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An Iot-based Classroom Management Framework Integrating Environmental Monitoring and Pedagogical Decision-making in Science Education: An Educational Design Research Approach

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Abstract

This study aims to develop and conceptualize an Internet of Things (IoT)-based classroom management system that integrates real-time environmental monitoring with teachers' pedagogical decision-making in science education. Using an Educational Design Research (EDR) approach based on the Plomp model, the study was conducted through three iterative phases: preliminary analysis, development/prototyping, and assessment. Data were collected from 23 teachers across nine schools through environmental sensors (temperature, humidity, light intensity, and noise), questionnaires measuring teacher self-efficacy, Technology Acceptance Model (TAM), and System Usability Scale (SUS), as well as interviews and focus group discussions. The results indicate that the four environmental parameters are pedagogically relevant and can be effectively operationalized as decision-support indicators for classroom management. Real-time data visualization through a dashboard enhanced teachers' situational awareness and supported adaptive pedagogical responses. Teachers demonstrated high self-efficacy, positive technology acceptance, and good system usability (mean SUS score = 75). The study proposes a conceptual framework positioning environmental data as a pedagogical trigger, with IoT functioning as a decision support system rather than a purely technical tool. These findings highlight the potential of IoT-based systems to support data-informed pedagogy, improve classroom climate, and promote student well-being in science learning.

Introduction

Student well-being and school climate have become a primary concern in contemporary science education, given the growing recognition that learning success depends not only on the curriculum and instructional strategies but also on the overall learning ecosystem (OECD, 2023; Toyinbo, 2023) A safe, comfortable, and well-managed classroom contributes to students' learning readiness, emotional stability, and engagement in learning (Fernandes et al., 2023; Widiastuti et al., 2020). In the Natural Science subject, the condition is crucial because the learning activities require students' focus, social interaction, and cognitive and emotional engagement (Fretes et al., 2024)

Along with the student-centered learning approach, teachers' roles have shifted. In addition to delivering materials, teachers also serve as learning organizers responsible for creating supportive conditions for students' well-being (Hasanah et al., 2022; Van Kessel et al., 2025). Teachers are expected to identify changes in the learning environment and adjust the instructional practices to align with students' needs. However, classroom environmental management is often based on intuition and personal experiences, rather than on a system that allows for objective and real-time monitoring (AlZoubi et al., 2024; Percia et al., 2025; Yang et al., 2019).

The absence of integrated support systems leads teachers to respond reactively and inconsistent in responding to the changing learning environment. In fact, in the dynamics of science learning, small changes in environmental conditions can influence the effectiveness of learning activities and students' psychological health during their study(Quevedo Piratova et al., 2025). Therefore, an approach is

necessary to link teachers' pedagogical awareness to the use of environmental data to support systematic classroom management oriented towards students' well-being.

Research Problem

Studies found that classroom physical conditions significantly influence student well-being, learning engagement, emotional regulation, and cognitive readiness (LoBue & Ogren, 2022; Toyinbo, 2023). In the subject of Natural Science, the influence is increasingly crucial due to the characteristics of the learning activities that involve observation, scientific discussion, experiments, and group work in a stable and conducive environment (Fretes et al., 2024; Opio et al., 2024). When the required condition is not fulfilled, students tend to lose focus and experience cognitive exhaustion and emotional discomfort, thereby affecting learning quality (Fernandes et al., 2023). Science learning involves observation and experimentation. Hence, environmental conditions serve as moderators or intervening variables that influence the results of the trial.

Although teachers' awareness of classroom environmental conditions improves, the classroom management in many educational units largely relies on subjective perception without measurable and real-time environmental data support. They are not supported by measurable, real-time environmental data (Hernandez & Cañas, 2024). The situation may become more complex in primary and early childhood education settings, as learners have not been able to express their discomfort verbally (Custode et al., 2023; Feldman, 2019). Moreover, not all teachers have the skills and comprehensive references to translate classroom learning conditions into suitable learning interventions (Van Kessel et al., 2025). Consequently, environmental disturbance influencing students' well-being and learning process is not identified early on, or it is not followed up with appropriate learning strategies. In this context, Internet of Things (IoT) technology is relevant because it enables real-time, objective, and sustainable monitoring of classroom environmental conditions, which teachers cannot fully observe. The use of IoT provides measurable data as the underlying reasons to make pedagogical decisions, allowing teachers to depend not only on their subjective perception but also on factual information reflecting the learning conditions.

