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Affecting Young Children's Knowledge, Attitudes, and Behaviors for Ultraviolet Radiation Protection through the Internet of Things: A Quasi-Experimental Study

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Abstract: Prolonged exposure to ultraviolet (UV) radiation is linked to skin cancer. Children are more vulnerable to UV harmful effects compared to adults. Children's active involvement in using Internet of Things (IoT) devices to collect and analyze real-time UV radiation data is suggested to increase their awareness of UV protection. This quasi-experimental pre-test post-test control group study implemented light sensors in a STEM inquiry-based learning environment focusing on UV radiation and protection in primary education. This exploratory, small-scale study investigated the effect of a STEM environment implementing IoT devices on 6th graders' knowledge, attitudes, and behaviors about UV radiation and protection. Participants were 31 primary school students. Experimental group participants (n = 15) attended four eighty-minute inquiry-based lessons on UV radiation and protection and used sensors to measure and analyze UV radiation in their school. Data sources included questionnaires on UV knowledge, attitudes, and behaviors administered pre- and post-intervention. Statistically significant learning gains were found only for the experimental group ($t_{14} = -3.64$, $p = 0.003$). A statistically significant positive behavioral change was reported for experimental group participants six weeks post-intervention. The study adds empirical evidence suggesting the value of real-time data-driven approaches implementing IoT devices to positively influence students' knowledge and behaviors related to socio-scientific problems affecting their health.

Keywords: Internet of Things (IoT); ultraviolet (UV) radiation protection; primary education; STEM intervention; inquiry learning

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1. Introduction

Overexposure to solar ultraviolet (UV) radiation is a risk for public health [1]. Excessive and prolonged exposure to UV radiation can lead to adverse effects, including some eye diseases, diseases associated with vitamin D insufficiency [2], premature aging, sunburn, and skin cancers [3]. As the incidence of skin cancer is increasing rapidly, it has become one of the greatest threats to public health and has created a substantial economic burden for skin cancer treatment, particularly in countries such as New Zealand, Australia, the USA, UK, and Germany [3,4], as well as in Europe [5]. Children are considered a high-risk population group [6] and are more vulnerable to the sun's harmful effects compared to adults, as their skin is thinner and more sensitive, and even a short time outdoors in the midday sun can result in serious burns [6,7]. Skin cancer is steadily increasing in prevalence, faster than any other cancer, disproportionately affecting a growing youth population [8]. Melanoma cases, perhaps the most aggressive type of cancer, are increasing, and so are other skin cancer types at increasingly younger ages [6,8,9].

The most proactive and effective way of preventing skin cancer is through education, increasing awareness of the dangers of UV radiation exposure, and promoting sun protection practices [3,6]. Researchers agree that the dangers of skin cancer can be ameliorated through prevention efforts, especially those targeted at children [10]. From a young age, children need to be educated about the sun's harmful effects on the skin and how best to protect themselves [7,11].

1.1. Related Work on Measuring Young Children's Sun-Related Attitudes and Knowledge

Most of the studies that focused on measuring young children's sun-related attitudes and knowledge followed a survey design that was based on a one-time administration of a questionnaire to a large sample of students, sometimes following a non-technologically supported intervention [7,10,12,13]. For example, using a structured questionnaire, in Aquilina et al.'s study, 965 Maltese secondary school students were surveyed concerning their sun-related attitudes and knowledge. The study demonstrated a high level of sun awareness among Maltese secondary school students [7]. In the study by Aquilina et al. (2004), despite the high knowledge scores and relatively positive attitudes, the rate of deliberate suntanning was still high, especially for girls. Their study showed that although necessary, knowledge is not enough for a change in attitude and even less so for a sustained behavior change. In the study by Wright et al., a randomly selected sample of 488 children from 27 primary schools in New Zealand was surveyed regarding their sun-related knowledge, attitudes, and behaviors. Wright et al. (2008) found that although knowledge increased with school year level, there was a decline in sun-protective attitudes and behaviors [13]. Saridi et al. (2012) [6] recorded habits and attitudes of 2163 primary school students in Greece regarding sun-protection measures and pointed out the necessity of health education programs for students and parents/teachers alike to raise awareness about everyday sun protection.

