found in the article and its Supplementary Materials.

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education sciences

Article

Student Engagement, Learning Environments and the COVID-19 Pandemic: A Comparison between Psychology and Engineering Undergraduate Students in the UK

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Abstract: This study compared student learning engagement from two UK departments exploring their participation in face-to-face and synchronous online learning environments. Overall, 446 undergraduate students from Psychology (soft/non-Science, Technology, Engineering, and Mathematics (STEM) discipline) and Electrical Engineering and Electronics (EEE) (hard/STEM discipline) completed an online questionnaire over the second semester of the 2020–2021 academic year, where the teaching was mainly online. The questionnaire included validated scales regarding teaching and students' characteristics and an open-ended question regarding the role of learning environments. There was a significant difference between the two learning environments in both departments, with most of the students believing that they were better engaged with their learning process in face-to-face environments (quantitative analysis). Additionally, the thematic analysis of student qualitative responses revealed that online student engagement was influenced by (1) Behaviour, (2) Affective, and (3) Cognitive challenges (i.e., additional workload, lack of communication and distractions in the home environment) and opportunities (i.e., the effective use of study time and online content through interactive learning environments). This study could assist academics, university policymakers, and researchers to understand student engagement alongside learning environments, reconsidering the opportunities and challenges that were gained from online learning due to the COVID-19 pandemic.

Keywords: student engagement; academic performance; learning environment

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1. Introduction

Across the world, researchers in higher education have discussed over many years what "student engagement" is and how it enhances the student learning experience [1,2]. Zepke (2018) [3] has recognised that there is not one clear definition for this term, due to the diversity and complexity of this area as well as the various dimensions in which researchers have studied it. For example, the most discussed dimensions are related to cognitive (i.e., learning goals, self-efficacy, deep learning), affective (i.e., learning environment, teachers), behavioural and social (i.e., participation and interaction) student engagement [4,5]. Many researchers have discussed how student engagement may be influenced by the sociocultural (emotional, cognitive, and behavioural) perspective [6] or individuals' characteristics, a feedback loop between teacher, peers, and the learning environment [7], or the role of reflexivity influenced by the tasks and social interactions in a specific learning environment [8]. Frequently, researchers have confused student engagement with motivation, which are both highly connected, but student engagement arises from motivation [9,10]. Other researchers have explored how student engagement was linked to academic performance [11–14] or to teachers' involvement [15]. Finally, many researchers have aimed at conceptualising student engagement with the educational interface, including the psychosocial constructs of self-efficacy, emotions, belonging, and well-being [16], the role of feedback regarding the receiver's and sender's behaviour with message characteristics [17] or the impact of self-regulated learning on cognitive and socioemotional collaborative interactions supported by student-led and teacher-led tasks [18].

The integration of technology into university curricula has gradually increased in recent decades offering new opportunities and challenges for student engagement when considering teachers' beliefs and attitudes, prior experience, and modes of transformative learning [19]. Blended learning approaches (combination of face-to-face and online activities) were mainly followed by the on-campus courses to incorporate flexibility, stimulate interaction between teachers, peers, and course material, facilitate students' learning processes, and foster an effective learning environment [20,21] where undergraduate student behavioural and emotional engagement was affected by how various digital learning tools are used by teachers to support student learning [22]. Halverson and Graham (2019) [23] have further studied the relationships between learners' characteristics, instructional methods, and learning outcomes with cognitive and emotional engagement in a blended learning environment proposing a further need to explore these associations. Additionally, students' perceptions about learning activities in a blended learning environment may influence cognitive and emotional student engagement [24]. The role of educational technology was also explored following the bioecological model and its relevant recommendations for macro-, exo-, meso-, and micro-levels under the perspectives of activities, environment, peers, and teachers [2,25]. These studies discussed how two student engagement frameworks (1. bioecological model and 2. cognitive, affective/emotional, and behavioural framework) could be combined to integrate a technology-enhanced learning environment interacting with the short and long learning outcomes on a social and academic level.

The role of academic performance as a learning outcome has also been discussed by many educational researchers regarding student engagement. For example, Dunn and Kennedy (2019) [26] have explored motivations utilising the emotional, cognitive, and behavioural framework, which pointed out the importance of intrinsic motivation and social media use on student engagement and performance, whereas technology use was related to extrinsic motivation. Another model regarding technological use found a positive effect on self-directed learning (individual characteristics) and student engagement, where academic performance has been indirectly affected by technology via self-directed learning [27]. Vo et al. (2017, 2020) [28,29] have explored the difference between "soft and hard" courses (Science, Technology, Engineering, and Mathematics (STEM) versus non-STEM courses) regarding various elements, such as clear goals, feedback, instructor support, material quality, instructor facilitator, content presentation, collaborative learning, and grades. Evidence suggests that the blended learning approach has a larger contribution to STEM students' performance than students from soft disciplines, with the factors of clear goals, material quality, and collaborative learning being amongst the most significant predictors of student performance. According to the literature, online and face-to-face activities, teacher support, and feedback processes may also play a crucial role in successful blended learning design [30,31]. Baragash and Al-Samarraie (2018) [32] have further examined the role of Learning Management System (LMS)-based and web-based learning on student experience and academic performance over the face-to-face learning process that has taken place in a formal university environment. For each of the three delivery modes, the level of interactions between teachers and students differed, whilst students overvalued the web resources to "obtain a quick and easy information to assist in their mastery of the course content" (p. 2096). A recent literature review examined the opportunities and challenges that LMS, synchronous and social media tools have provided to collaborative learning through the real-time interactions between students and self-regulated learning through the reflection process [33].

The studies on student engagement have been mostly referred to as blended learning, which involved face-to-face teaching with synchronous communication between teachers and students and the integration of online learning technologies into a physical environment [34]. Various digital tools could support blended learning approaches, supporting face-to-face and online activities [35]. Galvis (2018) [36] has explored the factors that may influence Higher Education institutions with their decision-making process on blended learning. One of the reasons is that the learning environments are expandable through the various digital resources, enhancing the interactions between teachers and students and/or among students. Blended learning approaches, including online activities, can also increase flexibility, allowing students with work and home commitments to follow courses [37]. However, by working in an online environment, students may receive less support from their teachers compared to a face-to-face environment and may be less engaged with their learning [38].

Due to the recent global COVID-19 pandemic, many Higher Education institutions across the world shifted their teaching delivery process from a face-to-face lecture in a blended learning environment to a fully online learning one, allowing students to continue learning in a safe environment [39,40]. Students could study online content asynchronously in their own time and space, while they could synchronously interact with their teachers and their peers via online conferencing platforms [41]. From a very early stage of the pandemic, researchers have pointed out several challenges and opportunities for teaching and learning related to technology, pedagogical challenges, socio-economic factor, digital competence, inadequate interactions and student self-study skills including the well-being and mental health of teachers and students [42–45]. For example, researchers have explored the role of student and teacher digital competence for the rapid change of practice by a blended learning approach, mostly delivered on campus to the integration of online conferencing tools (i.e., Zoom (5.12.0, Zoom Video Communication, Inc., San Jose, CA, USA), Microsoft Teams (1.5.00.17656, Microsoft, Washington, DC, USA) [46]. Others have questioned the teaching shift by raising concerns about its impact on student engagement [47], with synchronous and asynchronous online teaching to be reconsidered under the perspectives of learning activities, feedback, and digital platforms [48]. Zeng and Wang (2021) [49] examined the teaching elements in the design of online courses during COVID-19, such as feedback, teacher support, and social presence, that might play a role in student satisfaction (highly related to academic performance).

The Higher Education sector faced critical challenges during the COVID-19 pandemic with subsequent lockdowns, which disrupted University life [50], but there were only limited studies that have explored the behavioural, cognitive and affective student engagement dimensions. Salas-Pilco, Yang and Zhang (2022) [51] identified the main characteristics of student engagement from these tripartite dimensions in online learning were related to digital skills development, technological issues, emotional support, student self-regulation, perceived self-digital literacy and development of soft skills (i.e., communication, collaboration and teamwork skills). However, while previous studies explored student engagement focused on one learning environment (blended face-to-face or online), the teaching process and student characteristics in both environments remain unexplored.

This study aims at exploring the effects that learning environments (blended face-to-face learning before the COVID-19 pandemic and online learning over the pandemic) have on university student engagement under the behavioural, affective, and cognitive dimensions regarding student academic performance, student characteristics, and the teaching process. Students from two departments, Psychology (soft/non-STEM discipline) and Electrical Engineering and Electronics (EEE) (hard/STEM discipline), participated in this study to further explore any potential difference between students' preferences for synchronous face-to-face or online learning environments. Figure 1 illustrates the elements that were explored in this study regarding teacher-student interactions.

In this study, students from two departments were invited to complete an online questionnaire which included Figure 1 elements. The main assumption of this study was that the students for both departments felt more engaged when they followed a face-to-face lecture rather than online. This assumption was made because these students had chosen to follow an on-campus course and the COVID-19 pandemic had disrupted their studies, forcing them to follow the teaching in an online environment.

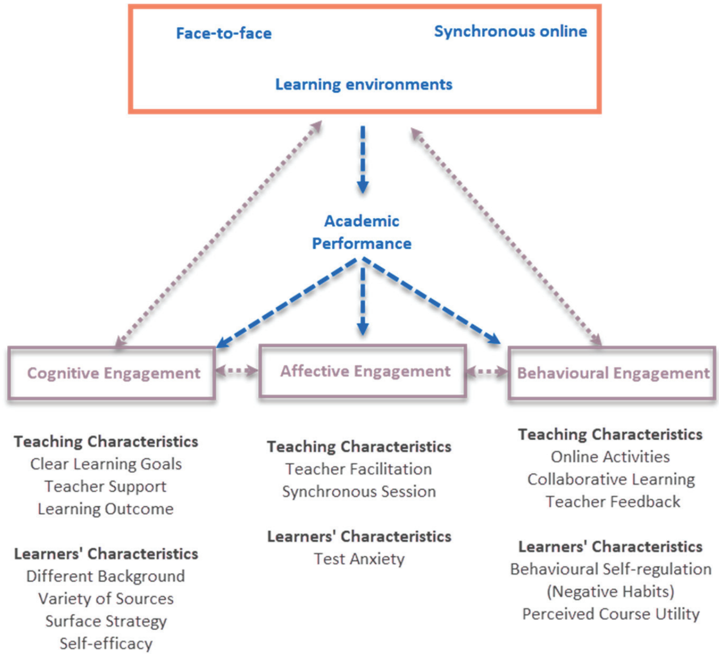

Figure 1. The learning and teaching elements that may play a role in student engagement.

This study includes the student academic performance as an indicator of their engagement with their courses. Therefore, it was important for the aim of this study to initially explore whether there was any significant difference between academic performance in the two departments and/or student preferences in learning environments.

Research Question 1 (RQ1): Are there any differences between academic performance and/or students' preferences in face-to-face and synchronous online learning environments in each department?

It has been previously discussed that the teaching delivery elements (i.e., teacher support, feedback and learning goals) could influence student engagement, but it has been explored whether there is any difference between these elements, the face-to-face and online learning environments, and how students from two departments (Psychology and EEE) have been engaged. Specifically, this study assumed that the teaching process might not have a significant difference in student engagement between the two departments when similar settings were followed.

Research Question 2 (RQ2): Are there any differences between various aspects of the teaching delivery process (i.e., learning goals, feedback, teacher support) with face-to-face or online learning environments in each department?

Additionally, as has been discussed in the Introduction part, the student characteristics (i.e., self-regulation, self-efficacy, test anxiety and background) can influence the behavioural, affective and cognitive engagement dimensions. This study assumed that there was a difference between student characteristics and their preferences in learning environments for both departments, with most students being engaged in the face-to-face environment because students had weak interactions with their teachers in online environments.

Research Question 3 (RQ3): Are there any differences between students' preferences in synchronous learning environments (face-to-face or online) and their characteristics (i.e., self-efficacy, behavioural self-regulation) in each department?

Finally, this study also assumed that students felt more engaged with the face-to-face teaching process, whereas they felt disengaged with their learning process due to the

COVID-19 pandemic, as they were forced to follow online teaching. Thus, it should be explored whether the COVID-19 pandemic influenced their learning experience.

Research Question 4 (RQ4): Does the COVID-19 pandemic influence students' learning environment preferences?

2. Methods

2.1. Experimental Conditions and Participants

This investigation took place in the Psychology and Electrical Engineering and Electronics (EEE) departments at a research-intensive university in the Northwest of England during the 2020–2021 academic year. Both departments followed similar learning approaches before and during the COVID-19 pandemic by integrating learning technology tools into their teaching approaches to support two-way live communication between students and teachers through online polling systems (i.e., Kahoot! (Kahoot!, Oslo, Norway), PollEverywhere (PollEverywhere, San Francisco, CA, USA) and Padlet (Nitesh Goel and Pranav Piyush, San Francisco, CA, USA) [52]. Over the COVID-19 pandemic period, both departments used web conferencing tools (i.e., Zoom and Microsoft Teams) to synchronously communicate with students, as well as pre-recorded videos and online discussions for asynchronous teaching and communication between students and teachers. For both departments, students worked on various online coursework over the semester and completed an online summative exam period at the end of the semester, whereas before the COVID-19 pandemic, the final exams took place in a physical environment.

Overall, psychology and EEE undergraduate students for the three undergraduate levels of studies (N = 446, Males = 130, Females = 316, Mean age = 20.6, and Standard Deviation (SD) age = $\pm$3.97) fully completed an online questionnaire on student engagement over two months (March–April 2021). Table 1 provides information about the participants in both cohorts per year of studies. In the 2020–2021 academic year, the first-year students attended online lectures with little experience with face-to-face practical classes. This was due to the COVID-19 pandemic restrictions. On the contrary, second-and third-year students had previous experience with face-to-face learning environments over the 2018–2019 and 2019–2020 academic years. An opportunity sampling design was utilised as participants were recruited via emails, social media, discussion boards, word of mouth, and the Department of Psychology recruitment website. The University of Liverpool's Research Ethics Committee approved this study.

Table 1. The Number of Participants and Response Rate.

Year	Psychology (Response Rate %)	EEE (Response Rate %)
1st-year undergraduate students	189 (49.1%)	37 (27%)
2nd-year undergraduate students	75 (22.7%)	36 (21%)
3rd-year undergraduate students	71 (21.8%)	38 (13.1%)
Total students responding(% of all cohort)	335 (32.2%)	111 (18.5%)

The survey was conducted online, using a 10–15-min-long questionnaire hosted on the Qualtrics web-based survey platform (www.qualtrics.com, accessed on 11 February 2021). A participant information sheet and a consent form were provided to the participants before anonymously completing the online questionnaire. They also received a debrief after the questionnaire completion.

2.2. Questionnaire

The questionnaire had four sections consisting of 70 multiple choice questions and one open-ended question. The first section (Section 1) included 6 questions about student preferences in learning environments. The answer choices reflected their learning preferences and their interactions with teachers and/or their peers. For example, participants were asked whether they mostly preferred to attend lectures in a physical environment (i.e., lecture theatre, classroom) supplemented with technologies such as lecture recordings and online voting systems (i.e., PollEveryWhere, Kahoot!) or synchronously in an online environment (i.e., Zoom/Microsoft Teams) in their own space supplemented with asynchronous online activities such as watching pre-recorded videos at their own time.

The second section (Section 2) consisted of 38 questions that aimed to assess students' engagement with their learning processes, including factors such as clear goals, teacher support, teacher feedback, teacher facilitation, online activities, synchronous session, collaborative learning, and learning outcome. The work of Vo, Zhu, and Diep (2020) [29] inspired this part of the questionnaire, which explored the difference in student engagement in blended learning environments for soft and hard disciplines.

The third section (Section 3) included 25 questions that assessed students' learning characteristics and habits, such as course utility, self-efficacy, test anxiety, surface strategy, source diversity, and negative habits. This questionnaire has been inspired by the Motivation for Strategies and Learning Questionnaire (MSLQ), as it measures both attitude and behaviour [53]. The updated version, entitled "The Digital Strategies and Motivated Learning (DSML)", released by Cho and Summers (2012) [54] incorporated the changes in current blended learning environments, and a shorter version has been used in many other studies [46,55]. Participants responded to Sections B and C on a 7-point Likert Scale (1 = Strongly disagree/Not at all and 7 = Strongly agree/Very great extent).

The last section (Section D) included two questions to assess the effects of the COVID-19 pandemic on students' learning process. The first item assessed to what extent (5-point Likert-scale, 1 = A great deal to 5 = Not at all) participants felt that they had developed new learning habits to cope with the changes of moving to an online learning environment due to the pandemic. This question would be used to explore whether the COVID-19 pandemic was a moderator for student preferences in learning environments. The second item was an open-ended question that allowed students to provide their comments on their behaviour/attitudes towards their current learning experience and how they felt this affects/impacts their learning process (e.g., how their learning motivation/engagement was affected, and how their ability to work from home and the COVID-19 restrictions influenced their learning). The questionnaire has been uploaded to the ZENODO online repository platform (Organisation Européenne pour la Recherche Nucléaire, CERN, Switzerland) (https://doi.org/10.5281/zenodo.6982919, accessed on 20 August 2022).

3. Results

A one-way Analysis Of Variance (ANOVA) showed that there was a statistically significant difference between the two departments in student performance ($F(1, 444) = 20.24$, $p \leq 0.001$) (Table 2). However, ANOVA statistical analysis and Turkey post hoc revealed no statistically significant difference between the three years of studies for the Psychology students ($F(2, 332) = 1.17$, $p = 0.311$), or between the three years of studies for the EEE students ($F(2, 108) = 0.77$, $p = 0.465$). Thus, we could assume that the students from the three years of studies for each department had a similar level of engagement with their undergraduate studies.

Table 2. Participants' average grades per year per discipline (Mean (±SD)).

Year of Studies	Psychology	EEE
1st Year	60.2 (±9.42)	62.7 (±10.77)
2nd Year	58.4 (±6.62)	65.7 (±12.38)
3rd Year	60.1 (±9.56)	64.8 (±8.73)
Total average	59.8 (±8.91)	64.4 (±10.67)

In the first part of the questionnaire, the participants were asked to self-report their preferences in various learning environments regarding the delivery process, interactions with their peers, and interactions with their teachers. Table 3 illustrates the differences between the two departments and the years of studies regarding the students' preferences in the two types of learning environments. A chi-square analysis revealed no statistically significant difference between the two departments and the years of studies. Additionally, the majority from each department preferred to interact with their peers (Psychology: 74.9%, EEE: 67.4%) and teachers (Psychology: 67.5%, EEE: 63.1%) in a physical learning environment.

Table 3. Students' responses to questions related to their preferences when teaching was delivered into two different learning environments to support lecture sessions.

	Synchronously in A Face-to-Face Environment (i.e., Lecture Theatre, Classroom) Supplemented with Technologies such as Lecture Recordings and Online Voting Systems (i.e., PollEveryWhere, Kahoot)	**Synchronously in An Online Environment (i.e., Zoom/Microsoft Teams) Supplemented with Asynchronously Online Activities such as Watching Pre-Recorded Videos at Own Time**	**Chi-Square (α = 0.05)**
Preferences per department			
Psychology	61.8%	38.2%	$\chi^2(1, 446) = 0.37$, $p = 0.545$
EEE	58.6%	41.4%	
Preferences per Year of Studies			
1st-year undergraduate students	60.6%	39.4%	$\chi^2(2, 446) = 0.30$, $p = 0.862$
2nd-year undergraduate students	63.1%	36.9%	
3rd-year undergraduate students	59.6%	40.4%	

α is the limit of the significance level, $\chi^2(a, b)$ is the variance between groups, and p is the significance level.

To further explore the first research question regarding the difference between student performance and their preferences in learning environments for the two departments, a two-way ANOVA statistical analysis was conducted. Overall, there was no statistically significant interaction between the effects of department and student preferences on student performance, $F(1, 442) = 0.36$, $p = 0.550$. However, the simple main effects analysis showed that student performance was significantly influenced by student preferences in the learning environment ($p < 0.001$) and the difference in departments ($p = 0.044$). Table 4 illustrates the student performance descriptive statistics between departments for face-to-face and online learning environments.

Table 4. Participants' average grades per year per discipline per preferences in the learning environment (Mean (±SD)).

Teaching Delivered in Two Different Learning Environments	**Psychology**	**EEE**	**Total**
Synchronously in a face-to-face environment (i.e., lecture theatre, classroom) supplemented with technologies such as lecture recordings and online voting systems (i.e., PollEveryWhere, Kahoot)	60.0 (±9.15)	64.1 (±11.21)	61.0 (±9.82)
Synchronously in an online environment (i.e., Zoom/Microsoft Teams) supplemented with asynchronously online activities such as watching pre-recorded videos at own time	59.5 (±8.54)	64.9 (±9.96)	60.9 (±9.22)

A two-way ANOVA statistical analysis compares the students' responses regarding their learning environment preferences and teaching delivery elements (Table 5). The analysis shows a statistically significant difference in collaborative learning between the two departments. The EEE students used to work with other peers to complete laboratory and project assignments, while Psychology students mainly worked independently. For all the rest teaching delivery elements (i.e., learning outcomes, teacher facilitation, teacher support), there was any statistically significant difference in the learning environment due to the department. However, the effect sizes revealed significant differences in students' engagement with the online learning environment. A potential explanation of this finding should be related to students' habit of working online after the COVID-19 pandemic (Psychology students: 2.75 ± 1.095, EEE students: 2.77 ± 1.157, selecting their responses from a 5-point Likert scale where 1: A great deal to 5: Not at all).

Table 5. Comparisons between the two departments related to teaching delivery elements and student preferences in two types of learning environments.

Teaching Variable	Face-to-Face Environment (i.e., Lecture Theatre, Classroom) Supplemented with Technologies such as Online Voting Systems (i.e., PollEveryWhere, Kahoot)		Online Environment (i.e., Zoom/Microsoft Teams) Supplemented with Asynchronously Online Activities such as Watching Pre-Recorded Videos		ANOVA between Disciplines (α = 0.05)
	Psychology M (SD)	EEE M (SD)	Psychology M (SD)	EEE M (SD)	
Cognitive Engagement					
Clear goals (3 items, a = 0.839)	3.98 (±1.12)	4.26 (±1.21)	4.14 (±1.36)	4.56 (±0.93)	F(1, 442) = 0.275, p = 0.600, n^2 = 0.001
Teacher support (6 items, a = 0.877)	4.17 (±1.05)	4.36 (±1.20)	4.17 (±1.19)	4.60 (±1.04)	F(1, 442) = 0.923, p = 0.337, n^2 = 0.002
Learning outcome (3 items, a = 0.928)	2.06 (±1.20)	2.54 (±1.68)	3.59 (±1.89)	4.20 (±1.70)	F(1, 442) = 0.133, p = 0.715, n^2 = 0.000
Affective Engagement					
Synchronous session (5 items, a = 0.878)	4.19 (±1.20)	4.53 (±1.21)	4.51 (±1.24)	5.03 (±1.14)	F(1, 442) = 0.465, p = 0.496. n^2 = 0.001
Teacher Facilitation (6 items, a = 0.921)	4.12 (±1.10)	4.33 (±1.33)	4.23 (±1.27)	4.58 (±1.09)	F(1, 442) = 1.867, p = 0.173, n^2 = 0.001
Behavioural Engagement					
Online activities (5 items, a = 0.924)	3.94 (±1.20)	3.91 (±1.38)	4.46 (±1.31)	4.68 (±1.20)	F(1, 442) = 0.823, p = 0.365, n^2 = 0.002
Collaborative learning (6 items, a = 0.878)	3.49 (±1.24)	3.65 (±1.42)	3.29 (±1.18)	4.16 (±1.28)	F(1, 442) = 6.392, p = 0.012, n^2 = 0.014
Teacher feedback (4 items, a = 0.869)	3.83 (±1.25)	4.25 (±1.27)	3.89 (±1.46)	4.39 (±1.37)	F(1, 442) = 0.072, p = 0.788, n^2 = 0.000

a: Cronbach's Alpha, α: the limit of the significant level, M: Mean, SD: Standard Deviation, F(a, b) is the variance value, p: significant value, n^2: size effect, 7-point Likert scale (1: not at all, to 7: very great extent).

