Journal of Information Systems Engineering and Management
2025, 10(6s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Integrating IoT and Civic Education: SKILIKET System as an Approach to Environmental Monitoring and Awareness

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ARTICLE INFO

Received: 15 Oct 2024

Revised: 08 Dec 2024

Accepted: 19 Dec 2024

ABSTRACT

The integration of Internet of Things (IoT) technologies to address environmental sustainability exemplifies the current need for innovative data collection and community involvement. At the same time, the citizen science movement fosters voluntary participation to democratize science. However, access to robust training and large-scale deployment remains limited. This study proposes the SKILIKET system, a flexible training tech kit that monitors environmental variables in real time using IoT capabilities and a citizen science approach. The initiative seeks to foster participants' technical and civic competencies, using the system to help them understand socio-ecological phenomena. Drawing on Design-Based Research methodology, the authors describe co-creation activities that will be further conducted with higher education student teams to develop the ideal use of the system. This first stage (experimental design) anticipates the expected system interactions in a controlled environment, where students are encouraged to actively collect data from their immediate environment. This engagement aims to nurture a deeper understanding of socio-environmental issues, enhance public awareness, and support data-driven decision-making and public policy development. SKILIKET incorporates educational objectives and promotes civic skills, data literacy, and community-oriented problem-solving. This paper discusses the initial design, implementation strategies, and expected educational and societal impact of SKILIKET, highlighting its dual role in environmental monitoring and educational enhancement to achieve the U.N. Sustainable Development Goals (SDGs).

Keywords: Internet of Things, citizen science, educational innovation, higher education

1. BACKGROUND

The rapid advancement of Internet of Things (IoT) technologies has revolutionized education, environmental monitoring, citizen science, and many other areas. Mainstreaming IoT through citizen science efforts allows for increased real-time and dynamic data collection and analysis, encouraging broader public participation and involvement in science-related work [1]. While several projects have used IoT in citizen science initiatives, these tend to be context-specific and are not easily adaptable to other regions' local problems. [2] [3] [4] [5]. Moreover, the educational focus of existing IoT kits may differ by era and context, thus limiting their transferability and availability.

The system introduced here, SKILIKET (Science Knowledge Initiative for Learning by Innovation: Kit for Empowerment based on Technology), presents a pioneering effort to harness IoT for citizen science; higher education students will initially pilot it. The kit consists of portable hardware integrating sensors and actuators for environmental monitoring with active display, a mobile application allowing users to input qualitative environmental data, and an online platform that consolidates and visualizes these data for public access and reporting through IoT protocols. The SKILIKET system seeks to innovate through its physical and digital capabilities, flexibility of modular construction for interactive learning, and precise instructional documentation of adapting to various educational and citizen science training contexts.

Public engagement in scientific research, known as citizen science, gained considerable momentum in the last few years. As a practice, crowdsourcing harnesses individuals' collaborative power to support the gathering and exploration of massive data, yielding rich insights in a wide range of domains [6]. This process is facilitated by IoT-led systems using networked devices to collect data accurately and reliably from various sources [7].

The SKILIKET system fosters citizen science through a sound IoT foundation, empowering students to participate effectively in hands-on scientific research initiatives. SKILIKET enables students to contribute significantly to various scientific undertakings by supplying real-time data acquisition and analysis tools. Thus, this approach enriches participants' educational experiences and promotes environmental literacy and scientific awareness [8].

A. Internet of Things (IoT) and environmental sustainability.

The Internet of Things (IoT) is crucial for promoting environmental sustainability; it facilitates significant advances in multiple sectors. One of the most impacted areas is environmental monitoring, where IoT enables real-time data collection, which is essential for effectively managing natural resources and mitigating environmental impacts. IoT offers a cost-effective and accurate solution for monitoring air quality, humidity, temperature, and pollutants in various industries [9]. This capability extends from atmospheric CO_2 monitoring to ocean ecosystem health, providing critical data for effective environmental policies [10].

Botea-Muntean and Constantinescu [11] emphasize IoT's role in supporting the circular economy, highlighting how digitalization and IoT can drive sustainable business models through enhanced product lifecycle monitoring and AI (Artificial Intelligence) adoption. In urban contexts, Pamula et al. [12] illustrate the use of IoT sensors to improve environmental management in cities, addressing microclimate and pollutant transport issues, which are crucial for urban agriculture.