Research Focus

The advancement of the Internet of Things (IoT) offers opportunities for schools to monitor classroom environmental conditions in real-time by utilizing various environmental sensors (Ranjan Laha et al., 2022; Van Kessel et al., 2025). Several researchers have developed IoT systems that support environmental monitoring and educational facility management in the smart classroom and smart campus frameworks (Quevedo Piratova et al., 2025; Truong et al., 2023). However, most studies treat IoT as a technical monitoring tool separate from classroom pedagogical practices. To address the condition, the present study developed an IoT-based classroom management system that integrates environmental monitoring with the classroom management practices in the Natural Science subject. It focuses on the interpretation of environmental data and its use by teachers to design adaptive and contextual learning

strategies that promote students' well-being (AlZoubi et al., 2024). In the present study, IoT is treated as the supporting system of teachers' pedagogical decision-making.

Research Aims and Research Questions

The research aims to develop an IoT-based classroom management system that supports monitoring of classroom environments in the Natural Science subject and bridges the gap between technology utilization and teachers' pedagogical needs. The system was designed to help teachers make contextual and responsive classroom decisions oriented towards the students' well-being.

Based on the objectives, the research posed the following questions.

Research Question 1 : What are the relevant environmental parameters to be integrated into the IoT-based classroom management system in the Natural Science subject?

Research Question 2 : How can real-time environmental data be presented and interpreted to support teachers' pedagogical decision-making in the Natural Science classroom management?

Research Question 3 : How do teacher self-efficacy, technology acceptance (TAM), and system usability (SUS) support the implementation of the IoT-based classroom management system?

Research Methodology

General Background

The research employed Educational Design Research (EDR), referring to Plomp's model. It was designed to develop a theoretically valid and practically effective educational solution (Plomp & Nieveen, 2013) (Wang, 2024). EDR was selected because the present study not only aimed to produce artefacts in the form of an IoT-based classroom management system but also formulated a conceptual framework that explains how the system can be used by teachers in Natural Science classrooms.

Figure 1

Iterations of systematic design cycles by Plomp

Plomp's model emphasizes the iterative integration of the design process, implementation, and evaluation. The model consists of three main phases: preliminary analysis, development or prototyping, and assessment (Plomp & Nieveen, 2013). The preliminary phase identified the needs and learning context. It was conducted through a literature study, preliminary observations, and interviews with teachers to identify classroom management problems and initiate system specification. Furthermore, during the development/ prototyping phase, the IoT-based classroom management system was developed iteratively through designing, preliminary field testing, and revisions in accordance with the

recommendations from experts and users. The phase produced a functional and suitable prototype for pedagogical purposes. At the assessment phase, the system was implemented in the classrooms to evaluate its usefulness and the users' acceptance and self-efficacy. The phase also validated the conceptual framework as the basis for environmental data-based classroom management. The qualitative coding process was conducted independently by two researchers to ensure credibility and reduce subjective bias.

Participant

The participants were 23 teachers involved in the implementation of an IoT-based classroom management system. They were selected using purposive sampling techniques based on several criteria: (1) active status, (2) completion of training and assistance in using the system, and (3) involvement in the use of the IoT system in the classrooms. The research was conducted in 9 schools, which served as the units of contextual analysis from which the data were collected. To enrich the qualitative data, 9 school principals and officials from the education board were invited to be the supporting informants to provide institutional perspectives on the system implementation. The number of participants was adjusted to the field context and was adequate for the descriptive statistical analysis and the in-depth qualitative exploration.