Multiple regression analyses explore whether students' academic performance for each department and each learning environment, which was considered as an overall indicator of student engagement with the course, was associated with the teaching elements (i.e., clear teaching goals, teacher support, teacher feedback, teacher facilitation, online activities, synchronous session, collaborative learning, and learning outcomes). The regression model predicted approximately 3% of the overall variance in total Psychology student performance for those students who had the main preference for a synchronous face-to-face environment, F(8, 325) = 0.85, p = 0.561, with none of the teaching variables to significantly contribute to academic performance. The regression model predicted approximately 7% of their academic performance for psychology students who preferred an online learning environment, F(8, 325) = 1.16, p = 0.331, with none of the teaching predictors being significant. Thus, there was not any difference in how these teaching predictors were associated with the Psychology student performance in each learning environment, keeping the level of student engagement at the same level. Based on the EEE student responses, the regression model predicted approximately 6% of the overall variance in total EEE student performance for those students who preferred a face-to-face learning environment for the teaching delivery process (F(8, 37) = 0.46, p = 0.884), with none of the teaching predictors being significant. Finally, for those EEE students who had the main preference for an online learning environment, the regression model predicted 15.5% of the overall variance in their total academic performance, F(8, 37) = 0.85, p = 0.569, with none of the teaching variables to significantly contribute to their academic performance. Thus, the teaching elements were higher associated with academic performance in online environments rather than in a face-to-face environment for the EEE undergraduate students. This is in alignment with the previous findings of this study regarding the EEE students' preferences in the online learning environment.

A two-way ANOVA statistical analysis compares students' responses regarding learning environment preferences and individual characteristics (Table 6). The analysis revealed a significant difference between the groups of students regarding their surface learning approach, with those students who preferred the online learning environment responding higher on the relevant to surface approach questions memorising knowledge compared to those students who preferred the face-to-face learning environment. Additionally, the size effects revealed a significant difference in students' preferences in the online learning environment regarding a variety of sources (online material to study at their own time), behavioural self-regulation (self-evaluation and effort management for learning), self-efficacy (their capabilities to achieve academic success) and test anxiety (stress and anxiety before or during any test). The EEE students who preferred the online environment had a clear view regarding the course utility (student perceptions about the importance of the course to their future career) compared to the Psychology students and to the EEE students who preferred the face-to-face environments.

Table 6. The differences between students' preferences in learning environments regarding the student characteristics.

Student Individual Characteristics	Face-to-Face Environment (i.e., Lecture Theatre, Classroom) Supplemented with Technologies such as Online Voting Systems (i.e., PollEveryWhere, Kahoot)		Online Environment (i.e., Zoom/Microsoft Teams) Supplemented with Asynchronously Online Activities such as Watching Pre-Recorded Videos		ANOVA Analysis between the Disciplines (α = 0.05)
	Psychology M (SD)	EEE M (SD)	Psychology M (SD)	EEE M (SD)	
Cognitive Engagement					
Variety of sources (4 items, a = 0.809)	2.83 (±1.04)	2.69 (±1.03)	2.63(±0.89)	2.79 (±1.11)	F(1, 442) = 1.847, p = 0.175, n^2 = 0.004
Surface learning (3 items, a = 0.774)	2.92 (±1.13)	2.69 (±1.17)	2.77 (±1.04)	3.05 (±1.24)	F(1, 442) = 4.151, p = 0.042, n^2 = 0.009
Self-efficacy (4 items, a = 0.800)	3.17 (±1.06)	3.16 (±1.33)	3.00 (±1.07)	3.26 (±1.07)	F(1, 441) = 1.164, p = 0.281, n^2 = 0.003
Affective Engagement					
Test anxiety (4 items, a = 0.871)	2.38 (±1.21)	2.51 (±1.52)	2.28 (±1.17)	2.82 (±1.42)	F(1, 442) = 2.024, p = 0.155, n^2 = 0.005
Behavioural Engagement					
Behavioural Self-regulation/negative habit (7 items, a = 0.818)	2.80 (±0.99)	3.04 (±1.07)	3.13 (±1.16)	3.27 (±1.15)	F(1, 441) = 0.195, p = 0.659, n^2 = 0.000
Course Utility (3 items, a = 0.815)	2.25 (±1.06)	2.48 (±1.07)	2.25 (±0.96)	2.68 (±1.17)	F(1, 441) = 0.811, p = 0.368, n^2 = 0.002

a: Cronbach's Alpha, α: the limit of the significant level, M: Mean, SD: Standard Deviation, F(a, b) is the variance value, p: significant value, n^2: size effect, 7-point Likert scale (1: not at all, to 7: very great extent).

Further statistical comparison assesses the contribution of the COVID-19 pandemic to adopting a synchronous online learning environment and explores the differences between the two departments using a one-way Analysis of Covariance (ANCOVA). The question about students' "*new learning habits to cope with the University's move to online learning over* *the COVID-19 lockdown period*" was a covariate to control for the effects of various levels of learning environment preferences in undergraduate students. There was not any difference between the students between the two departments when they were asked to report to what extent (1: Not At All to 7: Very Great Extent) they learned better in a physical lecture/class environment rather than connecting from their home to the web-conferencing environment (e.g., Zoom, Microsoft Teams) (Psychology students: 5.2 ± 1.7, EEE students: 5.1 ± 1.8, F(1, 443) = 1.04, $p = 0.308$).

Deductive thematic analysis [56] was conducted to test students' responses to the online open-ended question on the existing student engagement framework (behavioural, affective and cognitive engagement), as discussed in the Introduction part. Microsoft Excel was used for conducting a structured tabular thematic analysis [57]. Overall, 178 out of 446 students from both departments left their qualitative responses in this final part of the questionnaire (online open-ended question) and Table 7 provides a breakdown of the number of students who left a qualitative reply per department and year.

The students' qualitative responses were split into three theme categories to explore student learning engagement and how it has been affected by the online environment (e.g., ability to work from home, and learning influenced by the COVID-19 restrictions). Based on the results of the analysis, 12 subcategories (i.e., lack of communication, heavy workload, interactive learning, authentic assessment, technical issues, lack of personalized learning) were extracted into these three main theme categories: (1) Behaviour, (2) Affective, and (3) Cognitive engagement dimensions, while the theme categories and the subcategories were defined around abstract concepts related to challenges and opportunities in online learning (Table 8).

Table 7. Breakdown of participant characteristics (department and year) leaving comments on the open-ended question.

Department	1st Year	2nd Year	3rd Year	Total Number
Psychology	68	32	38	138
EEE	14	15	11	40
Both Departments	82	47	49	178

Table 8. Students' qualitative responses regarding motivation and engagement over the COVID-19 pandemic split into various themes.

Theme and a Brief Description	Sample of Student Responses
Behavioural engagement(i.e., participation and interaction)	
Challenges due to the lack of communication: Several students have lost communication with their lecturers and peers through the online learning environment.	EEE student Year 1: *I have no real communication with lectures, and I don't even know the other students on my course as anything more than another name on a zoom call."*
Challenges due to heavy workload: Many students experienced more work hours because they could not adjust themselves to the new learning conditions.	Psychology student Year 3: *I fall behind sometimes and have to spend days catching up, whereas, if I was in a lecture hall, I would make all notes at the time of the lecture and not have to worry about catching up.*
Opportunities for interactive learning: The interactivity of online lectures incorporating quizzes, PollEveryWhere, Padelt online discussion, or other discussion opportunities into the synchronous sessions allowed students to engage with the learning process.	Psychology student Year 2: *I feel like the Padlet, and chat function allows me to be able to ask questions. Also, because the content is often a recap in the synchronous lecture, I know what I don't understand already.*
Opportunities for authentic assessment: Exams could be a venue for students to further increase their participation in the learning process.	EEE student Year 3: *I much prefer online exams, as you don't have to memorise everything which is very stressful, extremely time-consuming, and not applicable to real life.*

Table 8. *Cont.*

Theme and a Brief Description	Sample of Student Responses
Affective engagement (i.e., learning environment, teachers)	
Challenges due to technical issues: The Internet connection prevented them from engaging with the lecture session, and several more mentioned the use of the *library and other resources available in the University to gain in-depth understanding and engagement in the course*	EEE student Year 2: *During zoom calls, I often have issues with wifi, and considering that these live sessions are not recorded I feel I miss out on a lot of information covered during these* and *I have always revised in a library, and without this, I've really struggled, and it reflects heavily in my average grades.*
Challenges due to lack of personalised process: Many students were not engaged with the teaching process *because it is a very impersonal approach.*	Psychology student Year 3: *Due to the lack of enjoyment and personal interaction, the learning process is boring and painful, and I cannot wait for the Easter break."*
Opportunities for reducing learning environment stress: Some students who experienced stress due to the learning environment could not follow the teaching process.	EEE student Year 3: *I find the lecture environment very stressful, so much so that II find it difficult to concentrate in those situations because I am so nervous. Online classes have allowed me to collect and retain more information, as I am less anxious in this 'classroom' learning environment."*
Opportunities for the effective design of lecture time: Students usually attended a 2-h lecture in a physical environment which did not allow them to increase their productivity.	Psychology student Year 2: *2-h lectures in person feel like a waste of time as it is too difficult to keep up with what is being said, what is on the slides, and writing this down and trying to understand this. Online lectures allow us to take our time and understand the content. Synchronous sessions make it easier to get questions answered that we may be too uncomfortable to ask in person in a lecture hall."*
Cognitive engagement (i.e., learning goals, self-regulation, deep learning)	
Challenges due to distractions: Many other students have been distracted due to the home environment, which in many cases led to *procrastination*.	Psychology student Year 1: *I live in halls, but I cannot do any work there due to noise, the walls are so thin people walking by outside are a loud distraction. It's easier to procrastinate at home as there are always family issues to solve, children to support, and housework & chores to do!"*
Challenges for further procrastination: By losing their daily "learning" routine, students could not copy their university life.	EEE student Year 2: . . . *without the routine of travelling to campus, I find it difficult not to procrastinate. It has been a massive jump from sixth form (in which there is a very regular routine you must stick to) to university as now."*
Opportunities for effective use of time due to less commute: Students who should commute found online learning more useful.	Psychology student Year 2: *Because I commute to university, learning from home has allowed me to develop a more structured schedule for the day and I feel that I can get more done because I am not spending time on the commute."*
Opportunities for studying the subject in-depth: Students were able to keep notes in their own time and space and search for help over the online synchronous session if they wished.	EEE student Year 3: *Being online is easier as videos are out first and you can watch them write your notes and understand, then if there are any issues you can ask questions in the next session. Learning online is all right, I got used to it".*

Overall, the COVID-19 pandemic affected students' *mental health*, and/or their *ability to work and relax in the same environment*. 104 students out of 178 mentioned the connection of their learning motivation with the COVID-19 pandemic, which led to feeling "very unmotivated" to study and learn. This seriously impacted student engagement, as they "felt less involved in" their subject. Regarding students' behavioural engagement, the potential challenges could be related to additional workload and the lack of communication between students and teachers, whilst the potential opportunities could be regarding the interactive learning environment and assessment authenticity, allowing students to be more engaged with the course content. The qualitative responses revealed challenges and opportunities for the wide area of affective engagement. These could be related to technical issues and the use of University facilities alongside the reduction of class stress and effective teaching design. Finally, regarding cognitive engagement, the potential challenges could be related to potential distractions due to students' study environment, which might lead to potential procrastination. On the other hand, the potential opportunities could be related to the effective use of time and online content to study in-depth their cognitive subject. Finally, many students for both departments made a clear point that online exams have significantly reduced stress and anxiety, while they prefer to follow the small classes (i.e., tutorial sessions, seminars) and laboratory sessions in a physical learning environment. Special merit should be given to students with disability issues, who provided various additional comments about their learning experience in an online environment. For example, dyslexic persons prefer a physical learning environment because "*hearing others' ideas and opinions was crucial* to her/his understanding." On the other hand, deaf students prefer synchronous online sessions with asynchronous activities because "the *big lecture theatres are acoustically impractical*."

4. Discussion

This study aimed to explore students' preferences in different learning environments regarding their learning engagement, considering individual student characteristics (i.e., self-efficacy, self-regulation, test anxiety) and teaching delivery elements (i.e., clear learning goals, collaborative learning, teacher's role). Each of these elements is linked to behavioural, affective or cognitive student engagement, as has been discussed in the Introduction part and illustrated in Figure 1. Students from two departments (Psychology and Electrical Engineering and Electronics-EEE) over the three-year levels of undergraduate studies completed an online questionnaire, providing quantitative and qualitative responses. By inviting students from Psychology (soft discipline) and EEE (hard discipline), a secondary aim was to explore whether there was any difference in students' learning environment preferences regarding student background. Paying attention to these differences would enable the Higher Education sector to optimize the teaching process in different environments based on the requirements for each discipline.

4.1. Difference between Academic Performance and/or Learning Environments in Each Department

As this study was conducted over the 2021–2022 academic year, all first-year students had limited experience in the face-to-face delivery process due to the COVID-19 pandemic restrictions. The second and third-year students had more experience in both (face-to-face and online) learning environments compared to the first-year students, to whom teaching delivery was through an online environment. However, this study has not found any difference in students' preferences in learning environments over the years and within departments. On the contrary, there were significant differences between the two learning environments for both departments, with most students believing that they were engaged more in a face-to-face rather than in an online learning environment. This might be an expected finding, as these students had decided to follow an in-person course before being "forced" to adopt a new learning process due to the COVID-19 pandemic restrictions. Additionally, a study conducted before the COVID-19 pandemic explored the comparison between online and face-to-face courses with student satisfaction, concluding that "an online course cannot fully replace face-to-face learning, which offers a real-life learning experience, human interaction, and personal contacts with both tutor and fellow students" [58] (p. 43). However, by comparing students' academic performance for the two departments regarding their preferences in learning environments, it was found that academic performance was influenced by the learning environments, with EEE students gaining higher grades in an online learning environment than psychology students and those EEE students who preferred psychical learning environments. This finding might link to what Vo, Zhu, and Diep (2020) [29] found regarding the difference in blended learning environments between students from hard (i.e., EEE) and soft (i.e., Psychology) disciplines for online learning environments. It could be potentially explained by the way that teachers employed "the strategies that best foster the acquisition of disciplinary knowledge and competencies" (p. 490), with Psychology students (soft discipline) appreciate a blended learning approach based on discussions more than EEE students (hard discipline) to which the online content (i.e., visualised material) assisted them to understand the cognitive topic [59]. A potential implication of these findings was for teachers to reconsider the presented material, allowing their students to be cognitively engaged with the online content. Furthermore, by synthesising this study's findings with previous studies conducted during the COVID-19 pandemic, institutions and teachers must reconsider the teaching design process before adopting online elements for synchronous lectures. For example, Zeng and Wang (2021) [49] found the positive effect of synchronous learning on student satisfaction (highly related to academic performance) when the sessions were carefully designed, with teachers facilitating discussions, providing feedback to their students and facilitating student collaboration.

4.2. Differences between Various Aspects of the Teaching Delivery Process (i.e., Learning Goals, Feedback, Teacher Support) with Face-to-Face or Online Learning Environments in Each Department

Analysing the student quantitative responses regarding teaching delivery elements, a significant difference was found between the departments and the learning environments only regarding collaborative learning, with EEE students responding higher than Psychology students in both learning environments. This finding is in alignment with what Vo, Zhu, and Diep (2020) [29] found when they explored the difference between hard (i.e., EEE) and soft (i.e., Psychology) disciplines in a blended learning environment, suggesting that the teachers from the hard disciplines stressed the importance of collaborative learning and assessment allowing their students to gain the active learning experience. It might be easier for EEE teachers rather than psychology staff to integrate collaborative activities, as the engineering curriculum included more practical laboratory sessions and small class activities, and the teachers did not need to pay additional effort to design collaborative learning activities for their students. Additionally, students from both departments highly evaluated the contribution of online activities to their engagement in online learning environments as they interacted with their online content, teachers, and their peers, but they expected their teachers to provide clear goals. In an online learning environment, they were mainly students who should monitor to what extent they have reached the learning goals, employing the relevant learning strategies. Participants from the Psychology department believed that they received the same level for face-to-face and online learning environments regarding teacher support to be engaged with their courses. This is an important element for teaching, and teachers should consider it when they deliver an online course to increase student engagement cognitively by enhancing students' higher-order thinking [60] and effectively by reducing the drop-out rate [61]. Students also believed that they received better quality feedback from their teachers in online environments, which assisted them in facilitating their learning. Therefore, they were more engaged with their courses through synchronous online sessions, reaching their learning outcomes for their course. This finding aligns with a previous study on synchronous and asynchronous settings of online teaching over the COVID-19 pandemic [62], which reported that more feedback opportunities, including emotional support, were provided in synchronous online settings, supporting student learning facilitation process. The implication of these findings is for teachers to practice on feedback delivery process in a blended learning environment by utilising their practices from their online synchronous lecture and online environment. Although many researchers have studied how the blended learning approaches could enhance the feedback delivery process and collaborative opportunities [63,64], this study has focused on the differences between online and face-to-face blended learning environments under the same experimental conditions, pointing out the need for future research on this area. A recent study has discussed how teachers could redesign their courses to increase flexibility and student engagement in non-pandemic times, promoting collaborative activities and enhancing the feedback delivery process [65].

4.3. Differences between Students' Preferences in Synchronous Learning Environments (Face-to-Face or Online) and Their Characteristics (i.e., Self-Efficacy, Behavioural Self-Regulation) in Each Department

Based on students' responses to the questionnaire, EEE students who preferred to work in an online learning environment felt more confident in their ability to complete academic tasks (self-efficacy) and successfully engage with online learning material (variety of sources). They have also presented a higher level of behavioural self-regulation compared to Psychology students and those EEE students who preferred to follow a teaching approach in a face-to-face learning environment. Although a previous study found engineering students had higher self-regulation skills compared to various disciplines [66]; other researchers could not support this finding [67,68] due to the complexity of self-regulation [69]. On the contrary, a recent study conducted over the COVID-19 pandemic's first lockdown found that those students who have adapted themselves well to the new learning requirements presented a high level of self-regulation skills and confidence in their ability to use technology for learning purposes utilising the online learning opportunities [46]. Students who preferred a teaching delivery process in a face-to-face learning environment responded differently when asked about the surface learning approach compared to those who preferred online learning environments. By following surface learning approaches, students tended to minimise their commitment to understanding and their cognitive engagement in learning activities, finding ways to fix and reproduce their learning patterns [70]. Al Mamun, Lawrie, and Wright (2022) [71] have recently argued that the absence of teachers in an online learning environment highly influences cognitive and behavioural student engagement, facilitating their learning only by online learning material and embedded pedagogical approach. The students involved in this study preferred to interact with their teachers and peers in a face-to-face environment rather than in an online one. However, Schunk and Ertmer (2000) [72] pointed out that when teachers did not "dictate" to students what they needed to do and how to accomplish tasks in a face-to-face environment, they should assist students to develop the relevant self-regulate skills, feel confident in their ability for academic success; otherwise, it would be easy for students to follow a surface learning approach. The way that students coped with their learning process along with their previous experience on online tests also explained why there was a difference in test anxiety, with those EEE students who preferred the online environment to challenge their test anxiety over the COVID-19 pandemic compared to the other students [73]. Finally, as students have been "forced" to work more online over the COVID-19 pandemic, they were involved in reflecting on their learning experiences and course utility, which aligns with the recent findings on employability awareness, where students had been linking their course opportunities with employability and reflective practice in online learning environments [74]. Overall, these findings regarding the role of students' characteristics in learning engagement in the two environments could be utilised to assist teachers to enhance their blended learning approach by keeping their students behavioural, affectively and cognitively engaged. For example, the main implications of these findings for teachers and institutions are to provide opportunities to students to connect the course content with employability (i.e., promote the connection between the course characteristics and employability, allowing students to recognise the importance of their course), support students to develop confidence in their ability as they work online, and review the assessment process by considering the role of the student test anxiety in various settings.

4.4. Students' Learning Environment Preferences Were Influenced by the COVID-19 Pandemic

Although there was not any difference between the students from the two departments whether their preferences in learning environments have been influenced by the COVID-19 pandemic, the qualitative student response revealed challenges and opportunities in online learning environments regarding cognitive, affective, behavioural, and social engagement [5]. In summary, the challenges that students faced regarding their engagement in an online learning environment were related to lack of interactions with their students and teachers, additional workload, technical issues, including lack of the use of University facilities, and distractions over their lecture time from the home environment and family responsibilities. These findings about the challenges of the COVID-19 pandemic and university teaching and learning are in alignment with what has recently been presented by other researchers [42,75–77]. Additionally, the students who participated in this study mentioned the learning opportunities about the online environment, highlighting the importance of alternative teaching delivery alongside authentic assessments. For example, students felt engaged with their courses when they actively interacted with their teachers and peers in a flexible learning online environment, allowing them to move away from the knowledge memorising process following a knowledge construction approach. A recent study has discussed how a university learning environment could support teaching and learning flexibility by considering pedagogical approaches, technologies, and student learning needs in informal learning environments and without being on campus for face-to-face meetings [78]. The current study's findings also provided the reasons why students preferred this flexibility in learning and what universities, policymakers, and teachers should consider offering students a flexible online learning environment. For example, a practical implication of these findings is regarding the online exams/assessments that the institutions could offer to reduce student test anxiety. The institutions could deliver workshops and training for students to help them with the online exam revision enhancing their critical skills and promoting deep learning. Furthermore, the institutions could practice flexible ways to support teaching from home and university lectures, allowing students to have other commitments, such as work and caring duties, without disrupting their studies and utilizing the technology opportunities. Recently, a study has explored a mixture of different types of teaching and learning techniques, offering opportunities for teachers and students to participate in a variety of class roles, interacting via online, face-to-face or blended methods [79] (McKenzie et al., 2022), but future work on this area could assist institutions and teachers to reconsider the digital learning transformation in the post-COVID-19 pandemic period.

4.5. Limitations and Further Future Work

Finally, by conducting this study on the COVID-19 pandemic, students might have provided responses that were influenced by their mental health status [80]. This factor may have affected their engagement in studying and living in the same home environment. For example, this may have impacted their preferences in an online learning environment, as they might feel isolated from others and be fatigued without "human" contact. Another limitation regarding this study might be related to the sample and the data collection method. Although the sample size was large enough to extract statistically secure results, this was a sample from only one UK University, therefore generalisability can be questioned. In future studies, a more varied sample utilising students from other Universities should take place to gain an in-depth understanding of their engagement in various learning environments. For that purpose, the questionnaire of this study has been uploaded to the Zenodo open-access repository, where other educational researchers could compare their student engagement with the findings of this study. Although it might be considered that the experimental conditions of future studies on this area will be different without students being "forced" to follow the COVID-19 pandemic restrictions, this snapshot of student engagement could be a reference study. An additional limitation regarding the student sample might be that the number of participants from the Psychology first-year cohort was higher than the rest and all the first-year undergraduate students, including EEE students, had limited experience in the face-to-face delivery process compared to the students from the other years. However, these differences in experience might not play a role as there was not any statistically significant difference in student preferences within the year of studies for each department. Furthermore, the sample size for each year for each department was more than 30 participants, which satisfied the conservative rule of thumb, where at least 30 participants are necessary per condition [81]. Another limitation of this study was related to students' self-responses to an online questionnaire. Students had the opportunity to provide their qualitative responses to an open-ended question, but by allowing them to be involved in future focus groups, the findings of this study could be cross-checked. Finally, this study explored student engagement in the two learning environments mainly considering the teacher-student interactions. However, future work on student-student interactions in various learning environments may provide significant information about student engagement. The different types of interaction, including teacher-student, student-student, materials-student, and their effect on student engagement and motivation have been previously discussed by many educational researchers, with student-student interactions being one significant challenge in online learning environments [82–84].

