Microcontroller Systems in Education for Sustainable Development Service. A Qualitative Thematic Meta-Analysis

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Abstract — Goal of the present paper is to answer the research question: Can the proper use of Microcontroller Board Systems as educational tools help achieve the goals of Education for Sustainable Development? In order to answer the aforementioned question, a meta-analysis of the qualitative strategy of four recently published relevant papers was utilized. The technique of Thematic Analysis was used. The results show that the proper adaptation of Microcontroller Board Systems in the educational process can adequately help achieve the goals of the Education for Sustainable Development. In order to achieve these goals in the pedagogical framework, the Microcontroller System can be adapted in such a way as to serve the approaches of holistic & systemic thinking, HASS&STEM interdisciplinarity and multidisciplinary, constructivist approach to knowledge, cooperative learning, critical thinking, cultivation of values, and learning satisfaction of the Education for Sustainable Development.

Keywords — Education for Sustainable Development (ESD), meta-survey, Microcontroller board system, Qualitative thematic meta-analysis.

I. INTRODUCTION

A. Theoretical Framework

The present paper explores the possibility of utilizing systems based on Microcontrollers as educational tools in environmental education and, in general, in Education for Sustainable Development (ESD). The Microcontroller Board is a system that can serve as the basis for the composition of “intelligent” electromechanical mechanisms (electronic, electric, and mechanical components), that can be programmed, and, in general, controlled by the system. It

is an easy-to-use, and simple system that can be used also for educational purposes [1]. An important element is the system’s framing by web software (e.g., Tinkercad™), which can simulate an actual system’s application, from the stage of electromechanical composition, until the stage of programming and control, no matter if the application is indeed performed or not [2]. It is an open-source platform that is based on simple materials and software, it is an easy tool for quick standardization, that also address users without a background in electronics and programming, such as students of primary [3] and secondary education [1], [4]. The systems, with the help of relevant software, can read data from inputs such as sensors, keys, internet input, and transform them into output, such as engine activation, LED activation, internet publication, etc. [5]. The Microcontroller Board Systems were the “brain” of thousands of projects, from everyday objects to complex professional and educational robots (Microcontroller Board, n.d.) The applications of the Microcontroller seem to be sources of data of environmental interest, since they can include sensors for detecting gaseous pollutants, microparticles of the atmosphere, radiation, and climatic characteristics such as temperature, humidity, pressure, etc. [4]. These data sources can update computer systems, even smartphones [6]-[7]. Finally, the software interface by which they are controlled, can manage the data by outputting relevant information that can be utilized, or by controlling robotic mechanisms that can also be of use, by performing actions of environmental impact [5].

B. Goal & Research Question

In this way, the present research aims at exploring fields of utilizing Microcontroller Board Systems in ESD based on relevant research articles and applications of said systems. In particular, the goal of the present research is the answer to the following question:

Can the proper use of Microcontroller Board Systems as educational tools help achieve the goals of Education for Sustainable Development?

To answer this question, the following process is utilized: Firstly, recently published relevant papers are researched, which refer to the application of Microcontroller Board Systems in environmental education and, in general, in ESD. With particular emphasis in the results, discussion, and conclusions, the original texts of the papers are qualitatively analyzed based on the technique of Thematic Analysis (ThA). Attempts are made to identify conceptual patterns that refer to the educational process developed in each paper and are consistent with seven approaches that are considered

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necessary for the development of educational frameworks for ESD. The seven approaches are the ThA Categories. The patterns are classified in these categories, are examined qualitatively, and the answer to this research question is extracted.

C. Conceptual Definitions

1) Contextual Learning

It is based on a constructivist teaching and learning approach, by which people learn by building meaning through experiential methods, interpretation, and interaction with their environment [8] as cited in [5].

2) Computational Thinking

It is a field of techniques that approaches problem solving, the design of systems that help solve complex problems faced by people, and the understanding of human behavior based on fundamental concepts of information technology [9]-[10].

3) Discovery learning

It is a teaching method in which students act with the aim of discovering knowledge under the guidance of the teacher and is considered to develop students' research skills and contribute to their success more than traditional teaching processes and techniques [11].