Instrument and Procedures

Several instruments were used to answer the research questions. The questionnaires included items on the Internet of Things (IoT) system, which was equipped with temperature, humidity, light intensity, and noise sensors, and collected real-time data on classroom conditions. The data was displayed through digital dashboards. The development of the teacher self-efficacy instrument in this study is grounded in Bandura's theory, which emphasizes individuals' beliefs in their capability to organize and execute actions required to achieve specific goals (Bandura, 2006). In the educational context, this construct is elaborated through the Teacher Sense of Efficacy framework proposed by (Tschannen-Moran & Hoy, 2001), particularly in the dimensions of instructional strategies and student engagement. Furthermore, the self-efficacy indicators encompass teachers' ability to facilitate learning comfort and integrate student learning data into instructional decision-making (Mok & Moore, 2019; Skaalvik & Skaalvik, 2019; Zee & Koomen, 2016). Teachers' acceptance of technology was measured using the Technology Acceptance Model (TAM) instruments consisting of perceived usefulness and perceived ease of use (Al-Rahmi et al., 2019; Casey et al., 2023; Limpinan et al., 2025; Villena-Taranilla et al., 2023). The use of the Technology Acceptance Model (TAM) aimed to evaluate how teachers' perceptions of the usefulness and ease of use influence their readiness to adopt the IoT-based management system as a part of their daily teaching practices. The usefulness of the system was also evaluated using the *System Usability Scale* (SUS) (Sharfina et al., 2016)(Brooke, 1996). All instruments were tested for validity and reliability using Pearson's correlation and Cronbach's alpha coefficient. The research procedures included the installation of the IoT system, introduction of the system to the teachers, implementation of the system

in 10 effective days during classroom activities, quantitative data collection using questionnaires, qualitative data collection using semi-structured interviews, teachers' reflection, and evaluation by the school principals and the representatives of the education board. The evaluation assessed the system's sustainability and potential for a broader scale application.

Data Analysis

The quantitative data, consisting of the mean score, standard deviation, and score distribution for teacher self-efficacy, TAM, and SUS, were analyzed using descriptive statistics. The analysis results were used to describe the level of teacher self-efficacy, acceptance of technology, and usefulness of the IoT-based classroom management system. Meanwhile, the qualitative data were analyzed thematically. It included the open coding process, theme categorization, and interpretation of meaning. The analysis focused on how teachers interpret the environmental data, which included the instructional interventions and teachers' perception towards the roles of the IoT system in supporting classroom management and students' well-being. The validity of the findings was ensured using triangulation techniques that consisted of the results of questionnaires, interviews, and system utilization data.

Research Results

The results of the IoT-based classroom management system were presented based on the phases of Plomp's Educational Design Research (EDR). It consisted of preliminary analysis, development/prototyping, and assessment phases. The display emphasized the iterative process of system development and the completion of ready-to-use products.

Preliminary Phase

In the preliminary phase, the research began with a Focus Group Discussion (FGD) with teachers and the school principals to identify the needs related to classroom environment management. The FGD resulted in the mapping of users' needs of the environment parameter to be observed, ease of data access, and the system interface design that supports pedagogical decision-making. The findings of the phase underlie the formulation of the system's initial specification. The documentation of the need assessment process during the online FGD is presented in Figure 2. It illustrated the operational workflow of the IoT-based classroom management system in accordance with the users' needs. The initial design and operational workflow of the system are presented in Figure 2.

Figure 2

Initial design and operational workflow of the IoT-based classroom management system

In addition to the needs analysis, the phase included preliminary technical validation of the temperature, humidity, light intensity, and noise sensors through a series of functional tests conducted in the laboratory and in the partners' classrooms. The validation results confirmed that all sensors functioned

properly and achieved an adequate level of accuracy in monitoring classroom conditions. Hence, the data sources of the IoT-based classroom management system were deemed feasible.