5. Conclusions

In conclusion, this study not only discussed student engagement in an online learning environment over the COVID-19 pandemic but also attempted to explore any potential difference in face-to-face learning environments for two departments (Psychology and EEE). Student learning engagement has been discussed under the cognitive, affective, and behavioural dimensions. Student academic performance also provided valuable findings regarding student preferences in the face-to-face and online learning environments, and it was considered an indicator of student engagement with the course. Although other educational researchers have studied student engagement over the COVID-19 pandemic period, the authors have not been aware of any study which discussed this topic, exploring the role of individual characteristics and teaching delivery elements in face-to-face and online learning environments. The findings of this study could assist universities, policymakers, educational researchers and teachers in shifting teaching approaches over the post-COVID-19 pandemic era by adopting elements from online learning to a blended approach. For example, it is crucial for shifting knowledge from transition to the construction process for students to be engaged with their courses to follow the teaching way that better fits their needs (i.e., disability support, work and family commitment), being connected with their teachers over the lecture time, working on online collaborative activities, and receiving real-time feedback from their teachers. The post-pandemic era also needs to consider how teachers could further help their students with the self-regulation development process by providing clear goals and support throughout both learning environments. This area could be further explored, but this study might be a reference one for future work on student engagement in blended and online learning, as it studied student preferences in two environments before and during the COVID-19 pandemic period.

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Classroom-Integrated Movement and Music Interventions and Children's Ability to Recognize Social Interaction Based on Body Motion

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Abstract: Music and movement activities have been found to be beneficial for learning in childhood. The current study was part of the Arts@School project examining the effect of classroom-integrated arts-based interventions (music, movement, music-movement) on various student outcomes. The outcome of interest in the current report is the ability to recognize social interaction, which is one aspect of social cognition, an important but often ignored factor contributing to well-being and learning. The ability to recognize social interaction was studied using a test with two human figures either interacting with each other or moving separately. Children aged 10–11 completed the test pre and post intervention. The intervention groups and an inactive control group were four classes in a school. The interventions were delivered by teachers. The music intervention included listening, singing, and joint music making. The movement intervention was based on a creative dance approach and contained developmental movement patterns. The music-movement intervention focused on bodily experiences arising through activities combining music and movement. All intervention groups improved at the test, whereas the difference between the pre and post measurement did not reach significance in controls. This trend suggests that music and movement interventions integrated in the school learning environment may support children's ability to interpret body motion, an important aspect of social interaction.

Keywords: arts-based interventions; education; interaction; learning environments; movement; music; social and emotional learning; social cognition

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1. Introduction

1.1. Art Interventions, Child Development and Social Interaction

In recent years, there has been a growing interest within the arts field towards the potential benefits of art practices for student outcomes such as learning and well-being [1–5]. Looking at music and dance as art forms from a perspective of learning environments can be beneficial. Engaging in music activity has been found to enhance children's linguistic skills [6], verbal abilities [7], executive functioning [8] and support academic achievement [9]. Less research has been conducted on the effects of dance on children, but dance practice has been found to support children's basic reading skills [10] and improve memory and attention in adults [11–13].

From a developmental and educational perspective, not only academic skills, such as literacy, mathematics and language, but also social and emotional learning should be given attention when evaluating and investigating student outcomes. Social cognition is a very complex construct referring to processes related to the perception, understanding and implementation of cues that communicate emotional and interpersonal information [14,15]. It involves linguistic cues, but also nonverbal cues such as tone of voice, facial expression, gaze direction, body posture, movement and gestures, actions and touch [16]. Social interaction (any verbal and nonverbal interaction that takes place between two or more individuals) is one aspect of social cognition and requires a range of motivational, affective and cognitive processes in complex dynamic interplay [17,18]. The development of social and emotional competencies is generally recognized in today's Western educational systems to be important to successful learning, well-being and functioning as part of society. Healthy social development includes these aspects, and is associated with self-confidence, good peer relationships, persistence, good language development, communication skills and attention skills, and conversely, children with early challenges in this developmental domain are at risk for a range of later personal, social and academic difficulties [19–22].

Although relatively few studies have investigated the effect of arts-based interventions on child development [5], there are some findings suggesting that both music and dance/movement activities can be beneficial for social interaction. Children attending a music school-readiness group improved more in social cooperation, social interaction and social independence scales in comparison to controls attending a no music school-readiness group [23]. Relating to empathy, a trend was found suggesting children engaged in long-term musical group interaction improved more in empathy scores in comparison to controls [24]. Even a brief intervention-like session can sometimes show immediate effects. A short session of joint music making increased spontaneous cooperative and helpful behavior between pairs of 4-year-old children, compared to children in a non-musical session to which they had been randomly assigned in an experimental setting [25].

Dance/movement activities have also been found to positively affect social interaction in children. Children from families with incomes below the poverty line who participated in a twice-a-week eight-week creative dance program (to which they had been randomly assigned) made improvements in social competence and reductions in their behavior problems compared to control children [26]. The dance program in this study [26] was based on a creative dance approach developed by dance pedagogue Anne Green Gilbert [27], encompassing a series of developmental movement patterns that typically developing children naturally move through in the first year of life. Another study found that children engaged in creative dance improved in cooperation, communication, leading, following, awareness of others and felt stronger belonging to a group, though in this study there was no control group that would have allowed for comparison [28].

From a point of view of study design, most reviewed studies used random group assignment. However, Tervaniemi et al. [5] promote the use of naturalistic real-life group allocations without randomization in this area of research because of the benefits of group allocation based on preference and motivation. Habibi et al. [29] acknowledge that the interest of both children and intervention leaders should be considered when assigning groups to art activities to maintain motivation for a longer period of time.

Regarding children with some developmental challenges, music therapy intervention was found to enhance social competence assessments in 6–17-year-olds with social skill deficits [30]. A music intervention reduced aggression and improved self-esteem in 10–12-year-olds with highly aggressive behavior compared to controls [31]. Systematic creative movement and dance activities resulted in positive tendencies in creativity and body image, as well as in motor, speech and communication in children with hyperactivity symptoms, who were selected by their class teacher to participate in systematic creative movement and dance activities, compared to a control group with the same symptoms who did not participate in any activity [32]. Children with autism spectrum disorder (ASD) are an important group to investigate. Autism spectrum disorders are characterized by difficulties in social interaction [33]. In a review, Srinivasan and Bhat [34] highlight the potential of music and movement activity to support communication and social-emotional development in children with ASD. They propose, based on the evidence reviewed, that interventions grounded in singing, music-making, joint action and social synchrony can be beneficial for relieving deficits in social communication in children with ASD.

The studies reviewed have a multitude of methods and approaches. Based on their findings, it is reasonable to assume that engaging regularly in music or dance-related movement activities might have positive effects on some aspects of children's social development and social interaction.

1.2. The Body as a Source of Social Information

While much research related to nonverbal social information processing in general has been conducted on gaze following and emotion recognition through facial expression, less attention has been given to investigating social information embedded in whole body motion (review [35]). In recent decades, however, interest in this area seems to have increased, and studies have emphasized the body as an important source of social information. The discovery of the mirror neuron system [36] and subsequent extensive research in this area have revealed on a brain level how motor and sensory mirroring between individuals is an important part of understanding other people's goals and emotions, and a likely prerequisite of empathy [16,37]. The mirror neuron system is involved in both visual and auditory action recognition [38] and in understanding the intentions of other people's actions [39]. Several studies have concluded that emotions expressed through the body in different ways are well recognized by observers (review [40]). Thus, the body and its actions convey various kinds of information related to social interaction. Body motion is particularly important since interactions are dynamic.

Studies on body motion interpretation need stimuli that do not include cues from other expressive modalities to trace interpretation specifically to the movement of the body. Point-light displays, i.e., white dots on a black background indicating the joints of a moving body [41], have frequently been adopted in such studies, even though originally created for other purposes. In a point-light display, a still display resembles a random collection of dots. However, when it starts to move, a human body and its movements are immediately evident. There are no static cues, such as facial expressions, body shape or visual patterns, so perception is based on body movement. Such displays have enabled researchers to conclude that emotions are recognized from body motion depicted by dancers [42–44] from arm movements [45], gestures [46] and gait [47]. In their review, Witkower and Tracy [35] report that pride, joy, sadness, shame, embarrassment, anger, fear and disgust are all displayed and recognized through specific body movements.

Children distinguish between body motion and random motion already at an early age, as early as 3–6 months [48–51]. Typically developing children steadily improve in their ability to recognize point-light body motion, achieving a level equal to that of adults by the age of 5 years [52]. However, few studies have investigated children's ability to further interpret body motion [53].

Emotion recognition from body motion has been studied in children. Results show that 4-year-olds recognize sadness, 5-year-olds additionally fear and happiness and 8-year-olds additionally anger from expressive dance movement [42]. There is a steep increase in emotion recognition from body motion with increasing age until about 8 years, followed by improvement at a much slower rate through late childhood and adolescence [54].

Centelles et al. [55–57] developed and used a social interaction test to investigate the ability to interpret whether people are acting together from body motion. The rationale was that this ability contributes to fluent social interaction. For example, seeing people on a bus stop tap each other on the shoulder reveals a different social intention than seeing one person putting a hat on and the other tapping his mobile phone. The test consisted of point-light displays of two moving human figures, and the participant's task was to discriminate between *social interaction situations* and *no interaction situations*. In *social interaction situations* (*SI*) two humans did something together (e.g., sawing a log together), while in *no interaction situations* (*NI*) both performed their own actions (e.g., one paints, the other juggles). Centelles et al. [55,56] studied typically developing children, children with autism spectrum disorder (ASD) and adults. Typically developing children up to 8 years of age had a lower rate of correct responses than adults [55,58]. Children with ASD had a lower number of correct responses than age-matched typically developing children, suggesting that they had more difficulty discriminating social interaction situations [55,56].

The social interaction test was chosen to be used in the current study because it involves interpretation of whole-body motion, and it is well established and suited for children. Previously, test results have been reported in terms of number or percentage of correct responses (e.g., [58]). However, such a measure may be confounded by response bias. For example, if a participant prefers to respond, "yes, there is social interaction", the percentage of correct responses to SI situations is high, but at the same time there are many incorrect responses to NI situations. In order to determine participant's perceptual sensitivity without interference from response bias, the signal detection theory should be applied [59,60]: to determine sensitivity, discriminability index d' is calculated based on correct responses to SI (hits) and incorrect responses to NI (false alarms; see Section 2 for details). When two participants have equal sensitivity, i.e., ability to discriminate social interaction, their d' is the same even if one is biased to respond SI and the other is biased to NI (e.g., if the former gives 92% correct responses to SI and 74% correct responses to NI, while the latter gives 80% correct responses to SI and 89% correct responses to NI, both have the same discrimination ability with $d' = 2$). In the current study, the results of the social interaction test are given as d' since sensitivity to social interaction is of interest here.

1.3. Synchrony and Reciprocity in Social Interaction

Synchrony is an important ingredient in social interaction. Synchrony means that some events occur simultaneously or with the same timing. Another closely related term is temporal reciprocity, where actions are linked to each other in a joint temporal sequence [61]. Both occur in social interaction, as indeed, "social interactions typically involve movements of the body that become synchronized over time and both intentional and spontaneous interactional synchrony have been found to be an essential part of successful human interaction" [62] (p. 1). For example, synchrony in body sway has been shown to emerge from social interaction, e.g., when partners are discussing how to solve a puzzle, their bodies start to sway in synchrony [63]. In development, synchronization between parent and infant in terms of mutual gaze, shared attention and arousal predicts later social outcomes such as attachment and empathy [64]. Reciprocity is extremely common in social interaction, for example when handing a present to someone who takes it; there is a sequence of temporally coordinated actions enabling smooth interaction.

Synchronizing one's body with the body of another person and reciprocal actions contribute to sustaining successful social interaction [65–70]. Synchrony in pairs of point-light figures is associated with higher ratings of social cohesion [71]. Ratings of the degree of rapport manifested by a pair of walkers are the highest when they walk in synchrony [67]. Moving in synchrony enhances adults' sensitivity to other people's movements and promotes cooperative behavior [70]. Synchronous others are not only perceived to be more similar to oneself, but also evoke more compassion and altruistic behaviour than asynchronous others [72].

Moving in synchrony has been found to support bonding between groups of children, while merely moving around without synchrony in a mutual space does not have such an effect [73]. Compared to asynchronous movement, performing movements in synchrony with a peer has been found to lead to more spontaneous helping among young children; it has also been associated with increases in enjoyment, eye contact and mutual smiles between partners [74], and shown to positively influence children's cooperative behavior with a peer [24]. Pro-social effects of moving in synchrony have been noted already in 14-month-olds [75].

When looking at music and dance/movement as art forms, practicing synchrony and reciprocity—e.g., of body movement, effort, timing, rhythm, lyrics, timbre, sounds—is at the core of both. Engaging in such art forms might enhance perception of synchrony in other areas of life. Wiltermuth and Heath [76] suggest that cultural practices involving synchrony (such as music and dance) may enable groups to be more successful in coordination by strengthening social attachment. Dancing increases social bonding [77]. It has been found that adults with autism spectrum disorder who received a movement intervention based on imitation and synchronization showed a larger improvement in emotion inference and increased synchronization skills and imitation tendencies in comparison to controls who participated in a movement intervention that did not involve these aspects [78].

It could thus be expected that music and movement interventions may foster some social skills partly due to synchronicity and reciprocity inherently involved in their practice. This could be reflected, for example, in improved sensitivity to the perception of social interaction. Specifically, music and movement interventions could be hypothesized to enhance the ability to discriminate social interaction based on body movements of two people.

1.4. Current Study

The current study was conducted as part of the Arts@School research project, one part of a multidisciplinary research initiative concerned with examining the arts as public service called ArtsEqual [79]. This Arts@School research project investigated the effects of three arts-based interventions (music MU, movement MO, and music-movement MUMO) on various student outcomes, such as mathematical skills, executive control, motivation, well-being and social cognition, in elementary school children. The rationale behind using these interventions was to investigate the effects and feasibility of increasing arts-based education in a typical school learning environment. The three interventions were based on extended music activities according to the curriculum (MU; following the curriculum by the Finnish National Board of Education, 2016), a creative dance approach to movement activities (MO; developed by Gilbert [27]) and involving movement in learning music (MUMO; based on the approach by Jaques-Dalcroze [80]). The MU intervention focused on singing, playing instruments and rhythm awareness. The MO intervention involved exercises in body awareness, mirroring and creative movement. The MUMO intervention included moving to music both by improvising and by learning movement patterns. All interventions were conducted by classroom teachers themselves, guided by experts in dance and music pedagogy. The interventions were incorporated into the regular school day three times a week.

The aim of the research reported here was to study potential effects of the interventions on the ability to recognize social interaction based on body motion. There were several other outcome measures in the research project: scholastic measures (literacy, mathematics), neurocognitive measures (executive functions, intelligence, EEG), measures of motivation and well-being as well as interviews regarding children's experiences of interventions. This limited the number and extent of single measures because of the restricted time for testing. However, it was deemed important to investigate at least one aspect of social cognition, albeit in a very condensed and brief experimental format. After a careful consideration of available measures, the social interaction test by Centelles et al. [55–57] was selected since it involved body motion and it was short and suitable for the age group. As far as the three types of interventions are concerned, they were designed based on established arts-based approaches and were predicted to have different effects on several outcomes, for example the interventions with music were hypothesized to be associated with literacy measures (based on previous research on such links, e.g., [6]), but not all outcome measures were hypothesized to differ between interventions. The other outcomes studied in the project will be reported elsewhere.

The current aim was to answer the following question: do classroom-integrated arts-based music, movement and music-movement interventions improve the ability to recognize social interaction based on body motion in school children? This was investigated using a test in which point-light displays of two people either interacting with each other or moving separately were used to measure the recognition of social interaction [55–57]. The interventions in this study were based on the art forms of music and dance and adapted to the elementary school context, but they also implicitly included different forms of practice of synchronization and reciprocity, which are key features in social interaction. It was thereby assumed that all interventions would enhance children's sensitivity to social interaction. The hypothesis was that the children who took part in the interventions (MU, MO or MUMO) would improve in sensitivity to social interaction based on body motion more than an inactive control group.

2. Materials and Methods

2.1. Participants

Only those children who had written consent from their guardians were included as participants in the study even though entire classes participated in the interventions. Since the intervention study was conducted in one single school to have that as a fixed factor and each intervention was naturally integrated into the daily school activities by the pupils' own teacher with their own class, the downside was that anyone who did not agree to participate in research could not be replaced. Consequently, the number of participants resulted to be rather low in the participant groups reported here.

Thus, a total of 59 children took part in the study (25 girls and 35 boys). A total of 12 children (8 girls, 4 boys) took part in the music intervention (MU), 19 children (8 girls, 11 boys) took part in the movement intervention (MO), and 16 children (5 girls, 11 boys) in the music and movement intervention (MUMO). A control group of 12 children (4 girls, 8 boys) did not take part in any intervention. One girl was excluded from the MU group due to deviant data (see analysis section), leaving 11 children (7 girls, 4 boys). The mean age was 10 years 4 months (SD 5 months, range 9 years 9 months—11 years 0 months) in the MU group, 10 years 3 months (SD 4 months, range 9 years 9 months—10 years 11 months) in the MO group, 10 years 2 months (SD 4 months, range 9 years 9 months—10 years 8 months) in the MUMO group and 10 years 2 months (SD 4 months, range 9 years 9 months—10 years 11 months) in the control group in the beginning of the intervention in September. All children reported normal or corrected-to-normal vision.

The University of Helsinki Ethical Review Board in Humanities and Social and Behavioral Sciences has reviewed the study and stated that it is ethically acceptable (statement 31/2016).

2.2. Interventions

The study was conducted in a Finnish elementary school in 2017–2018 during the second year of the Arts@School research project. Out of four parallel classes in the school, three classes were assigned to one intervention each (MU/MO/MUMO), leaving one class as a control group that did not take part in any intervention. The classes were assigned to an intervention (MU/MO/MUMO/control) in agreement with the teachers to ensure both teachers' and children's motivation to engage on a long-term basis. Even if not all children participated in the study, the whole class participated in the intervention. For ethical reasons, the control group class (i.e., all children that had not been assigned to an intervention) was offered an intervention after the completion of the study.

The interventions were integrated into regular classroom teaching. Each intervention session lasted approximately 15 min and sessions were conducted approximately 3 times a week, with a total of approximately 50 sessions during the school year from September to May. They were planned through a collaboration between the classroom teachers and experts of dance and music education: professor of dance pedagogy Eeva Anttila (MO) and professor of music education Marja-Leena Juntunen (MU and MUMO).

The music intervention was conducted in line with the aims and means of regular elementary school music education. According to the Finnish music core curriculum, the aim of music education is to help pupils find personal areas of interest in music, encourage music-related activity and provide pupils with musical tools for expression, as well as supporting overall maturation and development (Finnish National Board of Education, 2016). Playful and holistic activities that provide pupils with a wide range of music styles and encourage expression of personal ideas are central to musical development in grades 1–4. Activities included singing, playing Orff-instruments, listening to music and creative tasks, such as making soundscapes, melodies and writing lyrics. Pupils were guided to learn music by ear through approaches that activate listening. A central idea is that joint music activity fosters social skills such as respect and responsibility-taking. As the intervention followed the guidelines of the core curriculum, the students had been exposed to similar music instruction before. The intervention provided extra instruction, including extra hours, as well as extra activities (e.g., Orff-instruments, soundscapes).

The movement intervention was based on the creative dance approach developed by dance pedagogue Anne Green Gilbert [27]. It encompassed a series of developmental movement patterns that typically developing human beings naturally move through in the first year of life. These movement patterns are initially manifested through primitive reflexes and then become more and more complex and functional as the child develops [81]. Exercises were based on involving the following elements in body motion: touching the body (tactile stimulation), balancing (vestibular stimulation), proprioception and motion, e.g., paying attention to the position of limbs during motion (kinesthetic stimulation), breathing (breath enhancing), movement between the centre and the extremities of the body (centre-periphery connection), spine movement (head-tail connection), upper-lower body connection, body-halves connection, e.g., movement between right and left, and crossing the centre line of the body (cross-lateral connection). The exercises included both individual and partner-work, such as mirroring and touch. The movement intervention aimed at supporting social skills and creativity among other developmental aspects, taking into account that foundations of social interaction develop reciprocally with developmental movement patterns and body integration [27]. The movement intervention was realized without music to make a clear distinction from the music-movement intervention.

The music-movement intervention was based on the approach of Émile Jaques-Dalcroze, integrating the whole body and movement in learning music [80,82]. In Dalcroze pedagogy, learning music is approached through group activities that combine music and movement and through the bodily experiences that arise through these activities, thereby activating the pupil's whole body to sense, receive and internalize music—the body functioning as an instrument itself. In the intervention, activities included rhythmic exercises integrated with singing games and dances from different times and cultures. Body/movement exercises focused on body control, balance, motor skills, coordination and relaxation. Social objectives of the movement-music intervention included communication (e.g., ability to lead or follow), respect and ability to work with different peers in different groups.

2.3. Social Interaction Test

2.3.1. Stimuli and Equipment

The stimuli in the social interaction test were point-light displays of two human beings, originally created by videotaping movement performed by two professional actors. The stimuli have been developed and used previously by Centelles et al. [55–57].

The displays included 25 social interaction situations (SI) and 25 no interaction situations (NI), which are presented in Table 1. Examples of stimuli are presented in Figure 1. The SI situations included emotional situations (of positive or negative valence), conventional social behavior (e.g., social gestures and responses) and social activities (e.g., dancing, sports). In the NI situations, the two actors moved side by side without interacting (movements such as jumping, lifting something, skipping, stretching, walking). The actors in the NI scenes were originally filmed separately and later mounted together for the display to prevent any synchronization between actors [57].

Table 1. Point-light stimulus list. The two point-light figures are referred to here as A and B.

Social Interaction Situations (SI)	No Interaction Situations (NI)
A reprimands B who responds	A hammers a nail, B steps sideways
A and B jump up and down, playing	A turns around dancing, B lowers a rope
A and B kick a ball to one another	A jumps, B paints a wall with a brush
A comforts B who is crying	A jumps up and down, B lifts a rock
Both play a hand-clapping game together	A kicks a ball, B paints a wall with a brush
Both dance together	A wipes his/her feet, B drinks
A offers a chair, B sits down on it	A sneezes, B turns around dancing
Both wave goodbye to one-another	A opens a wine bottle, B lifts a rock
Both wave for attention and jump to greet	A plays catch, B washes dishes
A scares B and B turns and gets scared	A running, B flutters a garment
A commands B to go away, B turns away	A carries a tray, B moves to touch a wall
A curtseys for dance and B bows to accept	A painting, B juggling
Both bow to one another	A picks up clothes, B sits down on a couch
A points up and B looks in that direction	A dries her/himself with towel, B lifts shoulders
A picks up a flower for B and B takes it	A polishing shoes, B writing on a blackboard
A commands B and B gets up offended	A pulls a rope, B pours a drink
Both toast with a drink	A lifts something on a shelf, B ties a shoelace
A and B lift up one another	A stumbles, B lifts something a shelf
A tries to catch something that B has	A sits down on a couch, B plays golf
A plays music with B dancing	A does dusting, B searches for something
A gives something to B that B takes	A sweeps the ground, B attaches a poster
Both laugh at something together	A playing cello, B painting on a wall
A stumbles and B catches A	A handles laundry, B carries a tray
A serves a plate that B receives	A handles fabric, B lifts shoulders
Both see a log together	A opens a cupboard, B stretches

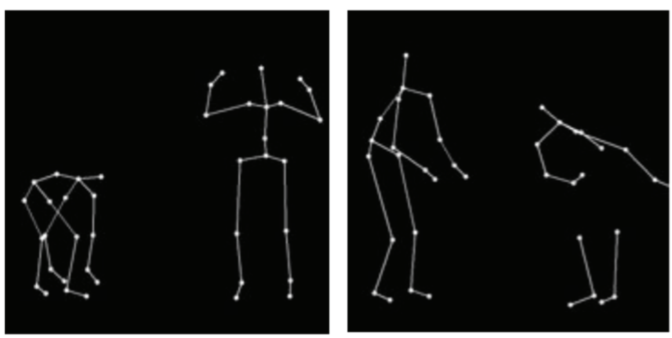

Figure 1. Examples of point-light stimuli. The images are screen-captures from test displays. Here, the two human figures are made visible with lines connecting the dots (there were no lines in the displays in the actual test). In the no interaction situation (NI) on the left, one figure ties a shoelace and the other lifts something onto a shelf. In the social interaction situation (SI) on the right, one figure curtseys for dance and the other bows to accept.