Despite IoT benefits, there is a need to reduce technological barriers, promote environmental resilience, and foster open innovation through accessible tools for large-scale environmental monitoring [13].

B. Intersection of IoT and citizen science.

IoT and citizen science are a powerful combination for data collection improvement and citizen participation in environmental monitoring and civic education projects, where everyday citizens contribute to scientific research using connected devices. IoT-powered citizen science can address critical issues such as air quality by empowering citizens to collect and analyze data inclusively, even without expensive scientific equipment or calibrated data [14].

The intersection of IoT and citizen science facilitates massive and dynamic data collection and fosters learning and awareness in communities. Depending on the design of the citizen science project, following Haklay [15], the level of citizen engagement can range from participation as a data-gathering sensor to complete interpretation and analysis. Moreover, initiatives that combine citizen engagement with elements of gamification and interactive learning, such as bird-call recognition in smart cities, demonstrate how such projects can improve participant engagement and retention, using IoT technologies to map acoustic data in real-time [16]. Similarly, integrating citizen science into secondary education through digital tools allows students to collect data on climate change and increase their knowledge and awareness of these critical issues [17]. In short, combining IoT and citizen science offers effective environmental monitoring and civic education, promoting active participation and learning in the community.

However, this integration also brings unique ethical, technical, and practical considerations [18].

C. Impact of IoT in Educational Environments.

IoT environmental monitoring systems allow educational institutions to track air quality, water pollution, and other environmental factors in detail and integrate these data into the academic curriculum, fostering a practical understanding of environmental science among students. Tagliabue et al. [19] highlight the implementation of IoT in educational environments to monitor indoor air quality, which directly influences students' study skills and well-being. On the other hand, Wu et al. [20] describe how IoT-based smart environmental sensing tools integrated into the daily lives of university students allow them to monitor and analyze environmental data in real-time and better understand the relationship between human activities and environmental changes.

The educational application of IoT enhances the collection of environmental data. It enriches learning by providing students with hands-on, practical experiences with emerging technologies and empowering the younger generation to create a more sustainable future.

2. MOTIVATION AND OBJECTIVE

This study responds to the need to provide updated IoT technology systems for citizen science projects that can be easily adopted in various educational settings. The SKILIKET system integrates technology and citizen participation to improve environmental data collection and analysis, combining objective measurements with subjective perceptions through a device, mobile app, and analysis platform. This multidimensional approach facilitates environmental research and management and promotes education, awareness, and community inclusion in science. The system's modular structure is adaptable to different contexts.

This study plans to outline a future intervention among collaborating teams of higher education students to test and enhance the SKILIKET system. The intervention will foster civic education and environmental awareness while engaging students in tech-based citizen science activities. This work presents the future intervention scheme and the features conceived for the SKILIKET system, including its essential components and functionalities. The body of the article presents the proposed stages of the future intervention for the primary outcome, followed by the discussion of the findings and the potential benefits of the system; it concludes with implications, limitations, and future studies.

3. METHODOLOGY

The co-authors adopted the Design-Based Research (DBR) methodology [21]. This approach uses iterative research that enables the design or improvement of educational practices by systematically exploring and designing learning environments. It embraces the design of educational interventions with recurring implementation and analysis cycles, targeting theory and praxis in tandem. DBR is collaborative, engaging various stakeholders in the design process and promoting adaptability to challenging real-world scenarios.

The broad and varied scope of DBR in educational settings encompasses studies on the positive impact of technology and the emergence of instructional resources. For example, Reeves and McKenney [22] emphasized that the essential characteristic of DBR is to solve practical problems and generate knowledge. In their study, they described examples of design research in educational communications and technology. On the other hand, the research by Kamarainen et al. [23] combined augmented reality (AR) with environmental probes to significantly enhance contextual learning experiences for teachers and students. Cochrane et al. [24] reported case studies of hands-on DBR activities in higher education, demonstrating the methodology's suitability and effectiveness in several disciplinary settings.

For this study, we adapted the DBR methodology to conceive the structure of a future intervention with student teams intended to engage with the SKILIKET system for environmental monitoring and civic education. The process involved ongoing synchronous and asynchronous co-author discussions in exploring, analyzing, proposing, and deciding the study's structuring and materialization. It involved the three stages of approach, conception, and development [Figure 1].