4) Learning Satisfaction

Regarding the concept of Learning Satisfaction, [12] mention that students' learning satisfaction of their school learning plays an important role. [It is] ... an index to evaluate students' learning results and it is also one of the most important indicators of teaching quality. Knowledge, skills, attitude, capabilities and emotion are all involved in the delivery of education, and they are also basic factors affecting learning results.

D. Educational Framework of Education for Sustainable Development

Education for Sustainable Development (ESD)...empowers learners to make informed decisions and take responsible actions for environmental integrity, economic viability, and a just society, for present and future generations, while ensuring respect for cultural diversity [13] as cited in [14].

Achieving the goals of Education for Sustainable Development (ESD) can take place within a pedagogical framework that is required to be characterized by six educational or pedagogical approaches [15] as cited in [16]: These are holistic & systemic thinking, HASS&STEM interdisciplinarity & multidisciplinary, constructivist approach to knowledge, cooperative learning, critical thinking, cultivation of values.

1) Holistic & systemic thinking

The holistic character of ESD supports a holistic approach to learning, combines fields of knowledge and experience related to humanity, arts, social, spiritual, science, technology, engineering, mathematics and mobilizes the development of the individual also holistically (morally, cognitively, socially, emotionally, and in a psychomotor aspect) [17]-[18]. Also, this holistic character of ESD concerns the recognition, interaction, and interconnection of

all educational and pedagogical dimensions such as the curriculum and the projected values [17]-[18]. The systemic theory in the field of ESD, takes the form of a simplified methodological approach of environmental situations and is referred to as systemic approach [19]. The notion that the environment should be considered as a whole is also adopted by international conferences on environmental education in the 1970s. At the Tbilisi Conference, for example, it is emphasized that the environment is a systemic reality [20]. Systemic thinking is, at the same time, analytical and synthetic, it moves from the individual parts to the whole, from structure to process, it focuses on relationships, interactions, connections and the frame of reference, and can contribute to this direction [21].

2) HASS&STEM Interdisciplinarity & multidisciplinary

The interdisciplinary and multidisciplinary models are the two main ways of integrating ESD in school. In the context of the interdisciplinary model, ESD is fed with concepts and approaches from the individual school subjects (courses), while in the context of the multidisciplinary model, the elements of ESD are sought to be integrated in the existing courses and to permeate the curricula [22]-[23]. The widespread interdisciplinary and systemic nature of environmental issues requires new forms of approach to shaping the content and structure of the ESD curriculum. Thus, we inevitably move to the concept of cross-thematic educational approach [24], which is a transfer of interdisciplinarity in school practice, in the direction of knowledge integration. However, the concept of interdisciplinarity is subject to various interpretations and is usually limited to a selection of activities from certain subjects accompanied by a relaxed teaching methodology. That is why the adoption by environmental education of the STEM methodology (Science, Technology, Engineering, Mathematics), which gives importance to teaching methods, contributes to the creative involvement of students in the search, discovery, and invention of solutions to problems. However, STEM's focus on certain subjects is very static and its disciplines should focus on a set of practices and processes, in order for special knowledge and learning to emerge. They need to be merged with concepts and values, which requires collaboration and interdisciplinary efforts with the Humanities, Arts and Social Sciences (HASS) disciplines. The benefit of switching from STEM objects to HASS objects is important because it allows ideas and problems to be approached from different perspectives [25]-[26]. In the Greek educational reality, the results from the implementation of an educational scenario of experimental interdisciplinary didactic management of educational objects of the STEM and HASS branches with the support of ICTs, prove that it is possible to design and implement didactic approaches that combine the interdisciplinary subjects of the two branches [27].

3) Constructivist approach to knowledge

Constructivism, one of the basic theories of learning, argues that the intellect is a function of constructing meanings based on the experience of the individual [28]. The construction of knowledge therefore takes place based on pre-existing experiences, mental constructs, beliefs, and "theories" that each person uses in order to interpret objects

or events [29]. Reference [30], by expressing the principles of constructivism, argues that learning takes place by correlating, integrating, and assimilating new concepts into existing propositional networks and the broader cognitive structures of the learner.