1.2. Related Work on Sun-Safe Prevention Interventions in Primary Education

Although skin cancer is an easily preventable disease, self-directed prevention behaviors in children are difficult to achieve [10]. Behaviorally-based intervention strategies are needed to facilitate the transition from knowledge to a change in attitude and then to a change in behavior [7]. As most children spend most of the peak hours for ultraviolet radiation at school, school instruction on sun-safe behaviors and attitudes is a popular primary prevention method. Environmental interventions (including providing places with shade and free sunscreen) were found to have a promising role in skin cancer prevention interventions among children and adolescents [5]. Some studies that used behavioral interventions in primary and secondary schools also had positive results [10,12,14], reporting significant improvements for knowledge and attitudes [14] and knowledge, attitudes, and behaviors [12]. Hart and DeMarco (2008) [10] found that primary prevention interventions have seen the most success in elementary schools rather than secondary schools, particularly when interventions used multiunit extended instruction over time, to augment students' knowledge of sun-safe behaviors and attitudes toward skin protection and to encourage students to practice more sun-protective behaviors [10].

1.3. State-of-the-Art Analysis on Using Internet of Things to Measure Ultraviolet Radiation

Previous prevention behavioral interventions [5,10,12,14] were not technologically supported. Contemporary homes are filled with digital technologies, and children are exposed to them almost since birth, initiating their first digital experiences at very early ages. In a world where computers, the Internet, and mobile devices such as smartphones and tablets are widely used for e-health [15], this trend is expected to become stronger. Our future has been envisioned around the concept of the IoT (Internet of Things) [16], a global computing infrastructure of trillions of connected devices that permeate the world we live in [17]. The IoT refers to a connection between sensors and actuators implanted into physical objects [18,19]. Ubiquitous computing and the Internet of things (IoT) are turning into everyday household technology at an ever-increasing pace, for example, in the form of connected toys [20] and in the form of sensors that can be used for data collection, processing and visualization [21]. By embedding sensors, an IoT network can collect rich sensor data that reflect real-time environment conditions [21], such as UV radiation levels in a specific environment.

An extensive number of studies were conducted to measure personal solar UV exposure in various settings [2], but these studies were not applied in education. Some recent studies focused on how UV radiation can be quantified and measured in real-time through the IoT [22] for measuring and controlling environmental pollution [23] and for positively affecting public health [1]. To facilitate the monitoring of solar UV intensity and cumulative dose, various UV sensors were developed in the past few decades, and many are commercially available [3], but they were not used for educational purposes.

1.4. The Necessity of This Study

IoT in education is a new conceptual paradigm that is still in its starting phase with a potential benefit and impact in the learning process that has not yet been realized [24–26]. Although there were several contributions on the inclusion of IoT into the education domain [27,28], there is still a lack of consolidated and coherent view on this topic [21], and there are several socio-technological challenges associated with it [29]. There is also a minimal number of educational applications that take advantage of IoT's potential in the learning process and are appropriate for lower grades of formal education, as the majority of applications targets higher education [27,30,31] or secondary education [32]. Despite opportunities for data collection, processing and visualization made possible with IoT devices for STEM activities [21,27,30], very few studies have focused on how the potential of IoT can be realized in primary education [27]. For example, only 11% (10 papers) of studies that employed IoT in education and were included in the literature review of [21] targeted elementary school students. Sensors and IoT data collection technologies allow students to be engaged in actual research in the way scientists are, and this helps students build an understanding of science concepts [29]. However, no studies were identified that used the IoT to influence young children's UV protection knowledge, attitudes and behaviors.

The study responds to the pressing need for increasing children's awareness of the dangers of UV radiation exposure by implementing a data-driven approach and IoT to influence primary school children's sun-related knowledge, attitudes, and behaviors; thus addressing a research gap identified in the literature. The study describes an inquiry-based activity sequence in which students had active involvement using IoT devices to analyze real-time UV radiation data collected through light sensors. This was expected to engage learners in an inquiry on their surroundings in a data-rich physical and digital school environment. A quasi-experimental pre-test post-test control group research design was used to evaluate the effectiveness of the proposed approach in increasing students' UV radiation knowledge and in positively affecting their attitudes concerning the need for UV radiation protection, a socio-scientific issue affecting their health.

2. Materials and Methods

2.1. Research Questions

This study focused on designing a STEM inquiry learning environment about UV radiation and protection by implementing IoT devices. It was enacted in formal primary education to answer the following research questions:

RQ1: To what extent does a STEM environment implementing IoT devices affect 6th-grade students' knowledge regarding UV radiation and protection?

RQ2: To what extent does a STEM environment implementing IoT devices affect 6th-grade students' attitudes, behaviors, and behavioral change regarding UV radiation protection?