In the first phase, we conducted a fundamental literature review of existing research on IoT technologies in environmental monitoring, citizen science projects, and educational interventions. Through this, we gained an understanding of the available information and highlighted potential gaps to be addressed by the intervention. Next, we settled on a theoretical framework that blends the principles of participatory science, focusing on IoT and environmental sustainability. We then revised the study objective to emphasize the importance of IoT in learning settings, proactive learning through practical experiences, and mainstreaming community science ventures into educational agendas.

As a second phase, the co-authors outlined the intervention's conceptualization. Various flows were presented based on iterative scientific support. Eventually, the co-authors agreed on the expected stages and their flow for the intervention, each deploying the SKILIKET system, data collection, analysis, and feedback.

The third and final phase fully outlines how the intervention will be delivered to student teams in a controlled environment. The integration of specific activities, timelines, and methods for collecting and analyzing data from student teams follows. The co-authors revised this latter version for further fine-tuning and approval, resulting in this paper's current proposal.

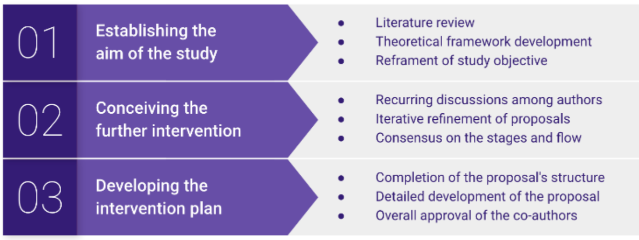

Figure 1. Applied Design-Based Research Methodology.

4. INTERVENTION PROPOSAL

To envision the structure of the future intervention with student teams to collaboratively decide the ideal interaction with the SKILIKET system, a participatory design approach was adopted based on Haklay and Francis [25]. Interventional stages involved conducting activities to develop students' awareness of contextual environmental phenomena. Through the iterative stages of our proposed methodology, participants' engagement is expected to progress per Haklay's levels [15], generating more interest and technical and theoretical understanding in each cycle of hands-on experience using the SKILIKET system. The authors collaboratively detailed the activities expected at each of the five stages, described below.

Stage 1. SKILIKET System overview. This stage aims to introduce the SKILIKET system technologies (i.e., IoT artifact, mobile app, and platform) to the student teams invited to participate in the environmental monitoring and awareness project. By design, the SKILIKET system monitors and transmits real-time data on environmental, physical, and social phenomena for decision-making. This initial stage presents the device's characteristics and capabilities. The conception of SKILIKET emerged from the idea of developing a technological device equipped with sensors and actuators arranged to be perceived as a living organism, featuring multicolor light changes, audio, and shapeshifting depending on the environmental sensing state. SKILIKET is envisioned as a device of considerable size and minimalist design yet possessing significant presence.

Technologically, the first SKILIKET prototype includes sensors for measuring temperature, relative humidity, atmospheric pressure, luminosity, and sound intensity. These sensors communicate with an ESP8266 microcontroller, including an integrated real-time Wi-Fi module. When the device is operational, the sensor data is collected, integrated, and transferred to Google Sheets for cloud storage and analysis. This first version successfully validated that the communication protocols are adequate for monitoring environmental data [Figure 2].

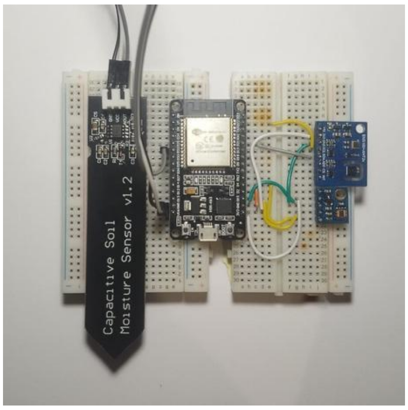

Figure 2. SKILIKET IoT artefact first prototype. Technology validation.