4) Cooperative learning

The fundamental elements that constitute collaborative learning are positive interdependence, interaction, individual and group responsibility, social skills, team self-assessment [31]. The value and necessity of cooperation at local, national and international level to address environmental problems is one of the guiding principles of ESD [32], [20]. Reference [15] as cited in [33], states that the solution of environmental problems can be achieved on the basis of cooperation between the actors in the educational process. She justifies it by stating that cooperation, promotion of the values of individual responsibility and co-responsibility are required, but also acceptance of the different way of thinking, since the problems of the environment are amenable to multidimensional solutions based on multidimensional views (p. 6).

5) Critical thinking

Critical thinking is a mental-emotional function that allows us to analyze, clarify, evaluate, and challenge our perceptions and beliefs, as well as to understand the views of others, in order to reach conclusions, findings, judgments and options for action [34]-[35]. It is, therefore, obvious, how necessary, and important is the application of critical thinking in the life of the individual, that is why it is necessary to cultivate it in school education as well. In this context, the development of critical thinking becomes a central feature of ESD since during the processing of issues related to the environment, critical questions must be analyzed and answered in conflicts of views and interests, and decisions and actions must be taken [21].

6) Cultivation of values

Values are guiding principles in a person's life. They can influence his attitudes, beliefs, behaviors, and rules, and can be considered as desirable goals for his life [36]. According to [37], the synthesis of ideas, opinions, and concepts, which constitutes the rational perception of the individual about the environment, is reflected in his environmental values. They themselves, as a decisive action aimed at solving environmental problems and achieving sustainable development, propose to create, and through formal and non-formal education, to cultivate proper environmental values.

II. METHODOLOGY

A. Method

A *Qualitative Strategy* is followed [38], based on the technique of *Thematic Analysis* (ThA) [39]. The research design is based on the collection of data from parts of the results, discussion, and conclusions of four sample papers, related to the topic.

The research process involves locating and selecting the sample papers. The ThA of the data follows, which is based on seven Sensitizing Concepts which constitute the

Categories of ThA. Relevant results and conclusions are drawn.

The selection of the sample papers was based on how recently the papers were published (all published in 2020) and their character as presentations of real educational applications of Microcontroller systems in environmental sustainability. Four such papers have been identified.

Seven Sensitizing Concepts have been identified, the first six of which are suggested by the relevant literature as requirements of the pedagogical frameworks aimed at achieving the goals of Education for Sustainable Development (ESD). An additional Sensitizing Concept emerged during the course of the research because strong references to its meaning were identified in the sample papers sample. The first six sensitizing concepts are as follows [40] as cited in [16]: (1) Holistic & systemic thinking, (2) HASS & STEM Interdisciplinarity & multidisciplinarity, (3) Constructivist approach to knowledge, (4) Cooperative learning, (5) Critical thinking, (6) Cultivation of values (p. 2). The seventh (7) Sensitizing Concept is Learning Satisfaction.

The research process seems to be characterized by Descriptive and Interpretive Validity since the accurate recording of data on the one hand, and the inclusion of the required information on the other, is by definition the goal and responsibility of the authors of the sample papers [41]. Theoretical Validity is attempted to be ensured by the full reliance on the research of the Sensitizing Concepts, which were produced by the existing theoretical concepts of literature, and Environment Validity is potentially intertwined with the goal of the present paper, which is to investigate the application to the natural, every day, social environment of the classroom [41], [38].

Finally, Credibility also seems to characterize the research as the quality of the data cannot be questioned, since it is data of published scientific papers and therefore the research design, in relation to this data, leads to true and trustworthy findings [42].

The methodological framework of data analysis is based on the identification of Conceptual Patterns which are grouped in Codes, Codes in Categories, and those in the final Theme of analysis. The detection is done with the help of simple office software; the Conceptual Patterns are highlighted in color and recorded in columns per Code in spreadsheet software (Fig. 1). There are 16 Codes, 7 Categories and one Theme (Fig. 2).

B. Researched Papers

1) Gkiolmas, Dimakos, Chalkidis, and Stoumpa (2020)

Gkiolmas *et al.* [4] conducted a case study on "An environmental education project that measures particular matter via a Microcontroller board interface" in a sample of students - members of the school's environmental team, which consisted of seven (7) students. The theme of the group project was the study of particles (PM) in the ambient air of both the school and their home. They explored the impact of a collaborative environmental education project on improving students' behavior, knowledge, and skills. In this project, based on the educational technique of "declining guidance" and "guided discovery", the students at a vocational high school created a robotic device, an artifact,

based on a Microcontroller board, for measuring the particle pollution of the PM2 and PM10 environment [4]. According to them, the students created, programmed, and used the measuring device, but also carried out an online bibliographic search on the subject of microparticles, which allowed them to gain a deep understanding of the subject.