2.2. Implementation of IoT in Primary Education

An activity sequence incorporating IoT devices consisting of four eighty-minute ultraviolet radiation and protection courses was designed and developed based on inquiry-based learning (IBL) principles [33]. With respect to technical equipment, students used commercially available sensors to measure ultraviolet radiation in their schoolyard (Pasco Wireless Light sensors), which were wirelessly connected to tablets, allowing students to collect data in real-time and observe and process these data through the Sparkvue software. Digital PASPORT Sensors contain an analog-to-digital converter and are automatically recognized by PASCO software when connected through an interface. Most of these sensors contain multiple sensing elements within one casing, which enables them to collect different measurements using a single interface port. The Wireless Light Sensor is a coin cell battery-powered wireless sensor that connects to a computer or tablet device through Bluetooth. The sensor measures light through two apertures. The Spot Light Aperture measures red-green-blue (RGB), and white. The Ambient Light Aperture measures illuminance (measured in lux or lumens per square meter), Photosynthetically Active Radiation (PAR) in sunlight, and solar irradiance (in watts per square meter). The Ambient Light Aperture also measures UVA (ultra-violet A) and UVB (ultra-violet B) allowing ultra-violet index (UVI) to be calculated. PASCO Data Collection Software displays and analyzes the measurements from the sensor. The software also supports remote data logging for long-term experiments. Since each sensor has a unique Device ID number, more than one can be connected to a computer or tablet at the same time [34]. The proposed sensors can be integrated into the primary school curriculum circumventing some of the technical challenges described in the literature [29].

With respect to the activity sequence, during the first lesson, students studied multimodal sources focusing on the question “Why is the sun dangerous?”. Students worked individually due to social distancing protocols enforced during the COVID-19 pandemic and discussed their findings. They then experimented with UV beads focusing on the question “Can we make UV light visible?” and suggested making UV beads bracelets to measure the extent of UV radiation exposure in their schoolyard. Students used their UV bracelets outdoors and made observations regarding UV radiation.

In the second lesson, students addressed the following problem: “The headmaster needs to know during which hours are UV index levels high to take some precautionary measures for students. How can you help?” Students studied the UV index and realized that precise measurement of UV radiation levels using appropriate instruments is needed. Students worked in pairs, placed light sensors in the schoolyard and in the football field, and measured UV radiation levels in real-time during the lesson and for the next two weeks.

In the third lesson, students interpreted sensor-collected data regarding UV radiation levels at their school and suggested products they considered as sun-protective (e.g., sunglasses, hats, and sunscreen) and desirable actions while outdoors to ensure protection from UV radiation (e.g., playing in the shade).

In the fourth lesson, students used sensors to examine suggested sun-protective products to determine their level of protection. They worked outdoors in groups of four and later discussed their findings in class.

2.3. Data Sources

Data sources were the following: (1) a test for assessing students’ knowledge regarding UV radiation and protection [7,35], (2) the Greek translation of the questionnaire measuring attitudes [7] and behaviors [36] concerning UV radiation and protection, and (3) the Greek translation of the RASP-B questionnaire for categorizing participants in the stages of the transtheoretical model of behavioral change concerning UV radiation and protection [36].

The test assessing students’ knowledge of UV radiation and protection consisted of 20 closed-ended (right or wrong) statements consistent with course objectives and validated in other studies assessing learning gains regarding UV radiation and protection [7,35]. The closed-ended questions were grouped into three categories: (a) questions referring to the risk of excessive sun exposure (questions 1–5), (b) questions relating to ultraviolet radiation (questions 6–12), and (c) questions concerning ways of protection against excessive sun exposure (questions 13–20). The researchers added the open-ended question “What do you know about UV radiation?" to eliminate the possibility of randomly selected answers to the closed-ended questions (Appendix A). The test's content validity was evaluated by an expert in Science Education and pilot-tested with a small number of students.

A modified version of the Aquilina et al. (2004) [7] questionnaire was used to investigate students' attitudes towards UV radiation and protection. The modification refers to changing the dichotomous "Yes/No" scale to a 5-point Likert scale indicating frequency of behavior or level of agreement for greater interpretation capacity. A modified version of the Borschmann and Cottrell (2009) [36] questionnaire was used to investigate students' behaviors towards UV radiation and protection. The original questionnaire included 14 statements, of which five were eliminated due to their inconsistency with course objectives. Participants were asked to choose an option from a 5-point Likert scale ranging from 1 (never) to 5 (always) (Appendix B).

The RASP-B questionnaire was used [36] to record any change in participants' stage of behavior towards UV protection. It included 12 statements, which allocate participants in the first three stages of the behavioral change model: a. Pre-contemplation (questions 1, 5, 10, and 12), b. Contemplation (questions 3, 4, 8 and 9) and c. Action (questions 2, 6, 7 and 11). Participants were asked to choose one option on a 5-point Likert scale ranging from 1 (I completely disagree) to 5 (I completely agree) (Appendix C). The RASP-B questionnaire appears to have satisfactory psychometric properties, with the Cronbach's alpha ranging from 0.67 to 0.76. Both questionnaires were translated into Greek and then back-translated for accuracy.