Stage 2: Hands-on exploration and discussion. The teams carry out practical activities linked to this stage's target level of involvement (Haklay's levels of engagement 1 to 4 [15]). This step in the iterative process always involves dialogue and reflection - discussion spaces with participants to motivate their engagement in the system and raise awareness of environmental phenomena. The *first discussion activity* explores the components and capacities of the SKILIKET system; it yields the participants' initial perceptions and knowledge of the system. The *second discussion activity* will follow the data collection process with the SKILIKET system, level 1 of iterative awareness. The *third discussion activity* interprets the data collected. Participants identify problematic issues from the information obtained in the *fourth discussion* activity. Finally, in the *last discussion* activity, participants engage in a collaborative wrap-up dialogue about the problem identified, the data collected, and their interpretation.

Stage 3. Progressive awareness. Teams will carry out a citizen science activity using the SKILIKET system in line with the expected level of engagement for the stage. To this end, pre-designed citizen science projects will be executed using the networked technologies of the system, i.e., IoT artifact, mobile app, and platform. Student teams will receive a citizen science case study for problem-solving. At each level, the challenge will involve participants engaging more or less in their roles as citizen scientists. For example, in level one, “citizens as sensors,” the instruction will be to collect data only, such as photographs of insects in their garden. Level two, “citizens as interpreters,” will involve identifying the type of insects photographed. In level three, “participatory science,” the teams will discuss defining their problem. Finally, at level four, “extreme citizen science,” they will analyze their data collection.

Stage 4. Data Collection and Analysis. Data from each citizen science activity generated by the student teams are collectively gathered for analysis and interpretation. This stage involves a stealthy systematic process by the SKILIKET system. Here, the data generated by the student teams are compiled to identify variables, compare them, and cross-reference them to understand the cross-sectional behavior of the data clouds produced. Data processing involves collecting quantitative data from the IoT device and qualitative data from the mobile application, which is transferred to a central server.

Stage 5. Information deployment and reporting. Once the data has been collected and analyzed, the results must be published in a logical structure for interpretation. Deployment of the data results occurs at this stage. Specifically, SKILIKET outputs results on two levels: physical and analytical. The physical level is within the SKILIKET device itself. The information returns to the SKILIKET system, where the actuators respond to the provided data. The device can emit continuous information in a new language (e.g., neuro-linguistic programming), simulating the living behavior of a plant or an animal. These messages convey information about the state of life in the community, such as noise, humidity, temperature, and air quality. Additionally, the SKILIKET device displays the information through pulses, light, color codes, or changes in physical form to engage the observer [Figure 3].

Figure 3. SKILIKET IoT artefact living behaviour concept. Image generated using OpenArt.ai by the authors.

At the second (analytical) level, detailed and complementary information displays through other media, such as a phone, mobile app, or dashboard. In the previous stage, the data were analyzed in the cloud system; then, the information was transferred to the displays, and organized for helpful interpretation. A standard IoT architecture describes the interconnection of wireless devices, hubs, routers, and cloud computing. While such an architecture can be complex, the principles underlying IoT are conceptually straightforward. The goal of this stage is for users to comprehend the information through the communication between the database and a visualization interface [Figure 4].

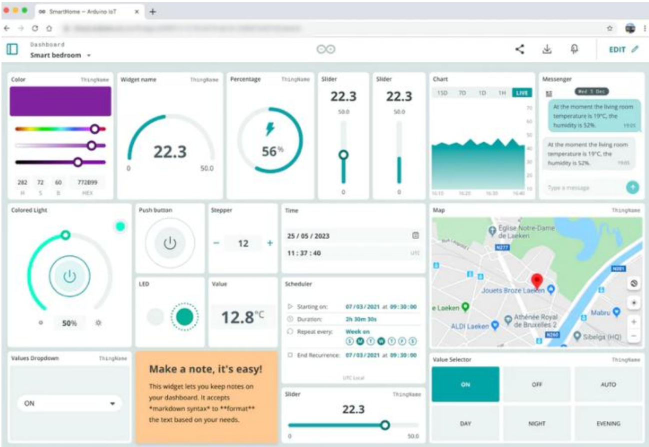

Figure 4. IoT visualization dashboard example [26].

Figure 5 presents the stages of the sequence to be followed by the student teams; there are four iterations, each progressing to a higher level of involvement (progressive awareness stage).