Each situation was presented twice, both as the original and as its mirror-version. Thereby, a total of 100 displays (50 SI, 50 NI) were used in the study. A total of 6 displays (3 SI, 3 NI) were used for a practice trial and the remaining 94 displays were used for the actual experiment. Each display lasted three seconds. The experiment was run on a laptop computer using a software designed for the current study using Presentation software version 20.0 (Neurobehavioral Systems, Albany, CA, USA), and a Cedrus XID Response Extension Box (San Pedro, CA, USA).

2.3.2. Design and Procedure

The child sat in a quiet room in front of the computer that was at approximately 50 cm viewing distance. The experimenter explained to the child that short videos with "dot-figures" of two people moving would appear on the screen. The child was instructed as follows: "If you think the two people are doing things together, press the left button.

If you think the two people are doing things separately, press the right button." ("Doing things together" and "doing things separately" are translated from the Finnish "toimia yhdessä" referring to two people acting/functioning/operating together and "toimia erikseen" (acting/functioning/operating separately or on their own). This was used instead of the word for "interacting" (in Finnish "olla vuorovaikutuksessa"), since this would have been too abstract a word for children of this age. The Finnish "toimia yhdessä" ("doing things together") stands well for different nonverbal and verbal interactive activities, such as dancing together, playing together, discussing and so on.)

Approximately half of the participants were asked to press the response buttons the other way around. Before the experiment, each child practiced with six displays, which were not included in the test. The test lasted approximately 15 min. It was possible to take a short break after the 20th, 40th, 60th and 80th displays. The children were tested twice, at the beginning of the school year in September (pre intervention) and at the end of the school year in April (post intervention).

2.3.3. Data Analyses

The theory of signal detection was applied in the data analysis, which enabled a separation of sensitivity from a possible response bias [59,60]. Discriminability d' reflects the participant's sensitivity, that is, the ability to discriminate the interaction stimuli from the no interaction stimuli and is not affected by response bias. The d' was calculated using the hit rate and the false alarm rate. Hits were the trials in which the participant recognized the interaction situation correctly, i.e., hits = proportion of correct responses to SI stimuli. False alarms (FA) were the trials in which the participant reported no interaction situations as interaction (NI reported as SI). In other words, FA is the proportion of error responses to NI stimuli, i.e., FA = 1—proportion of correct responses to NI stimuli. These values were normalized to obtain the z-score values z(Hits) and z(FA). The d' was calculated by subtracting the normalized values from one another: $d' = z(\text{Hits}) - z(\text{FA})$. False alarm rates of 0 were corrected using $1/2n$ and hit rates of 1 were corrected using $1 - 1/2n$, n equaling the number of trials [83].

The higher the d' is, the better the participant is at discriminating between SI and NI situations. For pure guessing (when the proportion of correct responses is 0.5 in this task with two response alternatives), d' is 0. When performance improves, d' increases approaching infinity for errorless performance. A usual range of d' scores is between about 0.5 and 4, and typical d' scores are between 1 and 2, corresponding to a proportion of about 0.70–0.85 correct responses (both SI and NI) for a bias-free participant.

For completeness of reporting, sensitivity index = discriminability d', response bias index = criterion c, measured proportion of correct responses to SI stimuli (hits) and measured proportion of correct responses to NI stimuli (which gives FA when subtracted from 1, i.e., FA = 1—correct responses to NI) are presented in Table 2 in results, even though the variable of interest was sensitivity to social interaction, d'. Criterion was calculated as $c = -0.5\ (z(\text{Hits}) + z(\text{FA}))$. Both measures were calculated using the proportion of correct responses to interaction stimuli (hits) and proportion of correct responses to interaction stimuli (FA).

The statistical analyses were conducted on IBM SPSS Statistics 28. First, the normality of the data was checked using Q–Q plots. Only one datum point deviated from normality due to an exceptionally high d' score exceeding 4, and therefore the participant was excluded from analyses.

A mixed-model analysis of variance was conducted to test for an intervention effect, i.e., whether d' increased after intervention (pre-post comparison), and whether the intervention groups (MU, MO, MUMO) differed from each other in the effect. The hypothesis that all interventions improve sensitivity to social interaction would manifest as a main effect of pre-post. If all interventions had a similar effect, there would be no interaction. Bonferroni-corrected paired-samples t-tests were then conducted to test whether all groups differed between pre and post measurements. In addition, whether responding was above chance level, that is, whether each d' score was significantly different from 0, was tested with one-sample *t*-tests.

3. Results

The signal detection theory measures discriminability d', reflecting sensitivity to perceive social interaction, and criterion c, reflecting response bias, for MU, MO, MUMO and control group are presented in Table 2, as well as the mean proportion of correct responses to interaction and no interaction stimuli, for completeness of reporting.

Table 2. Means (and standard deviations) for pre and post intervention d', c and proportion correct for SI (social interaction) and NI (no interaction) for intervention groups and controls.

	Movement		Music		Music-Movement		Control	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
d'	1.7363 (0.5851)	2.3255 (0.6937)	1.5628 (0.7483)	2.3848 (0.8938)	1.7072 (0.6615)	2.2903 (0.7050)	1.7109 (0.3924)	1.9867 (0.4239)
c	0.2409 (0.3428)	0.3123 (0.4170)	0.1870 (0.3104)	0.1728 (0.4086)	−0.0317 (0.3596)	0.1675 (0.5199)	0.2793 (0.3731)	0.2243 (0.2902)
SI correct	0.7256 (0.1025)	0.7816 (0.1015)	0.7118 (0.1257)	0.8221 (0.1135)	0.7779 (0.1361)	0.7882 (0.1558)	0.7072 (0.1382)	0.7660 (0.1111)
NI correct	0.8365 (0.1035)	0.8953 (0.1046)	0.8008 (0.1538)	0.8699 (0.1291)	0.7806 (0.1220)	0.8853 (0.0846)	0.8511 (0.0938)	0.8759 (0.0678)

First, it was tested whether sensitivity exceeded chance level for all groups by Bonferroni-corrected *t*-tests for pre and post d' scores. All scores differed significantly from 0 (all p:s < 0.01, Cohen's d:s > 0.39). This means that children could discriminate social interaction in the test and were not responding at random.

The main interest was to investigate whether sensitivity to social interaction increased after interventions. The pre and post intervention d' for all groups are shown in Figure 2. Performance in discriminating social interaction in body motion was quite good, and improved in the post measurement, particularly for the intervention groups.

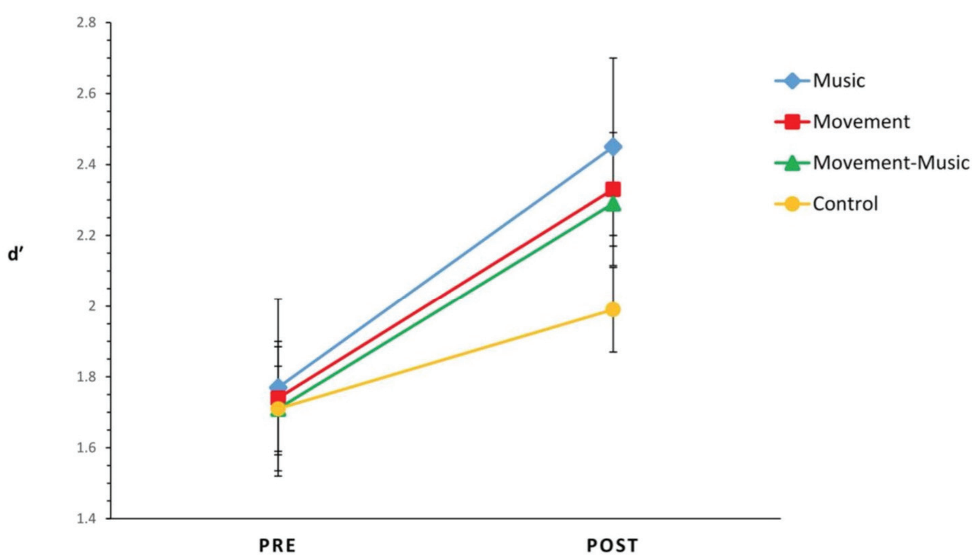

Figure 2. Pre and post intervention performance in discriminating social interaction by body motion, discriminability d' (mean and standard error of the mean), for intervention groups (MU: diamonds, MO: squares, MUMO: triangles) and controls (circles).

Since the hypothesis was that all interventions would enhance sensitivity to social interaction based on body motion, a mixed-model analysis of variance with discriminability (d') before and after intervention (pre, post) as a within-subject variable and intervention group (MU, MO, MUMO) as a between-subjects variable was conducted. There was a significant main effect of pre-post, $F(2.43) = 58.1$, $p < 0.001$, $\eta_p{}^2 = 0.58$, confirming that the interventions improved performance in the test. The interaction was not significant, $F(2.43) = 0.70$, $p = 0.50$, $\eta_p{}^2 = 0.032$, confirming that the improvement was similar for all interventions. Bonferroni-corrected paired-samples t-tests were conducted to compare pre and post intervention d' for each group. In the MU group, the post intervention d' was significantly higher than the pre intervention d', $t(10) = -4.21$, $p = 0.008$, Cohen's $d = 0.65$. This was the case also for the MO group, $t(18) = -5.05$, $p = 0.004$, Cohen's $d = 0.51$, and the MUMO group, $t(15) = -3.87$, $p = 0.008$, Cohen's $d = 0.60$. In contrast, the difference between pre and post d' was not significant in the control group $t(11) = -1.76$, $p = 0.43$, Cohen's $d = 0.54$.

4. Discussion

4.1. Ability to Discriminate Social Interaction in Body Motion and Arts-Based Interventions

The children in the current study were able to recognize social interaction from body motion, indicated by the relatively high discriminability (d'). The main research question was whether integrating arts-based music, movement and music-movement interventions in the daily learning environment could improve this ability. It was found in pairwise comparisons that d' was higher after the intervention in all intervention groups, whereas the difference between pre and post d' did not reach significance in the control group. Although these results are tentative, they imply that the interventions may have supported this aspect of social cognition, in agreement with previous findings showing that music or movement activity could support different aspects of social interaction in children [23,26,28,31,32]. Recent brain research on adults has found differences in brain activity between individuals with long-term training in dance or music and laymen [84]. The current behavioral finding suggests that effects of movement and music activity on body motion interpretation might be seen even after a relatively short period of a school year.

Interpreting body motion is an important dimension of adaptive social interaction [16,35], and healthy social development is important for well-being and learning [19–21]. Synchrony and reciprocity are key features in social interaction [62,66–69,72,85,86]. Since the movement and/or music interventions contained activities including synchronization and joint actions involving the whole body, these aspects could underlie the improvement in sensitivity to social interaction based on body motion.

Whereas the previous studies by Centelles et al. [55,56] provided valuable insight on the ability to discriminate social interaction from body motion, the data analysis in these studies produces some uncertainty to the interpretation of their results. As the total number of correct responses for SI and NI situations was used to compare performance between groups, possible response bias was not taken into account. Thereby, participants' tendency to favor either interaction or no interaction responses might have biased their scores. A strength of the current study was using discriminability d' of the signal detection theory to assess performance, and therefore the effect of possible response bias was eliminated in the data analysis.

4.2. Limitations and Future Directions

A limitation was a relatively small sample size, which was restricted by the number of same-grade pupils in one elementary school who agreed to participate in the research. On the other hand, having all participants in the same school meant that the overall everyday learning environment was similar for all pupils. The small sample size limited the statistical power, which emphasizes the need for further research with larger samples. Based on the current data, a power analysis gave a required sample size of 26 participants per group (power 0.8, effect size 0.4, significance level 0.05), which could be taken into account when designing future studies.

Furthermore, since no control activity was included in the control group, it cannot be ruled out that engaging in a joint activity as such might have supported test performance rather than the content of the interventions. Future research that includes a different type of control intervention (not music or movement) should be conducted to compare between other types of intervention. The type of joint group activities should also be investigated to find out whether arts-based activities (which could also include other art forms such as drama) are more effective than any other group activity, for example sports or games.

Very limited background information was gathered from the participants because there were several other measurements and formal assessments in addition to the social interaction test. It would have been useful to enquire about their hobbies. During interviews [87], few students reported music or dance hobbies. However, it is not possible to ascertain that hobbies related to the interventions could be a confounding factor. In future studies, more thorough background information collection is recommended.

The current study could be considered an initial step with tentative findings, hopefully encouraging further research in school-based arts interventions.

The results of the current study might be interpreted to imply that it could be useful to integrate movement and music activities in a regular elementary school learning environment to support social cognitive development. Though classroom teachers often find arts subjects challenging to teach [88,89], the current study suggests that they could successfully conduct such interventions with the help of experts.

This study also suggests that research focusing on the social development of children should consider the body as a source of social information. Social development in childhood is a complex area of research, however. Social cognition links with motivation, empathy and morality [17]. Being skillful in one domain related to social cognition does not equal overall social development. Skillfulness in interpreting others does not necessarily equal empathetic behavior [18], and sociability and social skills are different things [90]. In order to gain a more comprehensive understanding of children's social development, of which social cognition is a part, future studies would benefit from including several measures in their design, e.g., emotion recognition (body/face/voice) in combination with qualitative measures, such as self-evaluations and parent and teacher interviews, as well as metrics on children's involvement (e.g., motivation, engagement, enjoyment). The ability to recognize social interaction between two characters—as in the test of the current study—is a very specific task. It targets only a fraction of social cognition. However, in everyday encounters, this may be a useful skill since it may be beneficial to be able to interpret whether other persons are functioning together or separately, for example whether they are friends or not interested in each other. This ability might help in developing communication skills. Social and emotional learning and development should also be studied preferentially longitudinally.

5. Conclusions

Movement and music interventions were integrated in regular teaching and conducted weekly by classroom teachers in an elementary school. Out of various student outcomes, the current study examined the effect of the interventions on the ability to recognize social interaction based on body motion. The results suggest that students who participated in the interventions improved in sensitivity to social interaction. It would be important to further investigate adding movement and music activities to the school learning environment, which—among other things—might potentially have a positive influence on children's ability to interpret body motion, one aspect of social and emotional learning.

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education sciences

Article

Citizenship Outcomes and Place-Based Learning Environments in an Integrated Environmental Studies Program

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Abstract: This paper discusses the effects of the learning environment on an important and unique 21st century learning outcome—that of active citizenship, in contrast to more conventionally measured cognitive and attitudinal outcomes. In our study, we utilized a learning environment instrument, the Place-Based Learning and Constructivist Environment Survey (PLACES) with an integrated environmental studies program prepared for high school students in the Canadian context. Our research used a retrospective case study design to investigate how aspects of this unique learning environment are related to long-term, active citizenship outcomes as perceived by students from two previous student cohorts (N = 24 and N = 36) who were contacted several years after the culmination of the program. To access information about student perceptions, PLACES was implemented as part of a range of mixed methods which also included focus groups and interviews. This study is important because it links key aspects of the learning environment to long-term citizenship outcomes and is unique in that the data were collected five and eight years later as part of a longitudinal study. Our findings demonstrate that the learning environment and citizenship outcomes were closely linked, and that students' perceptions as measured by the PLACES instrument (past and present) were remarkably stable across all dimensions. These findings further indicate significant and positive implications for future learning environments research.

Keywords: learning environments; citizenship education; environmental learning; place-based education

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1. Introduction

How can 21st century youth become better educated to meet the increasing challenges of work, life, and citizenship? This is a question that education researchers have been trying to address for a long time. This topic has gained even more attention due to the diminished state of the environment, global economic imbalances, and evidence from various studies indicating higher levels of youth disengagement from politics and public life [1]. In the Canadian context, some studies express concern that the youngest cohorts (as they age) are voting in lower numbers than cohorts did in the past [2]. One response to this trend in Canada was the development of the "Being an Active Citizen" project: a program with a prime goal of providing enhancements to British Columbia's curriculum on law and citizenship to better prepare students to become informed citizens who actively participate in the life of their community [3]. Part of this initiative includes community engagement and social action as desirable outcomes that attempt to promote students in connecting with their local communities and/or environments.

In this scenario, two purposes of education can be seen: they must address both the development of individuals and that of the broader society [4]. With this intention, education can be seen as assisting individuals to become more competent in the pursuit of personal goals while at the same time setting the stage for their social participation. When considering an educational objective that includes environmental sustainability and personal/social responsibility, the term active citizenship comes to mind. The concept of citizenship is usually associated with voting, legal responsibilities, paying taxes, and obeying the law. Although arguably these are important parts of being a citizen, a much more involved concept is often referred to as active citizenship.

The term active citizenship was first used in a European Community context when proposals were developed for the European Commission's Lisbon Strategy [5], which focused on developing a competitive knowledge society and greater social cohesion. In this context, active citizenship is a term used to describe ways for "citizens to have their voice heard within their communities, a sense of belonging and a stake in the society in which they live, the value of democracy, equality and understanding different cultures and different opinions".

Barr used the term earlier, describing critical citizenship to represent active involvement at the community level [6]. In this conception, active citizens embrace social responsibilities and take on civic roles: they strive to be informed and maintain critical perspectives while also becoming actively involved in social, political and/or environmental issues [7]. In the light of past campaigns by UNESCO for example, it has become increasingly apparent that educated young people need to have skills and knowledge that will enable them to think and act critically while developing long-term responsible environmental and social behaviors [8,9]. In this regard, active citizenship becomes an important educational outcome to be gauged alongside the more traditional cognitive and attitudinal outcomes that are a regular part of educational evaluation.

2. Literature Review

2.1. Learning Environments

In some of the earliest work on human environments, scholars such as Rudolf Moos and Herbert Walberg stated that interest in the physical and social aspects of planning human environments such as towns, and public institutions was still increasing, and this remains true today [10]. Moos saw this concern as being responsive to the technological changes which (still) effect large-scale changes in the broader society. An example of this is the noted decrease in citizens' participation in civil society. He suggested that this created a need for a model to conceptualize and assess these psychosocial factors. Later, Walberg developed the idea that the evaluation of educational environments based on structural and behavioral theories required perceptual measures of what he termed the "feel of the class". It was noted that the analysis of behaviors linked to educational perceptions characterize some important aspects of the social learning environment [10,11]. Learning environment studies now seek to describe educational contexts and to identify empirical relationships among subject matter (curriculum), teaching practices, and educational outcomes [11]. In our study, we were interested to understand how aspects of the learning environment might affect students' long-term perception of citizenship outcomes.

From these early beginnings, the study of learning environments has now grown to become a dynamic field of academic inquiry and although its beginnings were in science education, it has application possibilities in many different areas of inquiry, and we assert that it is particularly applicable to inter- or multi-disciplinary fields of study such as environmental or place-based forms of education. Since its beginnings over 40 years ago, learning environment instruments have been developed, tested, and validated in a variety of settings and in a variety of countries [11]. These instruments have been made up of scales that are used to identify specific constructs in the learning environment. Examples of these include factors such as student cohesiveness, teacher involvement, material environment, cooperation, task orientation and equity. Each scale typically consists of items designed to evaluate a specific aspect of the learning environment. Over the years and in a variety of different countries, various scales have been designed, validated, and tested.

For our work, the concept of a learning environment incorporates ideas and perceptions related to both the physical and psychosocial environment where learning takes place each of which can be influenced by teaching practices [12]. For our study, we studied a unique, purpose-designed learning environment which included novel course work conducted substantially in both field-based and classroom settings.

2.2. Place-Based Education

The notion of a place-based education was first described by David Soble and Graham Smith, while other scholars have greatly expanded on these ideas [13–15]. Describing exactly what constitutes a place-based education becomes clouded partly due to the multifaceted and interdisciplinary nature of the literature in which this notion seems to reside. Gruenewald and Smith [15] noted that the idea of place-based learning connects theories of experiential learning, contextual learning, problem-based learning, constructivism, outdoor education, Indigenous education, and environmental education. This study also relates how learning environment methodologies can be employed effectively in place-based and environmental education studies and highlights the continued use of a valid and reliable tool for this purpose. Many benefits can be achieved by engaging students in place-based environmental education programs; these include: improvement in their academic achievement, problem solving, critical thinking, and co-operative learning skills, and an increased motivation to learn [16,17]. Keeping this focus in view, this study further reports on the continued efficacy of a purpose-designed learning environment instrument: the Place-based and Constructivist Learning Environment Survey, or PLACES [17].

Through place-based environmental education, learners' cognitive structures may be altered, attitudes modified and the learning environment that develops around these programs may enrich and stimulate further learning. For some, these elements are viewed as interconnected and will change as a whole system, not as separate parts. This research was hence consistent and congruent with this ecological view of education [18]. As part of this study, an evaluation of the learning environment was conducted at multiple temporal points to examine the types of learning environments developed in place-based, experiential settings and to determine the suitability of the PLACES instrument for long term case study and other environmental education research.

3. Research Objectives

The objectives of the research program were to conduct a longitudinal study using perceptual measures unique to place-based and constructivist oriented environmental education programs; and further to describe the types of learning environments which promote active citizenship outcomes in students. The research design uses a retrospective case study method involving three previous cohorts from a specially designed high school environmental studies program (ES 10) focusing on active citizenship as a key educational outcome.

Retrospective case studies are considered a type of longitudinal case study design in which the data collection is conducted after the fact [19]. Retrospective case studies have three common factors: collection of data occurs after a significant event, researchers have access to first-person accounts and archival data, and final outcomes are available that are presumably influenced by the variables and processes under study [19]. The study required participants to recall experiences that occurred in the program five and eight to nine years earlier and relate these to present day outcomes, therefore making it retrospective in nature.

The selection of a case study design also allowed for a rich collection of data and of greater depth than that of other research designs in our description of a key variable: active citizenship. Our goal was to determine the long-term perceived effects of the program in terms of active citizenship as well as to understand the contributing factors for this in a uniquely designed experiential and place-based learning environment.

3.1. Study Context

The context for this study was an integrated Environmental Studies program for grade ten students (ES 10) at a local high school in British Columbia, Canada. The ES 10 program integrated four high school curriculum courses: Science 10, Earth Science 11, Social Studies 10, and Physical Education 10. The three cohorts studied in this project all completed programs with the same course structure. These subjects were integrated in such a way as to give purpose to the subject material through experiential learning. Outdoor initiatives were used as vehicles to empower the learning experiences and foster attainment of program goals. Outdoor initiatives included some adventure-based activities, while others included field studies such as ecological monitoring or earth science investigation. The field studies in the program sometimes took place in the local community, while others took place during overnight field experiences. Students were exposed to many learning opportunities, often working with community members, other students, and professionals.

Adventure-based activities aimed to help students gain basic outdoor skills while at the same time developing cooperative skills and more self-confidence. The field studies aimed to engage students with the curriculum while exposing them to real-life problems and phenomena. The experiential component of ES 10 helped create unique opportunities to extend students' knowledge, while reflective practice, which was encouraged regularly through discussions and journaling, allowed students to think outside the extant paradigm and shift into a more comprehensive, integrated, and creative worldview. This was an important goal of ES 10 and lead to the concept of active citizenship as an intended educational outcome for the program.