2.4. Research Design

The study followed a quasi-experimental pre-test–post-test control group design. Delayed post-tests were also administered to experimental group students six weeks after the intervention for examining knowledge, attitudes, behaviors, and stage of behavior preservation. Primary school-age children are generally more responsive to efforts to increase sun-safe behaviors and improve attitudes toward skin cancer prevention than are adolescents [10]. Therefore, the study focused on upper primary school students. A primary school was chosen through convenience sampling. There were two sixth-grade classes in the school selected for the study. One class (to which the first author had access) was purposively selected as the experimental group; hence the other served as a control group.

2.5. Participants

Fifteen 6th-grade primary school students (eight boys and seven girls) were included in the experimental group and participated in four eighty-minute courses on UV radiation and protection during March and April 2021. Sixteen 6th-grade primary school students (nine boys and seven girls) constituted the control group and did not receive any instruction regarding UV radiation and protection.

2.6. Research Ethics

All participating students and their parents were informed in writing about the study's objectives and gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki and it adhered to the ethical standards of the American Psychological Association and General Data Protection Regulation guidelines. The study protocol was approved by the Ethics Committee of the Center of Educational Research and Evaluation of the country in reference (approval code 7.15.01.25.8.1/10) on 4 August 2020. All participants, and their parents' written consent was ensured.

2.7. Data Analysis

Descriptive statistics (mean, SD) and inferential statistical tests (paired samples and independent samples *t*-tests) were used for data analysis in SPSS 26 for answering both research questions. To verify the integrity of the outcomes, a comparative analysis using R, a programming language and environment for statistical computing and graphics, was performed for statistically significant results. Closed-ended questions of the knowledge test for RQ1 were scored dichotomously by allocating 1 point for any correct answer and 0 points for any wrong answer [37]. Phenomenography was applied to score the open-ended question [38] based on the emerging coding scheme shown in Table 1.

Table 1. Coding scheme for the open-ended question "What do you know about UV radiation?

Points	Rationale	Example
0	No answer Wrong answer Uses the question to answer	*"I don't know" (Student 9)* *"I do not know exactly, but I think it is the light from the sun" (Student 15)* *"I know it's a type of radiation (Student 7)"*
1	Refers to the sun as the source of the UV radiation Refers to some characteristics showing the severity of UV radiation, its effects on human health and the necessity to adopt protective behaviors.	*"I know it's harmful to the human body"* *"[. . .] we mustn't spend too much time in the sun, because we will get sunburned. If we want to stay (in the sun) we must take precautions" (Student 8)*
2	Refers to specific characteristics of UV radiation such as name, source, types Refers to severity as one of its characteristics and gives an example Refers to effects on human health and gives examples of precautionary measures	*"It has three types UVA, UVB and UVC. UVC can't pass through the ozone layer. The other two can, and in specific hours and seasons they can be very dangerous for humans" (Student 12)* *"Ultraviolet radiation (UV) is divided in UVA, UVB and UVC and it's dangerous when in high level. We need to be protected with proper precautionary measures so that it won't harm our skin." (Student 13)* *"UV radiation comes from the sun and can cause severe damage to eyes and skin." (Student 14)*

A second researcher coded all students' answers. Inter-rated reliability among the two coders was calculated at 81.81%, with four disagreements resolved among the two researchers.

For RQ2 referring to attitudes, the options *never/completely disagree* and *rarely/disagree* were considered as desired attitudes (for example: the response "completely disagree" in a statement such as the following: "I think getting sunburned occasionally does not do any harm" is considered a desired attitude). Desired attitudes were evaluated with one point; otherwise, they were evaluated with zero points. For investigating participants' behaviors, options *sometimes*, *usually*, and *always* were evaluated with one point since they were classified as desirable behaviors. For example: the response "usually" in a statement such as the following: "How often do you wear a hat when outside in the sun" is considered a desired behavior. In any different case, behaviors were evaluated with zero points. The total score of students' attitudes and behaviors was computed, respectively. An α level of 0.05 was set a priori for all statistical analyses.

Regarding participants' classification of the stages of behavioral change, the model suggested by [36] was used. First, the options were scored as follows: −2 points (completely disagree), −1 point (disagree), 0 points (no opinion), +1 point (agree), +2 points (completely agree). Each stage had four corresponding statements. The total grade of each participant for each stage of behavior was calculated. The total score ranged from −8 points to +8 points, and the participant was classified to the stage with the highest score.