During the development of the project, in parallel with the construction of the artefact, the students were introduced to other disciplines, mainly related to hovering PM. As discussed in the findings presented in Table 3, the students' overall experience with the construction provided, with the prerequisites for the discovery, on with knowledge related to PM emission, with the problems faced by living organisms who are exposed to environments containing high levels of PM10 and PM2.5, as well as with the ways of countering this problem and conclusively solving it, was judged - generally - as a beneficial experience. In addition, most of the students seemed to acquire the basic knowledge and programming skills to utilise the Arduino platform. (This can be seen in the meta-cognitive stage, in which they all stated that they considered themselves to be in a position where they could create something similar, with little or no external help.)

Finally, in the socio-sentimental domain, as it stems from Table 2 which comes from their diaries, it can be considered that the procedure was, at the very least, pleasant for the students. "Joy", "satisfaction" and "pride" are not sentiments that one encounters regularly in learners, especially in the Greek schooling system. Nonetheless, these emotions were quite regularly expressed by the participating students. Regarding teamwork, it is considered that the team functioned satisfactorily, especially from the third meeting onwards, and that it had sufficient cohesion and autonomy in decision-making. The students undertook roles, took initiative and, despite the fact that competition between members occurred, worked for the fulfillment of a common aim, realising above all the need for teamwork: "...no matter how much I want to change things, I cannot do this alone...".

It seems that the teaching intervention was successful in its entirety. Since a plethora of sensors is now available at low cost, similar interventions measuring other environmental parameters, such as different types of pollution in air, soil or water could be designed and implemented in secondary education, with the aim of promoting critical thinking about environmental issues at this stage.

Fig. 1. Detection and labeling of conceptual patterns in the paper of Gkiolmas *et al.* [4].

Codes (16)	Categories (7)	Themes (1)
Holistic & systemic thinking (in general) Computational Thinking Problems Solving Metacognition	Holistic & systemic thinking	Ability of utilizing Microcontroller Systems in ESD
Interdisciplinarity & multidisciplinary STEM Interdisciplinarity & multidisciplinary HASS (in general) Environmental & Sustainability Concepts (especially)	HASS&STEM Interdisciplinarity & multidisciplinary	
Constructivism (in general) Contextual Learning Discovery learning Experiential Learning	Constructivist approach to knowledge	
Cooperative learning (in general)	Cooperative learning	
Critical thinking (in general)	Critical thinking	
Cultivation of values (in general) Cultivation of environmental sustainability values	Cultivation of values	
Learning Satisfaction (in general)	Learning Satisfaction	

Fig. 2. Thematic Analysis Map: Themes, Categories, Codes & Marking Colors Index.

2) Savelides and Savelidi (2020)

Savelides and Savelidi [5] in their work - case study - on "The Intelligent Wall". The Electrical Analogy as an Educational Technique in the Context of HASS & STEM & Contextual Learning" designed, developed and evaluated a Prototype of an interdisciplinary educational scenario, in which the didactical technique of Analogs is applied, in which the Electric Analog is utilized with a Microcontroller Board as the main educational tool. The Scenario and especially the completeness of its interdisciplinarity were evaluated by 11 teachers of the course Research Project in Technology. The scenario didactically covers scientific areas of HASS & STEM [27]. According to Savelides and Savelidi in the scenario, students are asked to create their own teaching tool, a Model, the "Intelligent Wall". First the Model is created digitally and then as material. Then, students experiment with it, mostly with the help of ICTs. They experiment with the composition of different walls, digitally calculating heat loss and investigating how masonry affects carbon dioxide emissions, the economy, and the environment itself to solve related interdisciplinary problems.