3.2. Methodology

This study used a mixed methodology that incorporates both qualitative and quantitative research methods [20]. Data collection protocols included administration of quantitative surveys to three cohorts at several intervals after the program completion (0 years and 5 years for one cohort, then 8 years and 9 years for the other two cohorts). In addition, qualitative surveys and focus groups were completed for two cohorts after 8 and 9 years. As such, the study was longitudinal in nature as study participants reported on their perceptions of the learning environment many years after the program culminated.

Details of the data collection were as follows: in the first instance, 24 individuals participated in the survey only (at 0 years); in the second instance, 18 individuals participated in the survey; and in the third instance, 17 and 19 participated in the survey, respectively, while fully 24 individuals participated in the focus groups. As such, adopting both qualitative and quantitative methods provided a better understanding of the results and made conclusions more credible while enabling a deeper understanding of the processes occurring in this integrated curriculum program [21]. Further, the use of multiple sources of evidence that converge on similar facts allowed for triangulation to occur, which can lead to greater construct validity [21]. Qualitative methods also consisted of a group interview with past students from two previous cohorts as well as an open-ended questionnaire.

The quantitative methods consisted of two separate one-time surveys: one measured learning environment perceptions while the other measured perceptions of active citizenship. The rationale for utilizing these cohorts was to ensure data on long-term outcomes since these graduates completed the program eight to nine years earlier at the time of the data collection. Further data utilizing only the learning environment survey were collected for a third cohort. The rationale for including this cohort and limiting data collection to the learning environment questionnaire was due to the increased availability of pre-program and post-program data, as it related to the learning environment tool (PLACES). These data help to determine the consistency of the instrument over time relating to long-held perceptions of the learning environment.

3.3. Learning Environment Measures

The questionnaire selected for the learning environment measures used in this study is one that had been tested and proven to be reliable in measuring place-based learning environments [17,18]. As the questionnaire is not time- or age-sensitive, the questionnaire was easily adapted for use in secondary classrooms. The questionnaire is known as the Place-based and Constructivist Environment Survey (PLACES). The eight scales incorporated into PLACES were adapted from previously referenced inventories and were derived from data that emerged from a series of focus groups with environmental educators. PLACES is a compendium on constructs that were viewed by place-based and environmental educators as being most important for their practice [17]. The survey with all eight scales was used in this study as illustrated in Table 1 below.

Table 1. Sample Statements from all eight Scales for the PLACES instrument.

Relevance/Integration (CI)	I want my lessons to be supported with field experiences and other field-based activities.
Critical Voice (CV)	It would be ok for me to speak up for my rights.
Student Negotiation (SN)	I want to ask other students to explain their ideas and opinions.
Group Cohesiveness (GC)	I want students to get along well as a group.
Student Involvement (SI)	I want to ask the instructor questions when we are learning.
Shared Control (SC)	I want to help instructors plan what I am to learn.
Open-Endedness (OE)	I want opportunities to pursue my own interests.
Environmental Interaction (EI)	I want to spend most of the time during field local trips learning about my environment.

On the last day of each cohort program, participating students were asked to complete an "actual" form of this questionnaire. For the survey items, each statement was coded, using a Likert scale, and validity and reliability data were calculated for each sample (cohort). For the longitudinal part of the study, participating cohorts from the ES 10 program were contacted several years after program completion and asked to complete the same version of the questionnaire as part of a retrospective view of the program. Wordings on the questionnaire were put into the past tenses for this version to highlight that participants were reflecting back on their experiences, years earlier. Further data on the learning environment were collected via focus groups with cohort members after the administration of the follow-up questionnaires.

3.4. *Active Citizenship Measures*

During the time of data collection, a specific survey for active citizenship was yet to be developed. However, the ISSP Citizenship survey contains many active citizenship indicators as represented in the literature and was therefore used in this study. A summary of sample statements from each of the selected variables used in this this survey are provided in Table 2. The ISSP is a continuous program of cross-national collaboration, which runs annual surveys on topics important for the social sciences [22]. Stratified random sampling by province and age was used to collect data in Canada. Normative data from Canada provided a useful comparison to the study groups in question. For this survey, questions relating to six constructs were utilized: (1) community participation, (2) political action, (3) empowerment (self-efficacy for social/political change), (4) informed citizen, (5) tolerance, and (6) voice. These constructs are consistent with research relating to active citizenship [23,24]. This study used a total of 45 items from this survey.

All participants were initially contacted via email and invited to participate in the study. Both the PLACES and ISSP Citizenship surveys were then administered electronically through email to participants that agreed to participate. For each item on the questionnaires, participants responded to each of the statements using a Likert-type response scale (strongly agree, agree, neutral, disagree, and strongly disagree). Fillable PDF forms were used for all surveys and questionnaires and participants emailed back the completed forms to the researchers. Survey data were then summarized, and these data were later complemented by a range of qualitative data after the administration of the survey.

Table 2. Statements from Selected Variables from the ISSP Citizenship Survey.

Variable	Statement
Good citizen	There are different opinions as to what it takes to be a good citizen. As far as you are concerned personally, how important is it to help people in the rest of the world worse off than yourself?
Political action	Here are some different forms of political and social action that people can take. Have you boycotted, or deliberately bought certain products for political, ethical or environmental reasons?
Status of belonging	People sometimes belong to different kinds of groups or associations. For each type of group, please indicate your level of belonging. A trade union, business, or professional association.
Attitude (Self-efficacy toward voice)	To what extent do you agree or disagree with the following statements? People like me don't have any say about what the government does.
Rights in Democracy	There are different opinions about people's rights in a democracy. How important is it: That people be given more opportunity to participate in public decision- making?
Unjust law (willingness to act)	Suppose a law were being considered by Parliament that you considered to be unjust or harmful. If such a case arose, how likely is it that you, acting alone or together with others, would be able to try to do something about it?
Political Interest	How interested would you say you personally are in politics?
Informed citizen	To what extent do you agree or disagree with the following statements? I feel I have a pretty good understanding of the important political issues facing Canada.
International Issues Opinion	If a country seriously violates human rights, the United Nations should intervene? Or even if human rights are seriously violated, the country's sovereignty must be respected, and the United Nations should not intervene.
Tolerance	When you meet people that you strongly disagree with, how important is it to do or say something to show you tolerate them?

3.5. Qualitative Data

An open-ended questionnaire also shared with participants contained sections related to active citizenship components and professional pathways to complement the two surveys used. Another qualitative portion of the study included a focus group interview utilizing the Interview Matrix method [25]. This methodology allows for full engagement in dialogue, equal participation, focused discussion, and consensus building. The goal was to have participants from both cohorts in the focus group portion of the study. Both cohorts were interviewed at the same time to help limit recall effects associated with a single "familiar" group reuniting after several years (Smithson, 2000). Based on Chartier's work [25], an interview matrix was constructed using four basic questions consistent with Ireland et al.'s citizenship education research [26], highlighting the key underlying factors evident in school and daily life necessary to foster and sustain active citizenship. The four interview matrix questions used included factors such as voice, relevance, community, and skills, specifically:

- Do you believe the ES 10 program helped foster the development of skills related to one's ability and/or desire to make a contribution of sorts to the community or beyond?
- Sense of community and belonging includes the desire to be part of a strong, safe community based on networks and friendships that foster trust, concern for well-being, sense of self-worth and encouragement towards individual and collective social responsibility. Could you comment on the ES 10 program that you were involved with as it relates to sense of community as described above?
- Did the program in any way allow you to have a voice in matters that affected you? If so, how? Do you think this had any effect on the way you think and act today?
- What is it that you remember the most about the program in terms of unique learning environment features? This could also include "specific" experiences that may have affected you in some way. These examples could be positive or negative.

4. Results

4.1. Perceptions on the Learning Environment

The PLACES survey has previously exhibited exceptional reliability and validity in high-school settings [17,18] and this instrument was used to measure perceptions of the learning environment in this study. For the dataset in this research, calculated values from the Cronbach alpha and discriminant validity indicated that all eight constructs were demonstrated to be acceptable within scale reliabilities but also discriminated validly between the eight constructs measured. As a result, we are confident that the measures taken by our survey of ES 10 alumni are a reasonable representation of student perceptions in the program (both initially and long term). Figure 1 is a representation of a 2007 cohort in the program illustrating the perceptual data collected near the end of one ES 10 program versus the same cohort's results obtained five years later. The most significant finding here was how closely the results measured near the end of their program matched perceptions held by student alumni five years later. These results indicate the persistence of participants' long-held beliefs toward the learning environment is ES 10 and for the various constructs measured by the PLACES instrument.

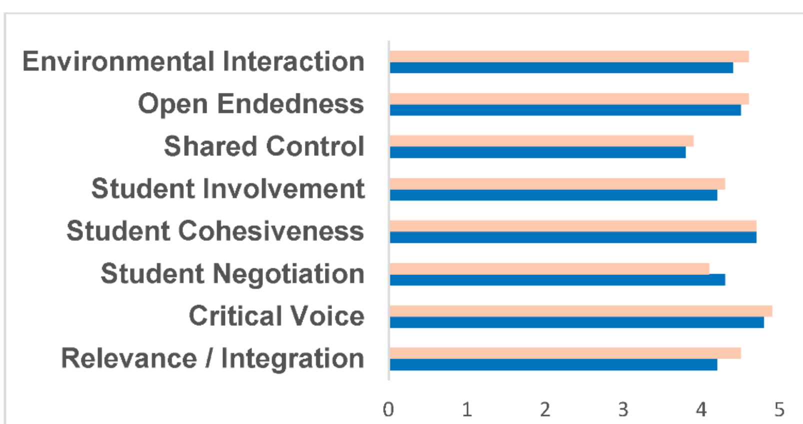

Figure 1. Learning environment data: program end vs. five years later.

Figure 1 also demonstrates that the PLACES instrument was a useful tool for understanding alumni perceptions of the ES 10 learning environment. In the study, the PLACES instrument was viewed as key in describing both the effects and features of the unique ES 10 learning environment and its contributions to participants' perceptions of their citizenship activities. It is important to note that the average mean score for all PLACES constructs was high and considered positive (above 4), with the exception of the "shared control" construct which was rated as between satisfactory and good (with an average rating of 3.5). Nevertheless, a key finding here was that student perceptions were very stable over the longer timeframe of this study and that aspects of the learning environment were closely associated with citizenship outcomes.

The construct of group cohesiveness (and a strong sense of community) emerged as major theme identified by participants in this study. The ES 10 graduates' ratings for this construct on the PLACES survey were the highest of all constructs and indicate the relative importance of this feature for participants. Qualitative data also clearly indicated that the ES 10 graduates believed that overall, the program fostered a cohesive group experience and built a strong sense of community through the strong relationships that developed among class members.

Data presented in Table 3 further illustrate this by outlining the major theme(s) that ES 10 alumni identified as key influences on their current activities and lives between high school and present day. These are also linked to the intended goals of the ES 10 Program and constructs measured by the PLACES instrument. In general, these results describe how student participation in this program can change students' expectations for learning and for the educational learning environments they encounter in school. They also provide us with rich (more holistic) descriptions of the learning environments experienced by students.

Table 3. Alignment of Program Goals, PLACES Constructs and Emergent Themes.

Stated ES 10 Goal	Related PLACES Scale and Description	Theme(s) Identified by ES 10 Alumni
Responsible citizenship	**Relevance/integration:** Extent to which lessons are relevant and integrated with environmental and community- based activities	**Active Citizenship** The program showed us concrete examples of community commitment and activism … (Sarah)
Self-confidence. Leadership skills.	**Critical Voice:** Extent to which students have a voice in the classroom procedures or protocols.	**Confidence using voice** ES allowed me to voice my opinion, the teacher cared and listened … Coping with ambiguity and decision making in the classroom helped me to work with others in the future … (Lucas)
Friendships and positive peer relationships.	**Group Cohesiveness:** Extent to which the students know, help and are supportive of one another	**Importance of community building** ES encouraged a sense of caring for each other and the greater community. (Sharon)
A responsible attitude about learning. Long term interests in different subject areas.	**Student Involvement:** Extent to which students have attentive interest, participate in discussions, perform the work and enjoy the class	**Self-discovery** ES10 was an innovative and engaging program that allowed students to learn through activities but also encouraged students to explore … and find something to care about… (Alex)
Decision making skills.	**Shared Control:** Extent to which teacher gives control to the students with regard to the curriculum and activities	**Democracy in the classroom and future expectations** I remember appreciating the decision-making powers that our instructor granted us, and feel that the trust he placed within our group allowed us to achieve some things well beyond our years at the time … (David)
Decision making skills. Critical thinking skills Leadership skills.	**Open Endedness:** Extent to which the teacher gives freedom to students to think and plan own learning	**Flexibility in schedule and curriculum leading to critical thinking and decision making** Big one for me was the freedom of creativity, a flexible structure allowed for one to expand on one's creative outlet. Coping with ambiguity was difficult but helped in critical thinking and decision making… (Celeste)
Skill and knowledge in a range of field studies and outdoor pursuits. Responsible citizenship	**Environmental Interaction:** Extent to which students are engaged in field or community-based experiences	**Willingness to make a difference** ES helped me desire to better the world from an environmental perspective, through all the outdoor experiences and seeing what nature was all about. ES planted a seed to give to the greater community, to think outside yourself. (Emily)

As a mixed methodology case study, we also demonstrate here that outcomes from the focus group and surveys supported one another in triangulating findings about the unique design of the ES 10 learning environment. Table 3 demonstrates that the goals of the program, and the emergent themes from our qualitative findings were closely linked to the eight constructs presented in the PLACES instrument. This in some ways gives us a further qualitative confirmation of the efficacy of the survey instrument in evaluating the learning environment of place-based education programs.

4.2. Active Citizenship Outcomes

Results from the ISSP Citizenship survey [22] were utilized to compare values from the ES 10 group to data collected in 2004 on 47 countries, including Canada (N = 1211), as part as the ISSP. Comparisons include the ES 10 results compared with reported data to for all ages in Canada and more importantly data from the same age group (23–24 years of age). The results indicate areas where the ES 10 group score higher or lower than the comparison groups. Since the variable list for the ISSP Citizenship survey includes constructs that can be used as indicators of active citizenship, the comparison provides an indicator of the long-term effects of the ES 10 program relating to active citizenship.

Overall, alumni of the ES 10 program demonstrated a high level of engagement in activities and initiatives that fit within the definition of active citizenship as proposed and conceptualized in this study. When compared to their Canadian counterparts, ES 10 alumni scored higher in most of the ISSP Citizenship survey categories [22]. Based on a paired *t*-test, the differences in three of the categories were statistically significant. These were (1) Social and Political Action, (2) Good Citizen (measuring community participation), and (3) Voice. Further, qualitative data from this study found that the ES 10 graduates indicated various forms of involvement in their communities, a result that was a strong indication that they were currently engaged in varied amounts of active citizenship. Figures 2–4 give a visual representation of these enhanced citizenship outcomes for ES 10 alumni.

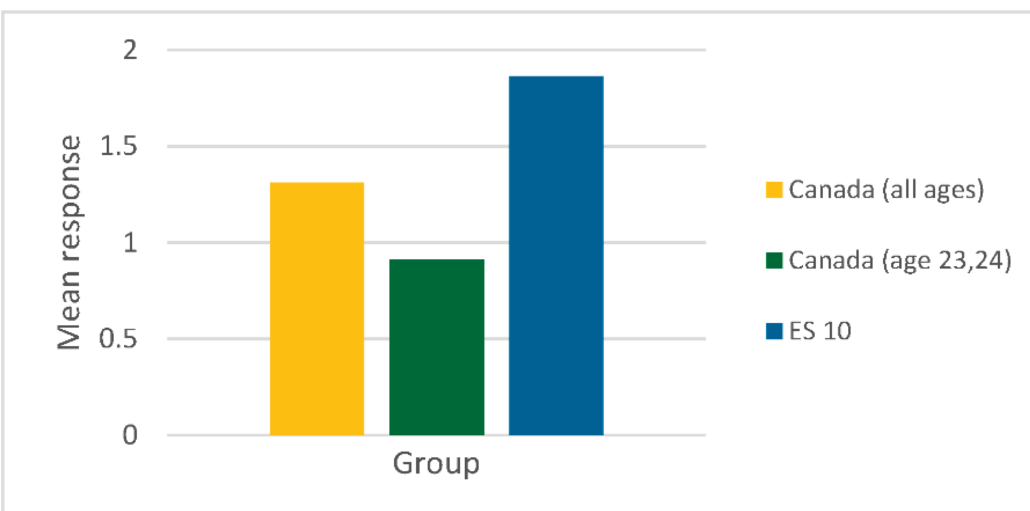

Figure 2. ISSP Citizenship Survey: Political Social Action—Overall mean scores.

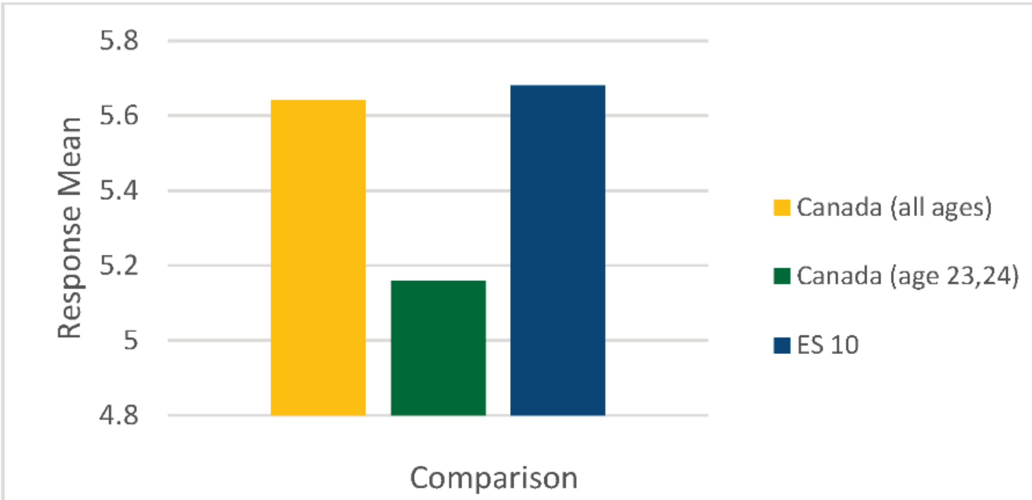

Figure 3. ISSP Citizenship Survey: Good Citizen—overall mean scores.

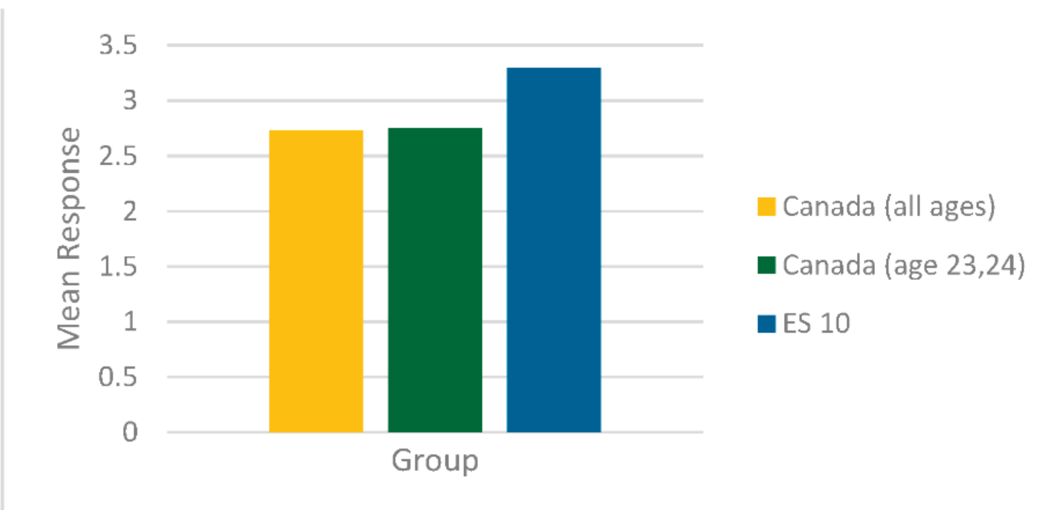

Figure 4. ISSP Citizenship Survey: Voice—overall mean scores as reported in ISSP (2012).

Another common theme from the ES 10 alumni was the idea that the program contributed directly to their desire for and belief that they could make a difference by getting involved in community activities and civil society. A further finding of this study was that those students who got involved in volunteering through school opportunities provided while they were in high school were also more likely to continue volunteering in areas such as those relating to social justice, humanitarian, health, or environmental themes after graduation. In this study, 14 of the 15 alumni who reported volunteering in school opportunities while in their Grade 11 and 12 years continued volunteering in their adult life in those areas mentioned. Furthermore, 11 of 15 alumni expanded their involvement beyond the local community level to include involvement in global initiatives as well. Table 4 gives some examples of the types of volunteerism that emerged from student comments during the focus groups and other forms of inquiry.

Table 4. Examples of Volunteerism (from student alumni comments).

Initiative/Association	Brief Description of Involvement
Red Cross	The Canadian Red Cross is a leading humanitarian organization through which mission is to improve the lives of vulnerable people by mobilizing the power of humanity in Canada and around the world.
Africa Canada Accountability Coalition	An advocacy group founded by an ES 10 graduate that engages Canadians with issues in Africa and why we must be concerned and proactive. Their focus has been on informing ourselves and the public about these issues, bringing them to the attention of media and political officials, and working towards an understanding of our responsibilities as human beings and consumers.
OXFAM	Oxfam Canada is part of a global movement for change made up of 17 Oxfam affiliates working in more than 90 countries to mobilize the power of people against poverty. Women's rights and overcoming inequality are central tenants of this organization.
Houses without borders	A network of ecological builders and other volunteers dedicated to natural building. Their focus is educational and organizational, connecting We a network of professionals and volunteers with those in need especially in poverty-stricken areas.
Global health/environment initiatives	Promotion of sanitation practice and environmental awareness in Africa. Medical outreach in Africa. Sustainable forestry practices advocacy in Brazil.
International Aid work	Reto Juvenil Internacional/Youth Challenge International in Costa Rica
Juvenile Diabetes Research Foundation	Various educational, fund raising, campaigning for juvenile diabetes research.
Environmental Youth Alliance Society	Society's focus is to engage and empower youth to create meaningful, positive action for local communities and environmental health.

4.3. Limitations of the Study

As noted, our research used a case study approach and as such our study has a few limitations which should be noted. First, the selection of participants was based on a "convenience sampling" and may not be representative of the general population participating in place-based programs more generally. Second, the self-selection of students in the focus groups, may lead to positive selection bias as only students with positive perceptions of the program may have wished to participate. Finally, as the study is retrospective in nature our results may also be confounded by "recall bias", in that study participants may have omitted or misclassified some of their perceptions of the program.

5. Conclusions

It is now clear that research on learning environments continues to develop in a diversity of ways [27] however, research linking learning environment factors to citizenship outcomes is still in its infancy [28]. This study yields some interesting insights into the unique learning environments experienced by students in place-based education settings and has led to the increasing value of the PLACES instrument in evaluating learning environments in curriculum integrated programs. In the reported case study, students rated all scales of the learning environment consistently even 5 years after the culmination of their program and these data were further strengthened by triangulation with qualitative comments from the focus groups.

The results also acknowledge the sensitivity of the PLACES instrument over longer timeframes, strengthening its potential use as an evaluative tool for place-based learning environments. This also creates opportunities for future research using PLACES to predict and describe active citizenship, and other desirable outcomes that may prove to be associated with the learning environment facilitated in these types of programs.

Active citizens are people who care about their local community and beyond. They are motivated to make a positive contribution and have a say in what is happening. They take part, make decisions, and influence a wide variety of factors that lead to more vibrant, sustainable communities from social, political, and environmental perspectives. Some active citizens get involved with matters that are important to them within their community—while others go beyond to participate in national and global initiatives. Finally, most active citizens are motivated by a strong desire to make a positive influence or change in the world. Based on the results of our study, we assert that a large portion of case study participants fell into this broad definition of active citizenship.