3. Results

3.1. Research Question 1

All 31 students were pre-tested regarding their knowledge regarding UV radiation and protection prior to the intervention to ensure group equivalence (Table 2). There were no significant differences concerning the initial scores achieved by the experimental group (Mean = 14.67; SD = 2.12) compared with the scores achieved by the control group

(Mean = 12.06; SD = 3.06), when an independent samples *t*-test was performed (t_{29} = 2.7, p = 0.253).

Table 2. Students' knowledge of UV radiation and protection before and after the intervention for the experimental and control group.

	n	Pre		Post		Delayed	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Experimental group	15	14.67	2.12	17.73 **	2.63	18.00 **	2.12
Control group	16	12.06	3.06	11.56	3.98		

** Significant result with $p < 0.01$.

After ensuring group equivalence, experimental students' pre and post-intervention scores were compared by performing a paired samples *t*-test. Experimental group participants showed statistically significant learning gains, in contrast with control group participants who did not (Table 2). The post-intervention experimental group students' performance significantly increased from 14.67 (SD 2.12) to 17.73 (SD 2.63) ($t_{14} = -3.64$, p = 0.003). This result was confirmed using R. Control group students' test performance decreased slightly but not significantly from pre- to post-intervention (Table 2).

For investigating knowledge preservation, a test was administered six weeks after the intervention in the experimental group. As shown in Table 2, learning gains significantly increased from 14.67 (SD 2.12) pre-intervention to 18.00 (SD 2.12) ($t_{14} = -4.152$, p = 0.001) six weeks after the intervention. This result was confirmed using R.

3.2. Research Question 2

All 31 students' attitudes regarding UV radiation and protection were measured prior to the intervention. An independent samples *t*-test was performed to establish group equivalence. Both experimental (Mean 3.71; SD 0.52) and control group participants (Mean 3.52; SD 0.69) held similar attitudes concerning UV radiation and protection, which were considerably high for both groups. No significant differences were noted (t_{29} = 0.844; p = 0.406), therefore groups were considered equivalent regarding their attitudes towards UV radiation and protection prior to the intervention (Table 3).

Table 3. Attitudes on UV protection pre- and post-intervention for the experimental and control group.

	n	Pre		Post	
		Mean	**SD**	**Mean**	**SD**
Experimental group	15	3.71	0.52	3.77	0.65
Control group	16	3.52	0.69	3.70	0.54

For comparing students' pre- and post-intervention attitudes for both experimental and control group participants, a paired samples *t*-test was performed. Experimental group participants' attitudes regarding UV radiation and protection were slightly but not significantly increased from 3.71 (SD 0.52) to 3.77 (SD 0.65). A similar pattern was revealed for control group participants, whose attitudes had a slight but non-significant increase from 3.52 (SD 0.69) to 3.70 (SD 0.54). As experimental group students' attitudes were considerably high from the beginning (approximating 4 out of 5), they were not measured again in the delayed post-test.

All 31 students' behaviors regarding UV protection were investigated prior to the intervention for group equivalence to be established. An independent samples *t*-test was performed. Experimental (Mean 3.15; SD 0.70) and control group participants (Mean 3.00; SD 0.58) reported similar behaviors concerning UV protection. No significant differences were noted (t_{29} = 0.656; p = 0.427), therefore the two groups were considered equivalent regarding their behaviors towards UV protection prior to the intervention (Table 4).

Table 4. Students' behaviors on UV protection in the experimental and control group before and after intervention.

	n	Pre		Post		Delayed	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Experimental group	15	3.15	0.70	3.25	0.71	3.52 *	0.71
Control group	16	3.00	0.58	2.88	0.87		

* Significant result with $p < 0.05$.

Experimental group participants' behavior regarding UV protection was positively differentiated from pre- to post-intervention. Pre-intervention behaviors held by experimental group participants were considered neutral at first (Mean 3.15; SD 0.70), moved to more desired ones immediately after the intervention (Mean 3.25; SD 0.71), and continued to be significantly and positively differentiated (Mean 3.52; SD 0.71) six weeks after the intervention ($t_{14} = -2.46$; $p = 0.027$), a finding confirmed using R. On the contrary, behaviors adopted from control group participants were negatively differentiated from 3.00 (SD 0.58) to 2.88 (0.87).