3) Lu, Hong, Chen, and Ma (2020)

Lu *et al.* [3] conducted a case study with the subject "Elementary school students learn Microcontroller board programming to assemble sensory-controlled works" which was based on a qualitative and quantitative strategy, involving 54 students from the fifth and sixth grade of elementary school in Taiwan as a research sample. The study aimed to design an interdisciplinary curriculum for science, technology, engineering, and mathematics (STEM) for elementary school students in order to cultivate their literacy in STEM. They report that in a series of courses of environmental and ecological interest, teachers taught students the operation of green buildings or the special habits of various animals. They also taught how to choose the right background and materials for assembling green buildings or animals. Finally, the students were taught the programming of the Microcontroller board for the assembly of green buildings or animals controlled by sensors, so that they can respond accordingly, such as opening and closing windows in the green building.

4) Alò, Castillo, Marín Vial, and Samaniego (2020)

Alò *et al.* [43] conducted a mixed strategy research (quantitative and qualitative) with the participation of 115 seventh graders from five public, underprivileged schools in southern Chile. The title of the research was "Low-cost emerging technologies as a tool to support informal environmental education in children from vulnerable public schools of southern Chile". Students participated in workshops based on Microcontroller board technology to address current environmental problems caused by global change and humanization [43]. The intervention was based on the observation of a positive attitude and interest in the subjects of science, as well as the desire to do experiments and practical work. They state that this gave students the opportunity to experience the development of a small environmental monitoring station with Microcontroller board technology as an activity, with the teaching technique of the project (collaborative teaching) and the application of

the scientific method.

III. RESULTS AND DISCUSSION

The results of ThA of the four papers, per Category, are as follows:

1) Category: Holistic & systemic thinking

In all four papers, conceptual patterns were found which relate to the Codes of this Category. For example [5] states that using Microcontrollers, "It is possible to develop real-world problem solving, especially based on models and techniques of Computational Thinking" explicitly noting Computational Thinking approaches and Problem Solving. A more general reference to holistic & systemic thinking is made by [43]: "The analysis applied to the open-ended questions allowed us to make connections between the different parts of the information collected and interpret it in more depth. We organized the codes through relationship networks that graphically represented possible structures or systems of relationships between codes... This exercise allowed us to synthesize the main concepts and their connections....". It is therefore concluded that as new teaching and learning tools, Microcontroller systems are likely to have a greater and long-lasting educational impact on students by developing Holistic & Systematic thinking skills through holistic problem solving [43]. Based on these, there can be educational applications that promote students' metacognition [3] and their holistic and systemic thinking in general [5].

2) Category: HASS & STEM Interdisciplinarity & multidisciplinary

In all four papers, conceptual patterns were found, which concerned interdisciplinarity & multidisciplinary, something considered natural since the papers were selected based on the composition of a STEM object (Microcontroller) with a HASS object (environmental sustainability). In addition, [3] reports: "Arduino programming to assemble sensory-controlled works could enhance the STEM literacy of elementary school students: the subject survey course teaching and the results of statistical analysis of the STEM literacy test showed that elementary school students who implemented subject survey learning were taught in cross-disciplinary fields". It seems that Microcontroller systems can be educational tools that can combine electromechanical technology, information technology and other sciences. Thus, the combination of the above two applications (in the environment and education) concludes that Microcontroller board systems can be applied in education for the environment and Sustainability [1]. The application of Microcontroller board programming for the assembly of controlled sensory projects, such as environmentally intelligent constructions, could improve literacy in STEM but also the Interdisciplinarity knowledge and Metacognition of students [3]. In general, it seems that Microcontroller board systems can be used in the school laboratory, in research courses and to approach interdisciplinarily the fields of HASS & STEM and therefore ESD [5].

3) Category: Constructivist approach to knowledge

In all papers, conceptual patterns were identified, which correspond to the Codes of this Category, which is also considered natural since all four works aim at the use of a state-of-the-art educational tool through which they aim at building new deep knowledge in their students. Characteristically, [4] reports: "*The recording of the development over time of an Environmental Education project based on the principles of Constructionism. The main idea of the project was the design of an 'artefact' – a measurement tool for air pollutants, based on the Arduino platform*". They themselves, referring to Discovery Learning, state "... which they would then use to investigate the quality of the air they breathe" (pp. 100027). And they continue by saying "During the second meeting (two teaching hours), students from both groups searched the world wide web for information regarding hardware construction and software development, in order to build their Arduino-based measuring device" (pp. 100027). Also, [5] states: "[it is] possible to use [the Microcontroller board], as it meets the principles of Contextual Learning, since it can be the start of the development of framed strategies such as associating a new idea with something familiar, encouraging exploration, discovery, or invention, use of concepts in realistic and relevant exercises" (p. 244). Thus, we can agree that it is possible to use Microcontroller board systems in environmental education in the context of Constructivism, Contextual and Discovery learning and Computational Thinking [5].