A major goal of the program under study was to create and document a learning environment that invites youth to engage in learning experiences with the potential to push them to think critically while fostering environmental and social responsibility. A further practical outcome for this study would be as a tool to enable teachers to conceptualize "active citizenship" differently: not as a curricular outcome to be covered in the syllabus but instead as a key outcome relating to their practice—and the resultant learning environments they foster for their students.

Finally, this study clears the way to consider a broader range of educational outcomes that may be influenced by the learning environment created in innovative educational programs. In this case, the outcome of active citizenship was achieved, and the learning environment created by the program played a critical role in fostering this outcome.

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Article

Integrating PhET Simulations into Elementary Science Education: A Qualitative Analysis

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Abstract: This research delved into the integration of PhET simulations in elementary science education, specifically aimed at Grade 3 students. The primary objective was to evaluate how the use of these digital simulations influenced students' conceiving of scientific concepts, focusing on "States of M1atter and Phase Changes" and "Solubility and Saturation". Employing a qualitative research approach, the study observed 19 students who worked in pairs and trios as they engaged with PhET simulations to explore assigned science topics and address related questions. The observations centered on tracking students' interactions with simulations and their progression through different knowledge phases. We used deductive and inductive content analysis to analyze the transcripts of the observation. The findings reveal that in the "Remembering" phase, students demonstrated a tendency to relate personal experiences to simulations, underscoring real-life context's role in learning. The "Understanding" phase highlighted how PhET simulations facilitated deeper comprehension, with students making insightful observations. Additionally, the "Application" phase showcased the effective translation of simulation-derived knowledge into practical scenarios, bridging theoretical and real-world understanding. Students' use of high-order thinking skills, at the analysis, evaluation, and creative phases, showed that simulations supported Grade 3 students in their learning processes of scientific concepts. The research underscores the efficacy of integrating PhET simulations into elementary science education, enhancing students' knowledge by promoting active engagement and problem-solving skills. Integrating simulations into teaching methodologies emerges as a promising avenue to nurture scientific expertise and holistic understanding among elementary school students.

Keywords: simulation-based learning; PhET; teaching methods; meaningful learning; educational research; elementary science education

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1. Introduction

The present research addresses the use of simulations in science learning by elementary school students. Educational researchers call us to use simulations in science teaching and learning in elementary school as this tool would enable students to generate and test their own conjectures of the relations in a particular scientific phenomenon [1]. In addition, educational researchers report that simulation can support elementary school students in their science learning [2,3]. In the present study, we used Physics Education Technology (PhET) in the elementary school science classroom as a tool that Grade 3 students can use to learn scientific topics. The elementary school is located in a small city in Northern Israel. This context (an elementary school in a small Arab city in Northern Israel) continues the few studies reported on the use of simulations in elementary school students' learning of science concepts and relations [2,3].

The use of simulations to enhance learning is a popular pedagogical technique. First of all, students can experiment with interactive simulations at any time and from any place on Earth where there is an Internet connection. Moreover, with the innovation of personal and classroom computing beginning in the 1990s, technology-enhanced simulations have seen increased use [4,5], and the further development of the web has expanded its global reach [6].

A simulation has two components: (1) a model that corresponds to some version of reality—a subject, system, process, or phenomenon, and (2) an interactive interface through which the user, adopting a real-world role [7], can manipulate the model at will within defined parameters, strategizing, making decisions, observing the consequences of actions, and adjusting knowledge and skills in response [7–9]. Designed for educational settings, simulations are typically used to prepare learners to think and act competently in real-world situations [10,11]. It is generally recognized, however, that like educational gaming, they require instructor contextualization and guidance to be successful [12–14].

Simulations have many advantages for enhancing learning [15]. For instance, they work well with inquiry-based and problem-solving projects [16,17] and open-ended learning environments [18], and they can simplify difficult, abstract concepts by presenting them in concrete ways [19] that are challenging and engaging and make use of perceptual and spatial abilities and memory in ways that are not possible with text or verbal instruction [16,20]. Learners are also able to manipulate situations, processes, and phenomena that would otherwise be too difficult, too dangerous (e.g., caustic chemicals), or impossible to work with (e.g., electrical currents, cell structure, varying accumulations of greenhouse gases) [12,16,21], and the cost of errors is minimal or nonexistent [8]. Simulations put students in charge of their own learning, allow for the fast manipulation of variables with immediate feedback [16], and lead students to adjust what they know in light of experimental data (i.e., manipulations of the simulation) [12]. Moreover, they are cost-effective, and a number of virtual experiments can be conducted by students in a short amount of time [12]. They can also be adapted for students with special needs, enabling them to participate in mainstream classrooms [16].

Many positive outcomes have been reported for simulations. They are an effective way to enhance cognitive, affective, and behavioral learning and to teach real-world skills [22], and they increase student interest and involvement in learning [13]. After a meta-analysis of 91 studies, Talan [19] concluded that, although the effect is not universal, the use of simulations has a strong, significant effect on students' academic achievement. In the context of science education, Cayvaz et al. [15] studied the effects of simulation- versus textbook-based instruction on middle school students on the topic of work and energy, focusing on learning achievement, inquiry skills, and attitudes toward science. They reported better scores on the achievement test for lesson content and (the classes' admittedly overall low levels of) inquiry skills (but not for attitudes toward science). Overall, they concluded that simulation-based instruction was significantly more effective than conventional methods. A 2011 report by the National Academies of Sciences, Engineering, and Medicine in the U.S. stated that gaming and simulations "have potential to advance multiple science learning goals, including motivation to learn science, conceptual understanding of science topics, science process skills, understanding of the nature of science, scientific discourse, and identification with science and science learning". Thisgaard and Makransky [23] reported that, in keeping with social cognitive career theory, virtual simulations may work to boost students' inclination to enter a STEM-related career.

There is currently a significant gap in the literature on simulation-based learning. A science mapping of 2812 studies between 1965 and 2018 by Hallinger and Wang [5] showed that, although there is global interest in this pedagogy, the predominance of publications come from authors located in a small number of Anglo-American countries, predominately the U.S., with Africa, Latin America, and Asia contributing only 17% of the entire corpus. Given that context influences the responses of teachers and students to teaching methods [11,24,25], there is therefore a need for investigation in different contexts.

Moreover, most of the scholarly activity on simulation is concentrated in the fields of medical and management education. Talan [19] notes that studies of simulation techniques in education consistently target the sciences as well as the health sciences, but only a very limited number address primary (especially preschool) education; therefore, there should be more investigation of the impact of simulations on academic achievement at all levels of education.

The PhET simulations used in this study consist of small modules designed for scientific exploration, each narrowly focused on a single activity/lesson, which can be incorporated into classroom instruction or made available on students' digital devices. Each simulation features a virtual representation of physical objects, often from the everyday life of students, that can be manipulated by the user (e.g., a seesaw or skateboard on which common objects or people can be loaded) and "disciplinary representations" that link the activity with the discourse of science [26]. For instance, in the simple simulation Build an Atom, the learner can select protons, neutrons, and electrons from dishes, drag them into the nucleus or shells of an atom, and receive feedback (disciplinary representations) in the form of a meter that registers the net charge and readouts that show the name of the element, its position in the periodic table, the mass number, and whether the atom is an ion or not. The PhET project offers over 160 simulations in physics, chemistry, mathematics, earth science, and biology; they are free and open-licensed, can be used online or downloaded for offline use with a minimal amount of preparation by teachers and students, and are designed for all levels of education, primary to postsecondary. The project, housed at the University of Colorado, is widely supported by foundations and commercial, government, and educational organizations, and the simulations are used all over the world [27,28].

The objective of this study is to evaluate the impact of integrating PhET simulations into science lessons at the elementary school level on students' comprehension.

The research question being investigated is:

In the context of PhET simulations, what is the influence of scientific simulations on students' understanding?

2. Materials and Methods

2.1. Research Context and Participants

The primary objective of this study was to assess the effectiveness of integrating PhET simulations into elementary school science education. To achieve this goal, we adopted a qualitative analysis approach and collected data through observations of Grade 3 students. These students were engaged in learning two specific science topics with the aid of digital simulations. The first topic pertained to "States of Matter and Phase Changes", while the second topic focused on "Solubility and Saturation".

The experiment involved the participation of 19 students in Grade 3 in an elementary school in a small city in Northern Israel. The students were organized into seven groups. These groups consisted of pairs or trios, depending on the students' preferences. There were two groups comprising pairs of students and five groups with three students each. In the present research, we will report the learning of one group of three students as this group's learning reflects the other groups' learning. The experiment simulation lasted for three weeks, during which the students took three science lessons each week.

Utilizing PhET simulations, these student groups immersed themselves in learning the designated science topics and in addressing science-related questions relevant to the two areas of knowledge. For clarity, we will outline the individual objectives of each question, provide a screenshot showcasing the simulation employed for resolving the question, and elucidate the role of the student in interacting with and manipulating the simulation. All the simulations belong to the PhET simulation site (https://phet.colorado.edu/).

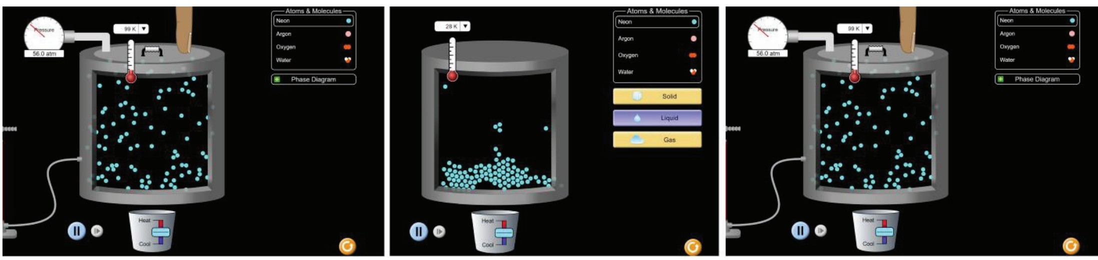
2.1.1. Remembering

Goals:

- The student will develop the capability to articulate the sequence of events occurring during the transformation of a specific substance from one state to another.
- The student will acquire the knowledge that the application of heat to a particular substance can instigate a change in its state.
- The student will possess the competence to establish connections between alterations in the state of a substance and observable occurrences in everyday life.

Simulation:

Figure 1 shows how the simulation worked in the remembering phase.



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

Figure 1. PhET simulation for the application of heat to instigate a change in matter states. (**a**) The substance in its solid state, (**b**) the substance in its liquid state, (**c**) the substance in its gaseous state.

Student Engagement: The student initiated the experiment by subjecting ice, existing in a solid state, to heat. The consequence was the transformation of ice into liquid water, representing the liquid state. The student then persisted in the heating process, resulting in the conversion of liquid water into water vapor, manifesting the gaseous state. Throughout this progression, the student keenly observed alterations in the substance's physical form and the distribution pattern of its constituent particles within each of the three distinct states.

2.1.2. Understanding

Goals:

- The student will attain an understanding of the mechanism involved in the dissolution of salt within water.
- The student will grasp the concept of saturation as it pertains to the point at which salt can no longer dissolve effectively in water.

Simulation:

Figure 2 shows how the simulation worked in the understanding phase.

Student Involvement: The student systematically poured salt into a beaker already holding water, initiating a dissolution process. As the student continued this addition, the salt seamlessly dissolved within the water. However, a pivotal moment arrived when the salt's dissolution ceased, and it commenced sinking to the beaker's base. Through this engagement, the student attentively observed the unfolding dynamics of salt dissolution, astutely identifying the point where an oversaturation of salt prompted its descent, thereby defining the concept of "saturation".

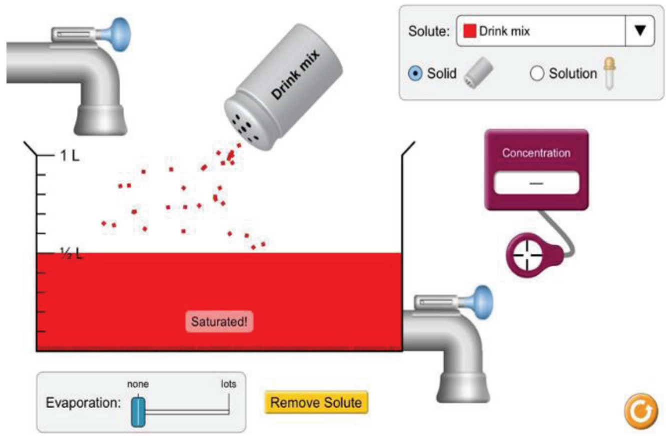


Figure 2. PhET simulation for dissolution of salt within water.

2.1.3. Applying

Goals:

The student should be capable of employing the comprehension they gained regarding solutions to effectively carry out the separation of both the solute and the solvent in a given scenario.

Simulation:

Figure 3 shows how the simulation worked in the applying phase.

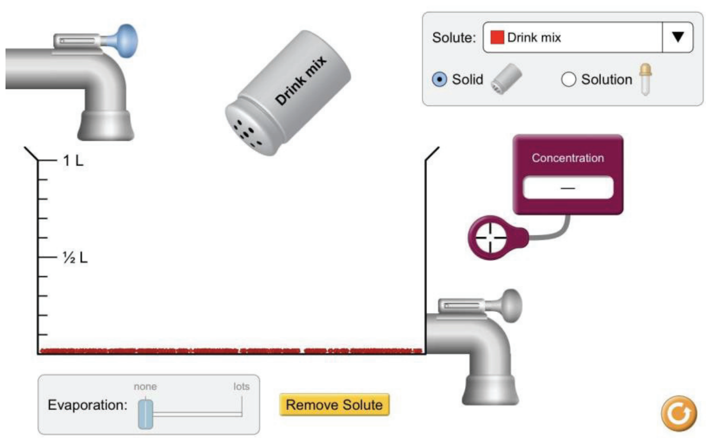


Figure 3. PhET simulation for separating salt from water.

Student Engagement: The student undertook the task of crafting a salt solution through the introduction of salt into a beaker already containing water. Subsequently, the student initiated the process of heating the solution. As heat was applied, the water within the solution underwent evaporation, resulting in the salt solidifying and settling at the beaker's base. Throughout this sequence, the student astutely noted the gradual reduction in the solution's volume as the heating continued. Ultimately, as the heating procedure concluded, all the water evaporated, leaving behind the salt in solid form at the bottom of the beaker.

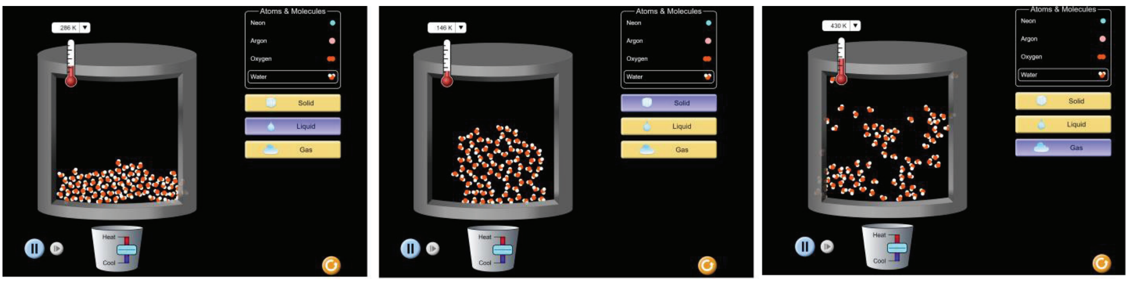
2.1.4. Analyzing

Goals:

The student should have the capacity to scrutinize the microscopic composition of a given substance in its three distinct states. This involves conducting a thorough comparison among these states, aiming to ascertain whether they accurately depict the three distinct phases of the substance.

Simulation:

Figure 4 shows how the simulation worked in the analysis phase.



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

Figure 4. PhET simulation for the microscopic composition of a given substance in its three states. (**a**) The microscopic level of the substance in its solid state, (**b**) microscopic level of the substance in its liquid state, and (**c**) microscopic level of the substance in its gaseous state.

Student Involvement: The student initiated the process by selecting a solid state of water (ice) and then proceeded to apply heat, causing the ice to transform into liquid water. The student persisted in heating the liquid water until it reached a point of evaporation, transitioning into gaseous vapor. Throughout this sequence, the student keenly perceived the altering arrangement of water particles during the progression from a solid state to a liquid state, and subsequently to a gaseous state, brought about by the influence of heat.

2.1.5. Evaluation

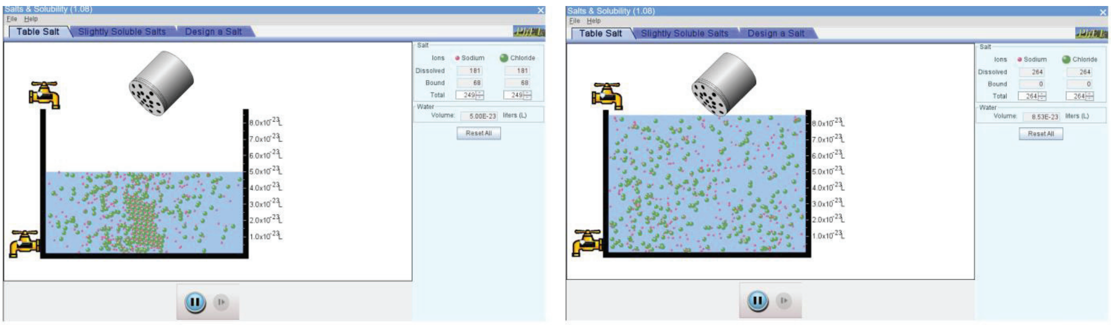
Goals:

- By the end of this process, the student should have the capability to design and suggest an experimental procedure aimed at demonstrating the correlation between the quantity of solvent and solute within a specified solution.
- Furthermore, the student should possess the competence to assess the effectiveness of the experiment they devised and executed, determining whether it can yield a precise and reliable outcome regarding the interplay between the amounts of solvent and solute.

Simulation:

Figure 5 shows how the simulation worked in the evaluation phase.

Student's Involvement: Students added salt gradually into the water, witnessing its dissolution. Eventually, there came a juncture when the salt particles began descending within the water. In response, the student introduced additional water, causing the sunken salt to re-dissolve. During this process, the student astutely noted that the added salt initially dissolved, followed by a phase of sinking. This precipitated salt later reverted to a dissolved state upon water addition. Furthermore, the student discerned a correlation between the concentration of dissolved salt and the quantity of salt initially dissolved, observing that the concentration increased progressively until reaching a saturation point.



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

Figure 5. PhET simulation for the interplay between the volume of the solvent and the quantity of the solute. (**a**) Precipitation of solute as a result of oversaturation, (**b**) dissolving of the solute as a result of adding a solvent.

2.1.6. Creation

Goal:

- The student will be able to illustrate the distribution of the salt particles within the water particles in solutions with a variety of salt concentrations.
- The student role: The student drew two illustrations showing the distribution of salt particles within water particles in two solutions, one diluted and the other saturated.

2.2. Data Collecting and Analysis Tools

Data collection was carried out through observational methods, wherein we recorded the learning activities of each group using video recordings. Our aim was to capture the interactions among students, as these exchanges provided insights into the specific stage of knowledge engagement within each group.

Subsequently, a combination of deductive and inductive content analysis was employed to scrutinize the transcripts of the students' learning videos. In the context of deductive content analysis, we employed the newly developed Bloom's knowledge taxonomy, encompassing distinct phases: remembering, understanding, application, analysis, evaluation, and creation. Table 1 outlines the thematic elements that facilitated the linkage between the unit of analysis (which was the sentence) and each corresponding phase of the taxonomy.

Table 1. Thematic elements of each phase of Bloom's taxonomy—based on Anderson and Krathwohl [25].

Category	Themes
Remembering	Recall, tell, what, when, list, find
Understanding	Explain, extend, classify, relate, rephrase
Application	Apply, choose, select, utilize, use
Analysis	Compare, classify, categorize, contrast, infer
Evaluation	Agree, assess, appraise, criticize, estimate
Creating	Build, change, combine, create, elaborate

Table 2 describes an example of the analysis conducted in the frame of the analysis of the transcripts at the coding stage.

Taking advantage of the deductive and inductive content analysis methodologies, we followed different studies in the literature, such as Daher [25].

Table 2. An example of data analysis.

Raw	Participant	Action/Interaction	Analysis
5	Teacher:	What will we do to convert a substance from the solid state to the liquid state	
6	Student 1	We are in the solid state, and I remember when we conducted the melting experiment in the laboratory. We lit a candle under the beaker containing ice. Now, I will do the same thing; I will ignite the fire under the beaker. Look how the particles move away from each other, and the substance takes the shape of the beaker. This was not visible in the previous experiment; it's wonderful.	Remembering: The students remembered what they did in the previous experiment.
7	Student 2	Now we have the substance in the liquid state. I will ignite the fire again to convert the substance into the gaseous state. It reminded me of an incident with my mother where she forgot the water on the stove, and when I returned, there was no water left.	Remembering: The student remembered a real-life incident related to the topic of the lesson that happened at home.

In the previous example on data analysis, we depended on the deductive content analysis when we linked the sentence "it reminded me" with the remembering process of the learner and thus with the category of remembering in Bloom's taxonomy. We depended on inductive content analysis to verify the conditions or properties of the remembering, here the remembering of a real-life incident.

2.3. Validity and Reliability of the Analysis

The validity of the qualitative research analysis processes stemmed from the analysis method that ensured theoretical saturation [29]. This theoretical saturation stemmed from the existence of no new category type that emerged from the given data. In addition, it stemmed from the coder's agreement regarding the categories and themes emerging from the units of analysis of the same data. According to Lincoln and Guba [30], validity guarantees reliability, so satisfying validity also ensures reliability, which means that theoretical saturation confers validity and reliability to the research procedure. Two experienced coders (two of the authors) coded the transcripts, where the agreement between them was 0.947, which is accepted for ensuring validity of the analysis, and thus its reliability.

3. Results

The primary objective of this research was to authenticate the learning processes of elementary school students when exposed to digital simulations, with a particular focus on the PhET platform. Herein, we outline and expound upon these processes according to Bloom's taxonomy framework.

3.1. Remembering Phase

3.1.1. Description and Transcript

During this stage, the students responded to the inquiry: "How do you transition a substance from one state to another?" Prompted by discussions on the transformation of matter, the students drew upon their past experiments and relevant knowledge to elucidate their observations in the simulation regarding the alteration of matter from one state to another. Transcript 1 provides an account of the students' learning during this phase.

5 Teacher: What will we do to convert a substance from the solid state to the liquid state?
6 Student 1: We are in the solid state, and I remember when we conducted the melting experiment in the laboratory. We lit a candle under the beaker containing ice. Now, I will do the same thing; I will ignite the fire under the beaker. Look how the particles

move away from each other, and the substance takes the shape of the beaker. This was not visible in the previous experiment; it's wonderful. I want to heat the substance a little, not too much, because if the heating process continues for a long time, the particles will move far apart and scatter. So, for now, this is sufficient; I will reduce the fire, as the substance has taken the shape of the container (See Figure 1a above).

7 Student 2: And now we have the substance in the liquid state. I will ignite the fire again to convert the substance into the gaseous state (See Figure 1b above). It reminded me of an incident with my mother where she forgot the water on the stove, and when I returned, there was no water left. Hahaha, I will go and tell my mother that she should not leave the water on the stove for a long time because it will evaporate if it continues to boil for a long time, and there will be no water left for tea.

8 Student 3: I remember when we learned about this topic in class, and you gave us an example of making an ice cream and how we can convert it from the liquid state to the solid state. Now, I want to do the same thing; I will place the ice under the container for it to solidify, and the particles come closer to each other (See Figure 1c above).

9 Student 2: We can also create any shape we want using liquid dough. We made ice cream in different shapes like squares and circles when we learned about the topic, using suitable molds.