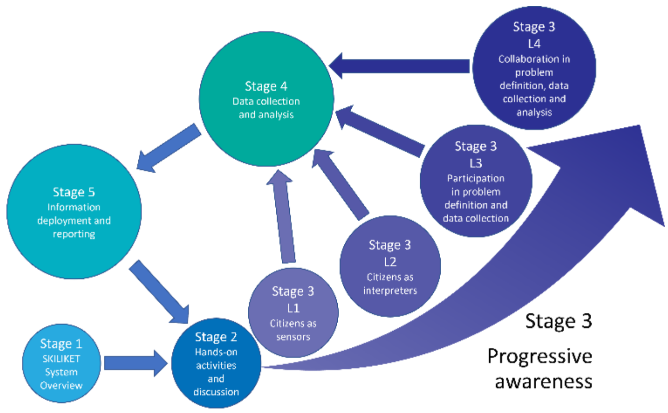

Figure 5. Resulting five stages of co-creation of expected SKILIKET system use (Adapted from Haklay [15]; and Haklay and Francis [25]).

5. DISCUSSION

Below are the findings regarding the anticipated potential of an intervention designed to test the SKILIKET system.

a) Potential to enhance socio-ecological awareness. The structured activities contain the expected outcomes described in the project's initial stage: students should collect and analyze environmental data using the IoT device and mobile app. As such, the proposed intervention is consistent with the research literature, specifically the work of Schäfer and Kieslinger [8], which stresses the role of citizen science in advancing environmental literacy. Integrating IoT with educational tools can stimulate a deeper understanding of environmental matters, thereby encouraging sustainability awareness and practices among students.

b) Projected improvement of participants' data literacy. The improvement is supported by the proposed progressive stages in which students engage in hands-on exploration, data collection, and analysis. The expected outcome aligns with the theoretical framework of Reeves and McKenney [22], which uses iterative educational interventions to promote digital literacy. As a prognosis, hands-on, technology-enhanced learning environments, such as SKILIKET, could enhance the essential skills needed for scientific inquiry and data-driven decision-making.

c) Anticipated encouragement of civic engagement through IoT. The SKILIKET system is devised to foster civic involvement by engaging students in real-time environmental monitoring and problem-solving activities. Foreseen outcomes are grounded in the participatory design phases, in which students will identify and address environmental challenges. This aligns with Poslad et al. [14], who note the potential of IoT-driven citizen science to drive deep civic engagement and environmental stewardship. The above suggests that integrating IoT technologies into educational initiatives can empower citizens to contribute to environmental and social well-being.

d) Potential for pragmatic integration of IoT into educational programs. Including practical activities in the intervention plan to test the SKILIKET system illustrates how integration within curricula could potentially benefit students' learning experiences. This concurs with Wu et al. [20], who described the advantages of integrating IoT technologies into educational settings to improve students' understanding of environmental change. From a broad perspective, the SKILIKET intervention makes the case that academic institutions could benefit from the uptake of IoT technologies to enable real-world learning opportunities and nurture a generation of environmentally aware citizens.

6. CONCLUSIONS

This study aimed to outline a proposal for an IoT-based intervention in citizen science for higher education student teams using the SKILIKET system. The vision considers the SKILIKET system's potential impact in enhancing civic education to improve environmental monitoring and awareness among higher education students. Findings suggest that SKILIKET has considerable potential to actively engage students in real-time data collection and analysis, encouraging a deeper insight into socio-ecological challenges that build technical and civic competencies.

Among other potential implications for practice are the improvement of environmental literacy and the fostering of evidence-based decision-making. Moreover, the system's design nurtures active participation and hands-on learning, which can be mainstreamed into curricula to underpin education for sustainability. On the research side, SKILIKET offers a solid framework for exploring the intersection of IoT, citizen science, and education, with insights into practical strategies for civic engagement and technical skills training.

This study has certain limitations, such as the controlled environment in which the initial phases of the system will be tested and the targeting of only higher education students, which may not fully capture the system's potential in various contexts. Future studies might investigate the scalability of SKILIKET in more extensive and varied settings and its long-term impact on participants' environmental and civic behaviors.

AKNOWLEDGMENT

The authors acknowledge the financial and technical support of Writing Lab, Institute for the Future of Education, Tecnologico de Monterrey, Mexico, in the production of this paper.

The authors gratefully acknowledge the financial support of the Novus Grant with PEP No. PHHT085-23ZZNV045 (Project ID: 419784 - SKILIKET: Environmental Empowerment through Citizen Science), Institute for the Future of Education, Tecnologico de Monterrey, Mexico.

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