4) Category: Cooperative learning

In each paper, conceptual patterns are identified, which highlight the use of collaborative educational techniques. Indicatively, [3] reports: "*The collaborative teachers and each group of students form a close synergy relationship, and work together to complete the teaching activities, giving full play to the team spirit of teaching and learning*" (p. 265). It therefore seems that Microcontroller systems can contribute to faster learning, within Collaborative and Experiential frameworks [43]-[45].

5) Category: Critical thinking

The goal and achievement of the development of critical thinking in students, is implied or expressed directly in all four papers by a significant number of conceptual patterns. Indicatively, [43] reports: "*These new teaching and learning tools will likely have a greater and long-lasting educational impact on students, promoting faster learning, problem solving ability and foster their critical thinking skills, among other benefits.*" (p. 651). Thus, it can be concluded that educational interventions, based on Microcontroller systems, which measure environmental parameters could be designed and implemented in education, with the aim of promoting critical thinking on environmental issues [4], to promote students' skills in solving problems, and advance their critical thinking skills [43].

6) Category: Cultivation of values

There is a small number of conceptual patterns that relate to the cultivation of values. In three of the four papers, the utilization of these systems with the aim of general cultivation of values is implied, and in two, patterns are

identified which imply the possibility of cultivating environmental values. Regarding this possibility, in its general effect, [43] reports: *"Furthermore, the development of positive attitudes towards science and technology can motivate young people interested in science education and science related careers"* (p. 651). More specifically, regarding the cultivation of environmental values, [4] reports *"... the use of Arduino-based measuring devices raised high school students' awareness and curiosity towards the environmental factors under investigation..."* (p. 100027). In the same vein [5] reports: *"The criteria upon which the Design of a Prototype Scenario [with a Microcontroller Board tool] was designed and evaluated, were based... in the students' development of knowledge, skills, and perceptions, regarding...Social Responsibility, ... Sustainability – environment [and others]"* (p. 236). However, it seems (perhaps not very clearly) that the appropriately adapted application of Microcontrollers in educational scenarios can influence the change of attitudes and behaviors through the cultivation of values.

7) Category: Learning Satisfaction

Conceptual patterns have been identified, whose examination suggests that experiential applications with a Microcontroller as an educational tool, in addition to scientific knowledge and metacognition, give feelings of satisfaction, self-efficacy and enthusiasm to students and therefore contribute to the development of environmental awareness in a pleasant experiential way [4]. Characteristically, it states: *"Finally, in the socio-sentimental domain..... it can be considered that the procedure was, at the very least, pleasant for the students. "Joy", "satisfaction" and "pride" are not sentiments that one encounters regularly in learners, especially in the Greek schooling system."* (p. 100027). In the same vein [43] reports: *"Engaging activities can provide learning in an entertaining way, enhancing students' inclination in learning science."* (p. 648).

IV. CONCLUSION

The aim of this paper is to answer the research question whether the proper use of Microcontroller board systems, as educational tools, can help achieve the goals of Education for Sustainable Development (ESD). To answer the question, a quality strategy meta-survey of four recently published works on the subject was conducted. The Thematic Analysis (ThA) technique was used. The results showed that the appropriate adaptation to the educational process of the Microcontroller Board Systems can sufficiently help achieve the goals of Education for Sustainable Development (ESD). In order to achieve these goals in a pedagogical context, the Microcontroller system, can be adapted in such a way as to serve the approaches of holistic & systemic thinking, Interdisciplinarity & Multidisciplinarity HASS & STEM, Constructivist approach to knowledge, Cooperative learning, Critical thinking the Cultivation of values and the Learning Satisfaction. And the adaptation to these educational and pedagogical approaches seems to be possible.

In addition, the results showed that Microcontroller

systems, as educational tools, can support contextual and discovery learning, computational thinking and problem-solving ability through experimental learning environments. In addition, their integration into the educational process seems to give students feelings of satisfaction, self-efficacy, and enthusiasm, and therefore contributes to the development of environmental awareness in a pleasant experiential way.

NOTES

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