Transcript 1: Students' learning at the remembering phase.

3.1.2. Analysis of Students' Learning at the Remembering Phase

During their interaction, the students established correlations between their observations in the simulation and real-life scenarios where they encountered outcomes without delving into the underlying process of scientific transformation. Student 2 remembered an incident involving her mother, specifically recalling the consequences of boiling water on the stove until it evaporated. This memory prompted her to caution her mother against leaving water unattended on the stove for an extended period [R7]. Moreover, Student 3 harked back to the experience of creating ice cream through an experiment, wherein the particles underwent solidification and drew nearer to each other [R8]. Regarding this, Student 2 also introduced the notion of manipulating the substance into various shapes by utilizing appropriate molds during the freezing of the liquid mixture [R9]. We can say that the PhET simulation enabled the students to connect with their real-life experiences and thus be able to move forward toward understanding the scientific phenomenon.

3.2. Understanding Phase

3.2.1. Description and Transcript

The next question was: "Place a quantity of salt in a water container. What happened?" Based on the students' responses, as in Transcript 2, this question required an understanding of the process of dissolution and saturation of solutions.

12 Teacher: What happens when you place a quantity of salt in a water container?

13 Student 1: When I added some salt, it dissolved in the water, but when I added a lot of salt, the word "saturation" appeared, and some salt settled at the bottom of the container (See Figure 2 above).

14 Students: (The other students started pressing the saltshaker to release the salt, and after adding a large amount of salt, they observed the word "saturation").

15 Student 2: This is indeed what happens because we added a large amount of salt that the water could no longer dissolve, so the salt precipitated at the bottom of the container.

Transcript 2: Students' learning at the understanding phase.

3.2.2. Analysis of Students' Learning at the Understanding Phase

Addressing the inquiry, students comprehended various facets associated with the dissolution of salt in water. Initially, they deduced that when a small amount of salt is introduced, it dissolves within the water [R13]. This signifies their grasp of the primary dissolution process wherein salt particles vanish within the aqueous solution. Furthermore, the students made an observation that, contrary to dissolution, the salt began to precipitate and accumulate at the container's base [R13]. Additionally, the students recognized that upon introducing a substantial quantity of salt, the water loses its capacity to accommodate and dissolve the salt, resulting in salt deposition [R15]. All the students' deductions during the understanding phase were due to their manipulation of the PhET simulation and observing the resulting changes in the scientific phenomenon.

3.3. Application Phase

3.3.1. Description and Transcript

The next question posed was: "How do we separate salt from water?" This question necessitated an explanation of the process for separating salt from water, where this explanation depended on the application of the students' new knowledge. Transcript 3 describes students' learning at the application phase.

16 Teacher: Can you describe how to separate salt from water?
17 Student 1: If we ignite the fire, the water will evaporate and only the salt will remain.
18 Student 2: We evaporate the water to separate it from the salt.
19 Student 3: During the experiment that we performed, we evaporated the water, causing it to turn into a gaseous state and disperse. As a result, only the salt remained. It became evident that the water evaporated while the salt was left behind (See Figure 3 above).

Transcript 3: Students' learning at the application phase.

3.3.2. Analysis of Students' Learning at the Application Phase

The students displayed their grasp of the water evaporation process and its impact on salt, revealing an understanding that heating leads to the evaporation and dispersion of water while salt remains behind. Student 1 emphasized the role of ignition in the evaporation process (R17), Student 2 highlighted the concept of water evaporation (R18), and Student 3 remembered the gaseous dispersion of water and the retention of salt while experimenting with PhET simulation in the understanding phase (R19). Student 3 further expounded on the results of heating the solution, applying the recently acquired knowledge. Here, the students applied the knowledge conceived using the PhET simulation in the understanding phase.

3.4. Analysis Phase

3.4.1. Description and Transcript

The subsequent query presented was: "Is it possible for a single substance to exist in three distinct states?" Transcript 4 provides insight into how the students responded to this question.

19 Teacher: Can the same substance exist in three states? Please provide an example.
20 Student 3: Yes, a substance that can exist in three states is water. It takes the form of solid as ice, then transforms into a liquid as water, and changes into a gas as vapor.
21 Student 1: (Ignited the fire under the ice till it melted into water. She kept heating the water until it evaporated (See Figure 4 above)).
22 Student 3: If we examine the three microscopic levels of water and compare them, we can categorize them as three states of the same substance.

Transcript 4: Students' learning at the analysis phase.

3.4.2. Analysis of Students' Learning at the Analysis Phase

The students showcased their ability to scrutinize the substance's behavior and discern its various states (R19–R22). PhET played a crucial role in facilitating their analytical process, allowing them to observe the three states of water at the microscopic level. This analytical approach is reflected in how the students employed terms such as "examine", "compare" and "categorize" to describe the processes that occurred through the PhET simulation (R22).

3.5. Evaluation Phase

3.5.1. Description and Transcript

The students' assignment involved crafting an experiment aimed at elucidating the connection between the quantity of solvent and solute. Episode 5 captures the students' progress during the evaluation phase of their learning journey.

27 Teacher: Now, I would like you to plan an experiment that demonstrates the relationship between the volume of the solvent and the quantity of the solute. (The students restarted the simulation by pressing the reset button).

28 Student 1: Currently, we only have water as the solvent. We will add a small amount of salt and observe its dissolution. (The students observed that the salt particles separated from each other).

29 Student 3: Let's continue adding salt until the word "saturation" appears on the screen. Look, the word "saturation" has appeared, indicating that the water is saturated. If we add more salt now, it will precipitate to the bottom. (The students observed that the salt no longer dissolves in water due to reaching the saturation point (see Figure 5a above)).

30 Student 2: What happens when we add water to the precipitated salt? (The students added water to the container).

31 Student 1: Oh, the salt particles have separated again because we added water, and the salt dissolved in the added water (see Figure 5b above).

32 Teacher: So, what is the relationship between the solvent and the solute?

33 Student 3: Whenever the quantity of the solute (salt) increases, we must add more solvent (water). We also observed that the ion concentration of the salt increased when it dissolved, reaching a value of 271 (see Figure 5b above). On the other hand, when a portion of the salt precipitated, the ion concentration was 180. This indicates that the quantity of dissolved salt increases when water is added.

34 Teacher: Based on the experiment you performed in the simulation system, is it possible to accurately determine the relationship between the amount of solvent and the amount of solute?

35 Student 1: In the experiments we have carried out so far in the laboratory, we have come to the point where it is impossible to make a conclusion based on the results of one experiment. Therefore, we must have more measurements related to the volume of the solvent and the amount of the solute.

36 Teacher: What additional measurements are we required to carry out in order to accurately determine the relationship?

37 Student 2: We need to perform a number of experiments in which we maintain a constant volume of solvent (water) and add a different amount of salt each time and see if the salt dissolves or not. We then can observe when the salt begins to sink to the bottom of the container.

Transcript 5: Students' learning at the evaluation phase.

3.5.2. Analysis of Students' Learning at the Evaluation Phase

The query presented to the students entailed devising an experiment aimed at showcasing the correlation between the solvent's volume and the amount of the solute (R27). The students proceeded to chart out and execute an experiment that effectively depicted the interplay between the volume of the solvent and the quantity of the solute (R28–R31). Upon conducting the experiment, the students arrived at a conclusive understanding of the relationship (R31). Subsequently, the instructor prompted the students to assess whether the outcomes of their experiment alone could ensure a precise relationship (R32). In response, the students proposed a method that, once enacted, would yield a reliable assessment of the relationship (R28–R37). Here, the PhET simulation served the students only in part of their evaluation, but it was behind their design and evaluation processes.

3.6. Creation Phase

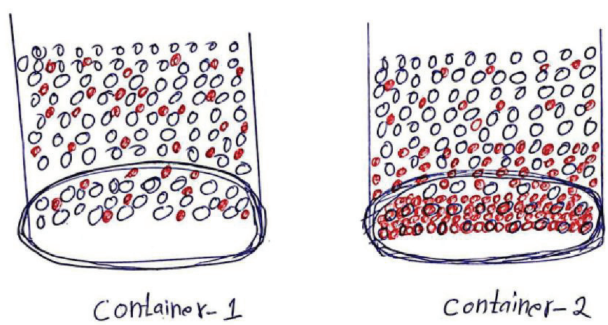
3.6.1. Description and Transcript

The inquiry posed was as follows: Salt was introduced into a pair of glass containers filled with water. A single spoon of salt found its way into the initial container, while the second container received three spoons of salt. In the former container, all the salt underwent dissolution within the water, whereas in the latter container, a portion of the salt settled at the container's base. Envisioning the presence of enchanted spectacles that grant you the ability to visualize the dissolved salt particles, create drawings depicting the arrangement of dissolved salt particles within each of the containers. Subsequently, elucidate the details and significance behind each of the illustrations you have rendered. Transcript 6 describes students' learning at this phase.

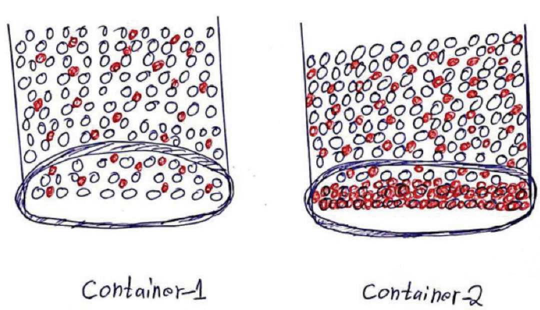
38 Teacher: Please discuss the question and draw the required distribution.

39 Students: (The students in the group discussed the questions and each student drew a drawing depicting the containers).

40 Student 3: In the first container, the salt particles will be homogeneously distributed throughout the solvent particles, while in the second container, more salt particles will be in the cold lower part.



41 Student 2: In both containers, the salt particles will be distributed fairly in the water, except that in the second container, there will be more salt particles in the water since we added more salt to the container.



Transcript 6: Students' learning at the creation phase.

3.6.2. Analysis of Students' Learning at the Creation Phase

Within this task, the student's objective was to integrate various components and synthesize them into a novel creation. Student 3 fashioned an illustration featuring concentrated salt in the lower section, whereas Student 2 crafted an illustration depicting salt particles uniformly dispersed throughout the entire solvent. Through her artwork, this student effectively contrasted the two containers, enabling her to aptly depict the precise scientific scenario. Here, the students utilized all that they learned using the PhET simulation to perform the creation processes of the scientific phenomenon.

4. Discussion

Educational researchers are interested in the different aspects of students' learning in specific educational contexts [31–35], especially in digital contexts [36,37]. The present research intended to study students' knowledge phases of Grade 3 students' scientific concepts in the context of PhET simulations. Below, we will delve into students' acquisition of scientific concepts and relationships through digital simulations.

4.1. Remembering Knowledge

Remembering occurred in two distinct contexts. The initial context is the domestic context, where Student 2 remembered an incident at his home and connected it with the experiment performed by the students. This act of remembering underscores the significance of home experiences in students' learning. Educational researchers emphasized the positive and negative roles that home experiences play in classroom learning [38]. The second context pertains to prior experiences with the PhET simulations. This remembering of previous experiences with technological tools underscores the positive impact that engaging with technology-driven experiments can have on future learning experiences [39]. In both of these contexts, the work with simulations was behind students' remembering of previous events and processes, which supported students' understanding of the new scientific concepts and relations.

4.2. Understanding Knowledge

Through the utilization of a lifelike simulation illustrating salt dissolution in water, the students meticulously observed the complete dissolution of salt within the water, with dispersion occurring throughout the entire volume rather than accumulating solely at the bottom. This insightful observation was facilitated by the students' engagement with digital simulations. Mengistu and Kahsay [40] reported that computer simulation used as teaching aids enhanced students' understanding of electric field and electric force concepts. Additionally, Nafidi et al. [41] found the proper integration of a simulation of relative chronology into students' training can augment their learning. Therefore, research, especially the present study, corroborates the assertion that simulations, particularly digital ones, enhance students' grasp of scientific concepts and relationships. All the previous indicates that digital simulations influence positively elementary students' learning of science.

4.3. Application Knowledge

The application followed students' comprehension of scientific concepts and relationships. An understanding was achieved with the aid of simulations, while the application did not necessarily demand simulation usage; however, students relied on the knowledge they gained through simulations. Previous research has indicated that the application phase's benefits through technology can vary. According to the study by Daher and Sleem [42], the conventional group outperformed the technology-based (360-degree video) group in terms of application knowledge. The present research results indicate that digital simulations support students' performance and knowledge during the application phase, which indicates that digital simulations could positively influence students' learning during the application phase.

4.4. Analysis Knowledge

During the analysis phase, PhET enabled students to scrutinize and compare the three states of water at the microscopic level, enabling them to analyze the substance's behavior and distinguish its various forms. Much like in the understanding phase, the

PhET simulation played a pivotal role in their analysis processes, involving examination, comparison, and categorization. This encouragement of analytical processes was attributed to PhET's visualization capabilities, which allowed students to compare the observed water states, particularly at the microscopic level. This facilitated their usage of precise scientific terminology related to the water's three states. This aligns with researchers who have highlighted simulations' role in facilitating students' analytical processes. Daher and Baya'a [43] elucidated how mobile simulations empowered students to analyze mathematical phenomena through authentic activities both inside and outside the classroom. Thus, the current research, in addition to previous research, indicates the positive influence of digital simulation on students' learning at the analysis phase.

4.5. Evaluation Knowledge

In the evaluation phase, students were tasked with designing an experiment that illustrates the connection between solvent volume and solute quantity. When the students proposed such a plan, the teacher prompted them to assess whether their experiment alone could ensure an accurate relationship, leading the students to devise a procedure for this purpose. In this phase, the students employed the simulation in the initial part but not the latter part. Thus, technology was only employed in a portion of the evaluation phase, where we addressed the student's ownership of the evaluation process rather than the teacher's use of a tool to gauge the student's comprehension. Here, it can be argued that the teacher asked the students to conduct a qualitative evaluation, in which the "quality" of the analysis is determined [44]. In this context, the students improved the quality of their earlier analysis pertaining to the relationship between solvent volume and solute quantity. The previous argument indicates that digital influences, even though used only in part of the learning process, can positively influence students' learning at the evaluation phase.

4.6. The Creation Phase

In this stage, students were challenged to synthesize various elements and employ them to depict a scientific phenomenon visually. The students harnessed all the knowledge accumulated in prior phases to deliberate on the phenomenon and subsequently create a relevant image. Despite the collaborative discourse, the students produced distinct images, influenced by the knowledge garnered in previous phases. Here, the student's individual attributes impacted the outcome of their learning, including their past aptitude in science. Researchers have asserted that personal traits influence current student learning. Daher and Shahbari [45] reported that students' characteristics shape their learning experiences in the virtual classroom. Thus, the present research underscores the impact of these personal attributes. In addition to the above, here, the participating students made effective use of all that they conceived using the PhET simulation to carry out the creation processes of the scientific phenomenon. Thus, though not utilized directly, the digital simulation positively influenced students' learning at the creation phase.

5. Conclusions and Future Practice

The outcomes of the research suggest that students have effectively grasped the process of dissolution and the concept of saturation point. This understanding is evident from their remarks, dialogues, and observations.

The students' enthusiasm for utilizing simulations to illustrate and clarify real-world material transformation instances highlights their capacity to establish connections between the scientific phenomena they observe in the simulations and their prior experiences with scientific experiments. Furthermore, they draw upon instances from everyday life, which enriches their comprehension of scientific concepts pertaining to changes in matter states.

By incorporating simulations into teaching methodology, students obtained direct and interactive opportunities to witness phenomena and alterations at both macroscopic and microscopic scales. This approach effectively nurtures scientific thinking and inference through hands-on experiments. It empowers students to visualize and delve deeper into transformation processes, identifying underlying causes, and comprehending the associated scientific explanations. As a result, the incorporation of simulations in teaching promotes active learning and facilitates a profound grasp of scientific concepts, empowering students to apply their knowledge in real-life scenarios. Additionally, it cultivates problem-solving skills and the development of scientific expertise. In light of the previous evidence of the benefits of simulations for elementary school students' science learning, it is logical to conclude that science teachers and learners in elementary school would benefit from using simulations in the classroom.

6. Limitations and Recommendations for Future Research

The present research examined the knowledge processes of Grade 3 students when learning science in the context of PhET simulations. The simulations influenced positively the students' knowledge processes in terms of Bloom's knowledge processes. One limitation of the present research is the small number of students who participated in the study, so future research is requested to affirm the results of the present research, especially among Grade 3 and elementary school students. The use of PhET simulations in the science learning of elementary school students is still new, which emphasizes that the current research should be furthered with future studies in all elementary grades, as recommended previously.

In addition to the above, the present research followed qualitative methodology to study the knowledge processes of elementary school students. Future research that follows the quantitative methodology is needed to triangulate the present results. We are aware of the difficulties of carrying out quantitative research among Grade 3 students, but this could be conducted with students in the late elementary school grades [46]. Wigfield [46] gives recommendations for researchers who come to use questionnaires in elementary school. Moreover, questionnaires are suggested for the early grades of elementary school students [47].

Students' knowledge has little been studied using Bloom's processes based on observation, where previously some attempts were made to do so through interviews [42]. This study attempts to accomplish that through observations. To advance our current effort to analyze knowledge processes based on observation data by using Bloom's taxonomy as a theoretical framework, further research is needed.

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Article

Exploring Students' Learning Experience and Engagement in Asynchronous Learning Using the Community of Inquiry Framework through Educational Design Research

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Abstract: Students' learning experience and their engagement in online learning environments are becoming increasingly important as blended learning grows more prevalent in tertiary education. In this study, asynchronous lectures for applied sciences courses, offered to polytechnic students of Applied Chemistry and Pharmaceutical Science at Nanyang Polytechnic, were designed using the Community of Inquiry framework. Students' perceptions of their learning experience and cognitive, emotional, and behavioral engagement in asynchronous lectures were determined through a survey study. The results showed that students were engaged and had positive learning experiences. Through an educational design research methodology, this survey study also determined and provided design features important for designing asynchronous lectures. Further research could explore the possibility of expanding the scope of the research to other institutions with students of different cultural backgrounds, learning preferences, and learning abilities.

Keywords: blended learning; asynchronous learning; community of inquiry; engagement; educational design research; student-centred learning; chemistry education; pharmacy education

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1. Introduction

Blended learning, a mix of online and face-to-face learning, has gained much attention and interest [1] as it develops self-directed, passionate, and lifelong learners. Significant attention has been placed on blended learning globally in recent years due to the COVID-19 pandemic. With schools and institutions pivoting to and retaining blended learning after the COVID-19 pandemic [2,3], it is important to ensure that students are engaged while receiving meaningful learning experiences while they are learning in blended learning environments.

There are several definitions [4] and models of blended learning based on implementation [1], and the flipped classroom model is the most used approach. This is the approach that our institution, Nanyang Polytechnic, employs as the main model, where "technology (is used) to invert the traditional teaching environment by delivering lectures online as homework and opening up the class period for interactive learning" [5]. Since students are required to acquire knowledge online before face-to-face sessions and asynchronously, the asynchronous lecture materials must be interactive and engaging to create a meaningful learning experience. In this study, we focus on the asynchronous lecture component of blended learning. The use of asynchronous lectures in a flipped classroom approach is beneficial because students can complete the asynchronous lectures at their own pace, which enables optimal learning as the interactive elements integrated into the asynchronous lectures could increase students' engagement through active learning [6–8].

With a shift from the didactic, teacher-centric approach—which focuses on the banking model of education [9]—to the student-centric approach, the learning environment is as important as the content. It was previously reported that some students found online and/or blended learning challenging [10,11] due to the influx of information from multiple sources [12]. Students' perceptions of asynchronous learning in applied sciences are varied, hence, the design of the asynchronous online learning component is important to the enhancement of learning perception and effectiveness [8,13].

1.1. Theoretical Framework

The Community of Inquiry (CoI) framework (Figure 1) by Garrison, Anderson, and Archer is a theoretical framework that considers the cognitive presence (CP), social presence (SP), and teaching presence (TP) crucial for creating a meaningful online learning experience for students [14]. This framework is one of the most dominant frameworks and has been described as "the ideal and heart of higher education" [15–23]. CP refers to building students' knowledge and problem-solving skills through the construction and conceptualization of their learning. During learning, social interaction, affectivity, and cohesiveness hold equal weightage and their importance is emphasized by the social presence. Finally, TP focuses on teachers' instructions and their facilitation of learning, and the design of the course. The CoI framework has been reported in many different contexts [16] and the validity of the CoI instrument [21,24,25] makes both the framework and the instrument suitable for the evaluation of students' online learning experience.

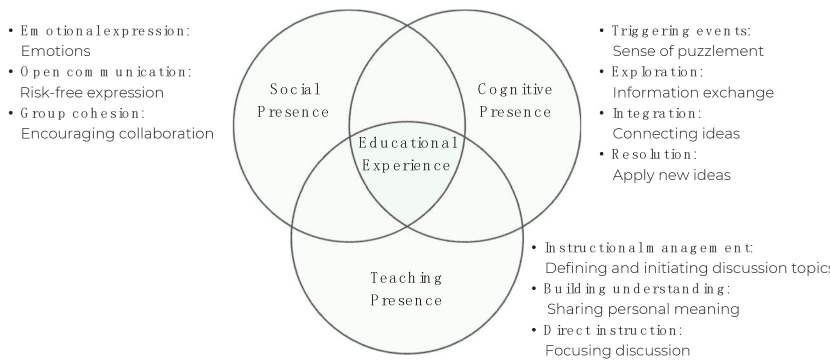

Figure 1. CoI framework, presences, and categories.

Arbaugh et al. compared the use of the CoI framework in applied and pure disciplines [26]. Due to the constructivist approach of the CoI framework, it is more pertinent to applied disciplines. The study also concluded that the development of applicable knowledge is emphasized by using the inquiry method. Since learning through inquiry is important in applied sciences, the use of the CoI framework is suitable. In applied sciences, CP is crucial as students need to use their knowledge to explore and connect existing ideas, to create new ideas, and to solve problems. This is aligned with the categories within the CoI framework (Figure 1). Collaboration is also essential in applied sciences as complex problems require expertise from multiple disciplines. This is emphasized by the social interaction, communication, and emotional expression within SP. Finally, TP is essential in the facilitation of learning and acquiring of knowledge which is needed for CP and SP.

The three-dimensional model of student engagement suggests that engagement is a multi-dimensional construct consisting of cognitive, behavioral, and emotional engagement [27]. Cognitive engagement refers to students' involvement in the learning tasks, including self-regulation as well as building connections with new knowledge. This form of engagement is not readily observable, as students who appear disengaged could in fact be cognitively engaged as they think and conceptualize the knowledge they have learnt. On the other hand, examples of behavioral engagement such as participating in class activities and completing learning tasks on time are readily observed. Finally, emotional engagement deals with students' feelings and perceptions about learning. An emotionally engaged student is passionate about learning and curious about the learning content. Students' engagement in asynchronous learning is important as it can minimize transactional distance—a psychological and communication space between the instructor and learner during asynchronous learning [28]. Additionally, Berry reported that higher levels of engagement correspond to better learning [29].

1.2. Research Purpose and Questions

Online chemistry learning has been reported [8], but the use of CoI in chemistry education has not been extensively reported [7,30–32]. There are even fewer studies on the use of CoI in pharmacy education [33,34]. Previously, we reported students' collective perception of asynchronous lectures via the CoI framework, and the relationship with the students' learning performance [35]. The results showed that the students' perception was positive and there was a weak but positive relationship with their learning performance. However, there are some limitations to the previous study. Students' learning performance is affected by both the design of the asynchronous lectures and their face-to-face classroom learning. Also, the study was only focused on one field of chemistry. Hence, to determine the applicability of designing asynchronous lectures based on the CoI framework, other contexts should be considered. In addition, more negative perceptions from students with regards to online learning of chemistry were reported [8]. Hence, it is imperative to improve the quality continuously to ensure the effectiveness of the learning environment.