As far as UV protection behavioral change is concerned, an improvement regarding the desired behavior was recorded for experimental group participants. The latter moved from hierarchically lower levels of behavior concerning UV protection to higher ones immediately after the intervention, based on the Transtheoretical Model of Behavioral Change (TMBC) (Table 5). Table 5 shows an increase in students categorized in the higher level of behavior measured, the action stage, from one student post-intervention to four students in the delayed post-test, a finding that is not observed in the control group, where we see a decrease in students categorized in the action stage from pre to post.

Table 5. Classification of participants' behaviors in the experimental and control group based on Transtheoretical Model of Behavioral Change (TMBC).

Stages of Behavior	**Frequencies of Desired Behaviors**				
	Pre	**Post**	**Delayed**	**Pre**	**Post**
	Experimental Group			**Control Group**	
Pre-contemplation stage	3	1	4	13	8
Contemplation stage	10	11	7	0	6
Action stage	1	2	4	3	2

Specifically, experimental group participants positively differentiated their post-intervention behavior pattern concerning UV protection for the statements "How often do you wear clothes that cover most of your body to avoid the sun?" (from 4 to 10 participants), "How often do you wear a hat when exposed to the sun?" (from 9 to 12) and "How often do you sit in the shade when you are in the beach?" (from 12 to 14). Six weeks after, participants' behavior regarding UV protection remained positive. Specifically, a positive differentiation was presented in six out of seven statements of sun-protective behaviors referring to "How often will you go sunbathing between 11:00 to 4:00?" (from 5 to 7), "How often do you wear a hat when exposed to the sun?" (from 12 to 13), "How often do you sit in the shade when you are in the beach?" (from 12 to 13), "How often do you wear sunglasses?" (from 10 to 14), "How often do you wear sunscreen?" (from 14 to 15), "How often do you stay in the shade to avoid the sun?" (from 10 to 13). Despite the improvement noted in behaviors adopted from experimental group participants, six weeks after the intervention, some participants regressed to lower stages of behavioral change (Table 5).

As for the control group, their post behaviors differentiated, with the number of participants in the contemplation stage rising from zero to six and the number of participants in the pre-contemplation stage declining from thirteen to eight. Positive changes observed in control group participants' self-reported attitudes and desired behavioral stages can potentially be attributed to the diffusion of treatment intervention [39]. The latter was inevitable in this study as students of the two groups shared the school spaces where the UV sensors were placed. They can also be attributed to control group participants' increased motivation for positive self-presentation [40] and an effort to present themselves in the most positive manner possible to outperform experimental group participants.

4. Discussion

The present study aimed to investigate the extent to which a STEM inquiry-based learning environment implementing IoT devices can affect sixth-grade students' knowledge, attitudes, and behaviors about UV radiation and protection. Regarding RQ1, findings demonstrated that experimental group students' learning gains were improved significantly by the end of the intervention, consistent with previous work reporting that non-technologically supported interventions regarding UV radiation and protection contributed to knowledge acquisition [7,13,14,35,41]. Contrary to previous studies that did not measure learning gains using delayed post-tests, our study showed that students' learning gains were preserved six weeks post-intervention. This may indicate that interventions incorporating IoT devices that students can use to collect data and solve socio-scientific problems that affect them personally are more likely to result in long-term learning effects.

Concerning RQ2, both experimental and control group students' attitudes towards UV radiation and protection remained positive from pre- to post-intervention with a slight but non-significant improvement by the end of the intervention. Moreover, experimental students' behaviors regarding UV protection were positive pre- and post-intervention and significantly improved six weeks after the intervention took place while control group students' behaviors deteriorated. Studies have shown that young children's attitudes on complex socio-scientific issues are difficult to change [42]. Studies have also shown the limitations of short-duration efforts. Although they can improve children's knowledge and, in some cases, improve attitudes and sun-protection behavior immediately after the program, their influence is likely to be short-lived [7]. Contrary to previous research findings, in our study, a delayed post-test showed that the effect of the intervention had been retained over time, at least with respect to self-reported behavioral change and intended practices for the upcoming summer.

The differentiating factor in the behavioral intervention described in our study as compared with the ones described in the literature thus far [10,12,14] was the integration of IoT devices in the curriculum to positively affect children's UV protection knowledge, attitudes and behaviors, through a real-time data-driven inquiry learning approach. The effectiveness of the described STEM intervention may potentially be attributed to several design characteristics. One of them is the authentic problem students were asked to solve that made them realize the need for real-time and accurate measurement of UV radiation levels through sensors. Another design characteristic refers to providing the ability to visualize, analyze and interpret meaningful data that students collected themselves using IoT devices to make informed decisions as to the extent to which specific products provide UV radiation protection. The use of IoT for real-time UV radiation data collection and analysis contributed to improving students' knowledge on UV radiation protection, in enhancing meaningful, active learning in an authentic environment that afforded experimentation to find solutions to real-life problems, as indicated by [27] and in positively influencing children's UV protection behaviors.

IoT is set to transform the education domain in many ways in the near future [21]. This exploratory study resulted in an empirically validated IoT intervention to increase young children's UV protection knowledge and positively affect desired attitudes and behaviors. The study contributed to the lack of published studies involving the effective integration of IoT in primary education STEM topics, which was introduced at a pilot stage in the country where the study took place in 2019. It increased our understanding of how innovative technologies combined with a data-driven approach can positively influence students' knowledge, attitudes, and behaviors related to socio-scientific problems affecting their health.

4.1. Limitations

Convenience sampling was used rather than random sampling, which would have been preferred to increase the generalizability of the study's findings. In addition, the first author held a dual role as the intervention designer/teacher and researcher. The study was exploratory, used a small sample, and was based solely on quantitative data. Due to the small sample of the study, the use of advanced Artificial Intelligence/Machine Learning techniques in order to provide more reliable results was not feasible. The use of a larger sample and the addition of qualitative data in the form of in-depth student interviews or observations conducted by parents or teachers concerning children's attitudes and behaviors regarding UV protection would strengthen the study.

The fact that a quasi-experimental design was used, in which the control group did not participate in an innovative intervention and did not receive any instruction, threatened the study's internal validity; a limitation commonly reported in quasi-experiments in the social sciences [43–45]. As previously mentioned, the data collected by control group participants might have been affected by factors such as "secondary" treatment infusion [39] and positive self-presentation [40]. Moreover, without objective measures of children's practice, we had to rely on their self-reports, which are susceptible to memory errors and social desirability tendencies, a problem also reported by [14].

4.2. Future Work

A number of devices and innovative methodologies have recently been promoted, advocating the benefits of monitoring personal exposure patterns to solar radiation. These innovations are beneficial to the community and researchers as tools for monitoring sun exposure behavior [2]. For example, Wu et al. (2019) [1] developed an IoT application in which when high UV is detected, it will notify users by pushing notifications to their mobile phone so that the users will take some appropriate actions [1]. Using objective measures such as wearables to monitor actual exposure has potential in future studies that will aim to measure the effect of behavioral interventions more accurately and systematically [5,46].

Our future work will first identify reliable and practical UV sensors for personal UV exposure monitoring [3] that are appropriate for use by school children, such as UV monitor bracelets as wearable devices [47]. It will then use wearable devices measuring UV radiation to triangulate children's self-reported data and measure the effect of IoT-based behavioral interventions on children's attitudes and behaviors more accurately and over time in future longitudinal studies with larger sample sizes. Future work will also empower students by involving them in a co-design process of IoT devices for inquiry learning, as Kusmin (2019) [27] suggested.

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Informed Consent Statement: All participating students and their parents were informed in writing about the study's objectives and gave their informed consent for inclusion before they participated in the study. All participants, and their parents' written consent was ensured.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy reasons.

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Appendix A. Test Assessing Students' Knowledge on UV Radiation and Protection

1. What do you know about UV radiation?

2. Read the statements carefully and circle the correct answer.

	A1. Knowledge of the risk of excessive sun exposure		
1.	Too much sun can harm people.	TRUE	FALSE
2.	Too much sun exposure can cause freckles.	TRUE	FALSE
3.	Too much sun exposure can cause wrinkles on the skin when you grow older.	TRUE	FALSE
4.	The sun is bad for your skin only when you get sunburnt.	TRUE	FALSE
5.	A suntan is a sign of being healthy.	TRUE	FALSE
	A2. Knowledge of UV radiation		
6.	UV rays are sun rays.	TRUE	FALSE
7.	UV rays are always dangerous for people.	TRUE	FALSE
8.	Ultraviolet radiation can harm your skin and eyes, only if you spend too much time in the sun.	TRUE	FALSE
9.	UV level is high all day long.	TRUE	FALSE
10.	UV rays helps in synthesizing vitamin D.	TRUE	FALSE
11.	UV index uses colors to show how danger UV rays are.	TRUE	FALSE
12.	UV rays can cause suntan and sunburn to the skin.	TRUE	FALSE
	A3. Knowledge of protection against excessive sun exposure		
13.	The sun is strongest and more harmful between 11 a.m. and 4:00 p.m.	TRUE	FALSE
14.	The ozone layer protects the earth from too much ultraviolet radiation.	TRUE	FALSE
15.	You cannot get too much sun, on a cloudy day.	TRUE	FALSE
16.	You do not need to protect your skin with sunscreen when under a beach umbrella.	TRUE	FALSE
17.	If you apply sunscreen, there is no need to wear a hat and shirt when in the sun.	TRUE	FALSE
18.	One application of sunscreen protects your skin for at least 4 h.	TRUE	FALSE
19.	The sun can harm your eyes, and you should wear sunglasses when out in the sun.	TRUE	FALSE
20.	Sunscreen with Sun Protection Factor less than 15 is not enough to protect you.	TRUE	FALSE