With these research gaps, this study aims to extend previous studies involving Chemistry and Pharmacy courses [7,8,30–34]. Additionally, the study also aims to determine whether the design features for designing asynchronous lectures can enhance students' engagement by minimizing transactional distance [28] in an asynchronous learning environment. This study would provide insight into the design features of asynchronous learning, specifically asynchronous lectures, through the following research questions (RQs):

RQ1: What are students' perceptions of the asynchronous lectures developed based on the CoI framework for different applied science courses?
RQ2: What are students' perceptions of engagement in the asynchronous lectures developed based on the CoI framework?
RQ3: What design features are important for designing asynchronous lectures that are perceived positively and engage students?

2. Materials and Methods

2.1. Methodology

Educational design research is defined as "the systematic analysis, design and evaluation of educational interventions with the dual aim of generating research-based solutions for complex problems in educational practice, and advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them" [36]. The educational design research approach was used as the methodology for this study [37]. This is suitable, as one of the aims (RQ3) is to derive design features for educators who are looking to implement asynchronous lectures with a positive impact on student engagement. The process started with preliminary research of the literature (Figure 2). Based on the context and needs analysis regarding providing students with a meaningful and engaging educational experience, the CoI framework [14] was selected as the theoretical framework, and the three-dimensional model of student engagement was selected for use in asynchronous learning [38]. Each phase consists of the design, implementation, and evaluation or assessment of the learning activity (asynchronous lecture). This iterative cycle is a key feature of educational design research, and it allows for the improvement of the asynchronous lecture design and to derive design features for asynchronous lectures.

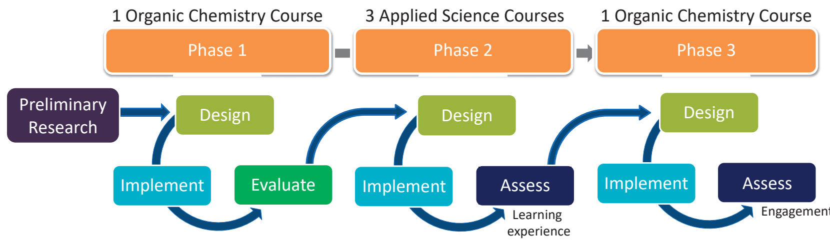

Figure 2. Phases 1–3 of the study, conducted through educational design research.

An Organic Chemistry course was selected for phase 1 of the study. Students' perceptions of asynchronous lectures were studied during this phase. Based on the previously reported evaluation results obtained from phase 1 [35], design features were derived and implemented in other contexts to assess their applicability to other courses for phase 2. The same cycle (design, implementation, and evaluation) was employed for phase 2. At the end of phase 2, the evaluation was conducted as an assessment, as it concludes part of the study (RQ1) to determine the students' collective perception of asynchronous lectures and their learning experience. Based on the results from phase 2, design features of asynchronous lectures could be further enhanced during the design stage in phase 3. The same cycle was conducted, and in the final assessment, the study focuses on students' engagement (RQ2). With the results from the three phases, design features were derived (RQ3).

2.2. Participants

Participants in this study were 17–19-year-old students with mixed abilities studying at the School of Applied Science, Nanyang Polytechnic. The selection of participants was via a non-random convenience sampling method as students come from the respective diploma courses and classes, and participation in the study was voluntary. Table 1 summarizes the number of participants, diploma programmes, and courses involved in this study. Phase 1 of the study involved 44 first-year students who were enrolled in an Organic Chemistry course. Phase 2 involved 65 first- and second-year students enrolled in three different courses. Phase 3 involved 64 first-year students enrolled in an Organic Chemistry course.

Table 1. Number of participants, diploma programmes, and courses involved in each of the phases of the study.

Phase	Sample Size	Diploma Programme	Course
1	44	Diploma in Medicinal Chemistry	Organic Chemistry
2	65	Diploma in Applied Chemistry Diploma in Pharmaceutical Science Diploma in Pharmaceutical Science	Analytical Chemistry Pharmacy Practice Pharmacotherapy I
3	64	Diploma in Applied Chemistry	Organic Chemistry

2.3. Instruments

A survey was used to measure students' perceptions. For phases 1 and 2, a 30-item modified CoI instrument [21] was used to measure the students' perception of the asynchronous lectures. From the original CoI instrument, four items were removed due to their irrelevance to this study. The items removed were "the instructor clearly communicated important course goals", "the instructor was helpful in identifying areas of agreement and disagreement on course topics that helped me to learn", "the instructor helped to focus discussion on relevant issues in a way that helped me to learn" and "I was able to form distinct impressions of some course participants". To minimize the possibility of obtaining neutral responses due to the lack of attention to the survey items [39], a 4-point Likert scale, 1 (strongly disagree) to 4 (strongly agree), was used instead of the original 5-point Likert scale. Despite the modification of the scale, the CoI instrument with a 4-point Likert was validated according to previous studies [21,24].

For phase 3, engagement was viewed as a multi-dimensional construct with three types of engagement: cognitive, emotional, and behavioral engagement [27,38,40]. The 14-item instrument [41] used in this phase included five items each for behavioral and emotional engagement from the Engagement Versus Disaffection with Learning Measure, along with a 4-point Likert scale, 1 (not at all true) to 4 (very true) [42]. The remaining four items for the cognitive engagement were taken from the Metacognitive Strategies Questionnaire [43].

In all three phases, two unstructured items—"What is/are the feature(s) in the asynchronous lectures that helped you learn? Why?" and "What is/are the feature(s) in the asynchronous lectures that didn't help you learn? Why?"—were included. Students' qualitative responses would provide deeper insight into the design features. Additionally, students were not briefed on the design features as the authors did not want to limit their responses.

2.4. Data Collection

Approval from the NYP Institutional Review Board (protocol code SCL-2020-005) was obtained before the study and students' implied consent was obtained before data collection.

RQ1 and RQ2 of the study focused on determining students' perception of the asynchronous lectures using the respective survey instruments mentioned. A cross-sectional approach was used where the data was only collected once at the end of the asynchronous lectures. This approach was selected as it can collect data with regards to students' current and immediate perception. Based on the results obtained for RQ1 and RQ2, the authors derived design features for designing asynchronous lectures.

3. Results

3.1. Phase 1—Prototyping the Design Features

The asynchronous lectures were designed based on the CoI presence and categories (Figure 1) to provide a meaningful, educational learning experience [14]. A total of 44 responses were received for this phase of the study and the mean scores for each item were calculated (Table 2). The mean responses ranged from 2.93 (*SD = 0.50*) to 3.80 (*SD = 0.41*). The item with the lowest mean response is related to social presence (social interaction). This is within expectations, as the asynchronous lectures are completed individually with almost no student–student interaction [44]. Despite being the item with the lowest mean value, it still gained a positive response. This could be due to the presence of the asynchronous discussion platform (Padlet) embedded to encourage student–teacher and student–student interaction. Other on the hand, the highest mean score is related to instructional management. Novice learners seemed to prefer to follow a specified learning sequence (program control) to help keep them on task and to scaffold their learning.

Table 3 shows the collective mean responses for each of the respective CoI presences. Students' perception of the overall learning experience (LE) was determined through the average mean scores of the three presences. This method of determining the perception of the learning experience was also reported previously [20]. The mean score of 3.41 for the learning experience meant that students had a meaningful learning experience with the asynchronous lectures.

Table 2. Survey items of the three CoI presences and the mean scores for phase 1 (n = 44).

CoI Presence	Code	Survey Item	Mean [a] (*SD*)
Cognitive presence (CP)	CP1	Problems posed increased my interest in course issues.	3.18 (0.69)
	CP2	Course activities piqued my curiosity.	3.36 (0.69)
	CP3	I felt motivated to explore content related questions.	3.27 (0.66)
	CP4	I utilized a variety of information sources to explore problems posed in this course.	3.36 (0.57)
	CP5	Brainstorming and finding relevant information helped me resolve content related questions.	3.41 (0.62)
	CP6	Online discussions were valuable in helping me appreciate different perspectives.	3.20 (0.67)
	CP7	Combining new information helped me answer questions raised in course activities.	3.25 (0.61)
	CP8	Learning activities helped me construct explanations/solutions.	3.50 (0.55)
	CP9	Reflection on course content and discussions helped me understand fundamental concepts in this class.	3.55 (0.50)
	CP10	I can describe ways to test and apply the knowledge created in this course.	3.27 (0.50)
	CP11	I have developed solutions to course problems that can be applied in practice.	3.30 (0.51)
	CP12	I can apply the knowledge created in this course to my work or other non-class related activities.	3.45 (0.55)
Social presence (SP)	SP1	Getting to know other course participants gave me a sense of belonging in the course.	3.20 (0.73)
	SP2	Online or web-based communication is an excellent medium for social interaction.	2.93 (0.50)
	SP3	I felt comfortable conversing through the online medium.	3.41 (0.58)
	SP4	I felt comfortable participating in the course discussions.	3.27 (0.59)
	SP5	I felt comfortable interacting with other course participants.	3.30 (0.51)
	SP6	I felt comfortable disagreeing with other course participants while still maintaining a sense of trust.	3.09 (0.71)
	SP7	I felt that my point of view was acknowledged by other course participants.	3.20 (0.63)
	SP8	Online discussions help me to develop a sense of collaboration.	3.32 (0.67)
Teaching presence (TP)	TP1	The instructor clearly communicated important course topics.	3.77 (0.42)
	TP2	The instructor provided clear instructions on how to participate in course learning activities.	3.73 (0.50)
	TP3	The instructor clearly communicated important due dates/time frames for learning activities.	3.68 (0.47)
	TP4	The instructor was helpful in guiding the class towards understanding course topics in a way that helped me clarify my thinking.	3.70 (0.51)
	TP5	The instructor helped to keep course participants engaged and participating in the course learning activities.	3.75 (0.49)
	TP6	The instructor helped keep the course participants on task in a way that helped me to learn.	3.80 (0.41)
	TP7	The instructor encouraged course participants to explore new concepts in this course.	3.61 (0.54)
	TP8	Instructor actions reinforced the development of a sense of community among course participants.	3.55 (0.63)
	TP9	The instructor provided feedback that helped me understand my strengths and weaknesses relative to the course's goals and objectives.	3.50 (0.63)
	TP10	The instructor provided feedback in a timely fashion.	3.57 (0.62)

[a] Based on a 4-point Likert scale (1 = strongly disagree; 4 = strongly agree).

Table 3. Descriptive statistics of the three CoI presences and the learning experience (n = 44).

	Mean [a] (*SD*)
Cognitive presence	3.34 (0.48)
Social presence	3.22 (0.45)
Teaching presence	3.67 (0.43)
Learning experience	3.41 [b] (0.39)

[a] Based on a 4-point Likert scale (1 = strongly disagree; 4 = strongly agree). [b] Collective responses for the three CoI presences.

The survey also included qualitative questions to determine design features which helped or did not help students when they learn asynchronously. Design features that were welcomed included practice questions with worked solutions, the clarity of the instructional videos, and the chunking of the information or video. Students provided feedback that they did not like the absence of face-to-face opportunities to ask questions when they were struggling with the materials, despite having access to the discussion platform, Padlet, within the learning platform.

3.2. Phase 2—Applicability of the Design Features

With the results obtained in phase 1, the CoI framework and categories were extended to three other applied science courses (Table 1). Similar data collection and analysis approaches were used. A total of 65 responses were collected for phase 2 (Table 4). The mean responses ranged from 2.95 (*SD = 0.99*) to 3.74 (*SD = 0.44*). Similar to phase 1, the same item related to social presence (social interaction) had the lowest mean response. The item with the highest mean response is related to clear communication of due dates. Although the item with the highest mean response differs from phase 1, the item with the highest mean response still belongs to the teaching presence category.

The collective mean responses for each of the CoI presences and the overall learning experience were also high. This indicates that the design features based on the CoI framework were successfully extended to other applied science courses, which provides insight to RQ1. The concurrence of results in both phase 1 and 2 also corroborates that the design features are important for designing asynchronous lectures that are perceived positively by students, providing insight to RQ3.

Qualitative feedback from the students had some common themes. Similar to phase 1, they liked that the materials (videos) were chunked and bite-sized. Students also mentioned that the interactive activities (i.e., drag-and-drop) and self-assessments (i.e., MCQ formative quiz) at the end of each asynchronous lecture helped reinforce their learning. One comment mentioned that the discussion platform, Padlet, allowed peer learning. This feedback further strengthens the design features required for a positively perceived asynchronous lecture. On the contrary, a handful of students mentioned that having to constantly click through the asynchronous lecture was troublesome.

The independent samples t-test revealed that the difference in the mean responses between phases 1 and 2 has limited practical significance for the three CoI presences and the learning experience, possibly due to the small sample size of the study. For TP, the mean responses between phase 1 (M = 3.67, SD = 0.43) and phase 2 (M = 3.53, SD = 0.67), $t(106)$ = 1.98, p = 0.167. For CP, the mean responses between phase 1 (M = 3.34, SD = 0.48) and phase 2 (M = 3.26, SD = 0.66), $t(107)$ = 1.98, p = 0.416. For SP, the mean responses between phase 1 (M = 3.22, SD = 0.45) and phase 2 (M = 3.15, SD = 0.80), $t(105)$ = 1.98, p = 0.513. Finally, for LE, the mean responses between phase 1 (M = 3.41, SD = 0.39) and phase 2 (M = 3.31, SD = 0.71), $t(107)$ = 1.98, p = 0.274.

Table 4. Descriptive statistics of the individual survey items, three CoI presences, and learning experience for phase 2 (*n* = 65).

CoI Presence	Item Code	Mean [a] (*SD*)	Mean [b] (*SD*)	LE Mean [c] (*SD*)
Teaching presence (TP)	TP1	3.62 (0.49)	3.53 (0.67)	3.31 (0.71)
	TP2	3.55 (0.61)		
	TP3	3.74 (0.44)		
	TP4	3.66 (0.57)		
	TP5	3.57 (0.61)		
	TP6	3.57 (0.73)		
	TP7	3.42 (0.86)		
	TP8	3.35 (0.84)		
	TP9	3.43 (0.75)		
	TP10	3.42 (0.81)		
Social presence (SP)	SP1	3.29 (0.80)	3.15 (0.80)	
	SP2	2.95 (0.99)		
	SP3	3.14 (0.88)		
	SP4	3.15 (0.71)		
	SP5	3.34 (0.69)		
	SP6	3.11 (0.79)		
	SP7	3.20 (0.77)		
	SP8	3.02 (0.78)		
Cognitive presence (CP)	CP1	3.14 (0.68)	3.26 (0.66)	
	CP2	3.15 (0.75)		
	CP3	3.09 (0.70)		
	CP4	3.22 (0.70)		
	CP5	3.40 (0.63)		
	CP6	3.22 (0.70)		
	CP7	3.34 (0.69)		
	CP8	3.42 (0.61)		
	CP9	3.38 (0.55)		
	CP10	3.29 (0.63)		
	CP11	3.31 (0.58)		
	CP12	3.18 (0.68)		

[a] Based on a 4-point Likert scale (1 = strongly disagree; 4 = strongly agree). [b] Collective responses for the items in each CoI presence. [c] Collective responses for the three CoI presences.

3.3. Phase 3—Student Engagement and Design Features

To provide further insight into RQ3 in terms of students' engagement in asynchronous lectures, phase 3 investigates students' perceptions of engagement in asynchronous lectures. A total of 64 responses were collected for phase 3 (Table 5). The mean responses ranged from 2.67 (*SD = 0.78*) to 3.58 (*SD = 0.50*). The lowest mean response was related to cognitive engagement and whether the asynchronous lectures improved their learning significantly. This could mean that students are not building strong connections with the new content. However, this does not necessarily mean that the students are not acquiring the knowledge, but it could be that the improvement in their learning was not as significant as they wanted. The highest mean response is related to behavioral engagement where students are participating and working hard to do well in the asynchronous lecture. This shows that students are motivated to complete the asynchronous lectures. In general, students are positively engaged in all three dimensions, with mean responses of more than 3.

Similar qualitative feedback was given during this phase of the study. Students liked the practice questions with worked solutions, the clarity of the materials, the chunking of the information or video, and the interactive activities. This further enhances our understanding of design features that motivate students to learn in an asynchronous environment.

Table 5. Survey items for the three dimensions of engagement, and mean scores for phase 3 (*n* = 64).

Engagement	Survey Item	Mean [a] (*SD*)	Mean [b] (*SD*)
Behavioral engagement (BE)	I tried hard to do well in this module.	3.58 (0.50)	3.52 (0.43)
	In this module, I worked as hard as I could.	3.53 (0.56)	
	I attempted the questions in the e-learning lecture.	3.52 (0.69)	
	I paid attention to the e-lecture.	3.48 (0.53)	
	When I studied for this module, I listened very carefully to the e-lectures.	3.47 (0.62)	
Emotional engagement (EE)	When I study for this module, I felt good.	2.83 (0.75)	3.18 (0.51)
	When I worked on a question during the e-lecture, I am more interested in the content.	3.03 (0.78)	
	The e-lecture and the activities (questions/drag-and-drop interaction) were fun.	3.33 (0.64)	
	I enjoyed learning new things.	3.31 (0.69)	
	When I worked on a question during the e-lecture, I feel more involved in learning.	3.41 (0.66)	
Cognitive engagement (CE)	I was engaged with the topic while going through the e-lectures.	3.19 (0.66)	3.17 (0.45)
	I put in a lot of effort when I study for this module.	3.39 (0.66)	
	Online learning has improved my learning significantly.	2.67 (0.78)	
	Online learning gives me more time to solve problems and learn at my own pace.	3.42 (0.64)	

[a] Based on a 4-point Likert scale (1 = not at all true; 4 = very true). [b] Collective responses for the items in each dimension of engagement.

4. Discussion and Conclusions

This study aimed to determine the applicability of the design features of asynchronous lectures, designed based on the CoI framework, in various contexts (RQ1); to discern students' engagement during the asynchronous lectures (RQ2); and to derive design features that can be shared with other educators looking to develop their asynchronous lectures (RQ3).

Phases 1 and 2 revealed that the prototype design features were well received by the students and were able to be applied in different contexts. A mixed-method design was employed to better understand the quantitative results. The high mean responses for teaching presence were supported by the features that the students liked. One of the features that was well received by students is the chunking of materials (TP: instructional management and direct instruction), which supports the development of metacognitive regulation through the planning of learning schedules (goal setting) [45]. Due to the asynchronous nature of the learning, face-to-face interaction is lacking. This is reflected both in the mean responses for social presence and in the students' feedback. The inclusion of a discussion platform helped mitigate the lack of opportunities for students to clarify their doubts and provided a space for social interaction between students and teachers.

Phase 3 further extends the study to understand students' engagement in asynchronous lectures. Through the three-dimensional model of student engagement, the mean responses for behavioral engagement were the highest. Behavioral engagement relates to students' motivation in learning, such as completing learning tasks readily. Hence, with higher engagement, students' motivation is enhanced, leading to better learning [29]. The features that engaged students were also the features that earned positive perceptions.

One of the limitations of this study is the use of a cross-sectional approach where there is only one point of data collection. The data could be narrow, and has limitations if it were to be generalised. To minimize this limitation, the asynchronous lectures are designed based on the validated CoI framework, hence, data obtained from the cross-sectional approach would be valid. Additionally, the study expanded its scope to include multiple contexts, which increases the generalisability of the results. Another limitation is that the study is confined within one institution and in one country. Future research could explore the possibility of expanding the study to other institutions and other countries with different cultural backgrounds and student profiles.

Through this study, design features (Figure 3) based on the CoI framework and the three-dimensional model of student engagement were derived (Table 6). These features help educators create asynchronous lectures that provide students with meaningful and engaging learning experiences. Educators are strongly recommended to incorporate all three CoI presences, based on design features stated in Table 6, to ensure interaction (student–student, student–teacher, student–content) [44], which engages students and decreases transactional distance in asynchronous learning [28].

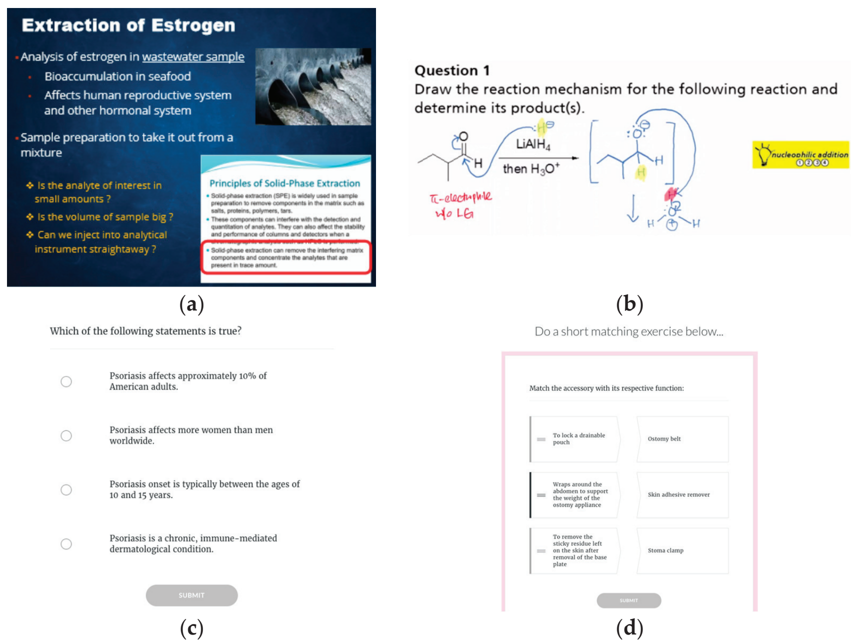

Figure 3. Examples of components in an asynchronous lecture: (**a**) triggering event to situate learning and create interest in the topic; (**b**) video of a worked example; (**c**) self-assessments at the end of each asynchronous lecture; (**d**) interactive activity (matching).

Table 6. CoI presences, categories, and design features.

CoI Presence	CoI Categories	Design Features
Teaching presence (TP)	Instructional management	Educators arrange the asynchronous lecture content, incorporating a collapsible menu to propose the learning sequence and enable students to monitor their progress in learning (program control). More adept students have the option to learn according to their preferred sequence (learner control).
	Building understanding	Educators oversee and support the discussion platform, employing interactive activities such as drag-and-drop exercises to actively involve less participative students.
	Direct instruction	Educators produce video recordings, segmenting them into concise intervals of 15–20 min per video. These recordings feature voiceover explanations of concepts, supplemented with annotations as needed.

Table 6. *Cont.*

CoI Presence	CoI Categories	Design Features
Social presence (SP)	Emotional expression	While this category may not be explicitly featured in the asynchronous lectures, it has the potential to be incorporated into the discussion platform.
	Open communication	Educators need to establish a secure learning environment, particularly within the discussion platform. All students and teachers should follow general rules and maintain positive online etiquette, characterized by mutual respect and encouraging tones.
	Group cohesion	The discussion platform, such as Padlet, is integrated to facilitate interactions between students, and between students and teachers.
Cognitive presence (CP)	Triggering event	At the commencement of the asynchronous lecture, a trigger, such as a brief video or image related to the topic, is incorporated. This trigger serves to captivate students' attention, pique interest, and evoke a sense of curiosity about the subject, encouraging them to delve deeper into the topic.
	Exploration	Supplementary resources sourced from the internet are integrated to offer students alternatives for gaining a better understanding and seeking clarification. This inclusion also enables them to broaden their knowledge of the topic.
	Integration	After each video, straightforward interactive activities like drag-and-drop, matching, and multiple-choice questions are provided to assist students in consolidating their learning. These activities aim to help students integrate information and knowledge into a cohesive understanding of the concept.
	Resolution	At the conclusion of each sub-topic, questions are posed to enable students to apply the concepts they have learned. Students are encouraged to independently attempt these questions before referring to video presentations featuring worked solutions accompanied by voiceover explanations.

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