Appendix B. Questionnaire Assessing Students' Attitudes and Behaviors towards UV Radiation and Protection

PART A: In this part, statements concerning people's attitudes towards UV protection are included.					
Instructions: In the next table, circle the number that represents you the most for each one of the following statements. For your answers use the scale 1 to 5. **1 = Never 2 = Rarely 3 = Sometimes 4 = Usually 5 = Always**					
A1. Attitudes towards UV protection					
1. I am shy to apply sunscreen in front of my friends.	1	2	3	4	5
2. Wearing a shirt at the beach does not look cool.	1	2	3	4	5
3. Covering up in the sun is a hassle.	1	2	3	4	5
4. I worry that the sun may give me freckles.	1	2	3	4	5
1 = Completely disagree 2 = Disagree 3 = Neither agree nor disagree 4 = Agree 5 = Completely agree					
A2. Attitudes towards UV protection					
1. My parents do not protect themselves from the sun, so I do not feel that I need to be careful myself.	1	2	3	4	5
2. I think getting sunburnt occasionally does not do any harm.	1	2	3	4	5
3. I do not feel that I should protect myself from the sun because skin cancer can never happen to me.	1	2	3	4	5
PART B: In this part, questions and statements regarding sun-protective actions are included.					
Instructions: In the following table, circle the number showing how often each of the following statements represents you. For your answers, use the following scale of 1 to 5. **1 = Never 2 = Rarely 3 = Sometimes 4 = Usually 5 = Always**					
B1. Behavior/Perceived severity					
1. In the past, how often did you go sunbathing at the beach between 11:00 a.m. and 4:00 p.m.?	1	2	3	4	5
2. How often do you wear clothes that cover most of your body (hands and legs included) to avoid the sun?	1	2	3	4	5
3. How often do you wear a hat when outside in the sun?	1	2	3	4	5
4. How often do you sit in the shade at the beach?	1	2	3	4	5
5. How often do you wear sunglasses?	1	2	3	4	5
6. How often do you use sunscreen?	1	2	3	4	5
7. How often do you stay in the shade to avoid the sun?	1	2	3	4	5
Instructions: In the following table, circle Yes or No.					
B2. Behavior					
1. Last summer, did you get reddish skin or a sunburn on your face or body?	YES			NO	
2. Think of a summer day. How many hours do you spend exposed to the sun? Put a tick in a box.					
a. 0 h	d. three to four hours				
b. less than an hour	e. more than five hours				
c. one to two hours					

Appendix C. RASP-B Questionnaire Assessing Students' Stage of Behavior towards UV Radiation Protection

RASP-B Questionnaire					
Statements referring to sun exposure and their peoples' beliefs about it are included in this questionnaire. Read the instructions carefully and answer all the following statements.					
Instructions: In the following table, circle the number representing your level of agreement for each of the following statements. For your answers, use the following scale of 1 to 5.					
1 = Completely disagree 2 = Disagree 3 = Neither agree nor disagree 4 = Agree 5 = Completely agree					
1. I do not think I spend too much time exposed to the sun.	1	2	3	4	5
2. I am trying to spend less time in the sun than I used to.	1	2	3	4	5
3. I enjoy spending time in the sun, but sometimes I spend too much time in the sun.	1	2	3	4	5
4. Sometimes I think I should spend less time in the sun.	1	2	3	4	5
5. It's a waste of time thinking about how much time I spend in the sun.	1	2	3	4	5
6. I have just recently changed my sun exposure habits.	1	2	3	4	5
7. Anyone can talk about wanting to do something reducing their sun exposure, but I am actually doing something about it.	1	2	3	4	5
8. I am at a stage where I should think about spending less time in the sun.	1	2	3	4	5
9. The amount of time I spend in the sun is a problem sometimes.	1	2	3	4	5
10. There is no need for me to think about changing my sun exposure habits.	1	2	3	4	5
11. I am actually changing my sun exposure habits right now.	1	2	3	4	5
12. Spending less time in the sun would be pointless for me.	1	2	3	4	5

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