Development or Prototyping Phase

The development/prototyping phase was characterized by the iterative process of system development, which was from 1.0 to 2.0 versions. The iteration process was conducted based on the results of the needs analysis and the users' feedback obtained during the previous phase. The detailed specification improvement is displayed in Table 1. The table shows significant changes in sensory features, recommendation features, and website functions.

Table 1

Comparison of system features and functionalities between version 1.0 and version 2.0.

The development from version 1.0 to 2.0 included the addition of a noise sensor, expansion of the recommendation features that comprise students' management strategies, and enrichment of the website features, completed with students' progress instruments. The preliminary field testing conducted in three schools revealed that teachers can utilize the environmental data to make the learning activities more adaptive, such as shifting the motor activities to calmer ones when the temperature increases. The findings confirmed that the system functions as a pedagogical support that is based on the actual conditions of classrooms, rather than a mere technical monitoring tool.

Assessment Phase

During the assessment phase, the research focused on evaluating the system's usefulness, users' responses, and implementation readiness at a broader scale involving 9 schools and 23 teachers. The recommendation features of the learning activities based on the room's condition received a positive response because they help teachers adjust real-time learning activities and promote differentiated learning. The teachers' reflections indicate that students' classroom participation improved when the classroom was well-managed. The final evaluation covered the development of the system guidebook, which was validated by teachers and the representatives of the Yogyakarta City Education Board, Indonesia. The evaluation results confirmed that teachers can use the system independently after initial assistance, and that the industrial partners are ready to produce the hardware. The findings show that the 2.0 version has achieved a more prepared technological readiness and is feasible for testing on a broader operational scale.

Analysis Results of Research Question 1

The analysis results at the preliminary research and development/prototyping phase showed that four main parameters of the environment – temperature, humidity, light intensity, and noise – are relevant to be integrated into the IoT-based classroom management system for the Natural Science subject. The parameters were selected based on literature studies, FGD results with teachers and school principals,

and the preliminary field testing at the partner's schools. The four parameters are directly linked to learning comfort, students' engagement, and effectiveness in science learning, which is observational and experimental in nature.

The classroom temperature was identified as the most influential parameter on the students' thermal and concentration stability. The observation indicates that increases in room temperature reduce students' learning focus, especially during motor activities or group discussions. Hence, real-time monitoring of temperature is essential to support learning activities. Humidity also influences students' physical comfort and endurance. High humidity makes the room stuffy and decreases the students' responses to the teachers' instructions. Therefore, ventilation and learning duration become relevant considerations in classroom management. Light intensity is a crucial parameter in science learning, especially during reading, writing, and visual observations. The testing revealed that inadequate light impairs students' ability to concentrate and observe objects in detail. In addition, noise significantly affects students' emotional regulation and concentration, especially during transitions between activities and group work. Monitoring noise is needed to support classroom management strategies.

Based on the four parameters, the research formulated the ranges of the environmental conditions as the basis for the data interpretation in the IoT-based classroom management system. The range is used to classify the classroom's condition into several categories: normal, cautious, and not optimal. The threshold ranges were adapted from indoor environmental quality standards and adjusted based on field observations during preliminary testing. The classifications were visualized into color indicators in the system (Table 2). The classification helps teachers to make adaptive and data-based pedagogical decisions.

Table 2.

Environmental parameters and threshold ranges used for classroom condition classification in the IoT-based classroom management system.

The synthesis results for Research Questions 1 and 2 indicate that the operational workflow of the IoT-based classroom management system in the Natural Science subject is formed as a conceptual flow that integrates environmental monitoring, data interpretation by teachers, and adaptive pedagogical responses. Monitoring the temperature, humidity, light intensity, and noise provides the foundation for a system that provides objective information about classroom conditions. The data were presented on a dashboard to enhance teachers' situational awareness and enable them to adjust their teaching strategies to classroom conditions. Based on the interpretation of the data, teachers made pedagogical adjustments supported by the system's recommendations. It created a responsive learning atmosphere in the Natural Science subject and an encouraging learning environment, thereby improving student well-being and school climate. The framework confirms the teachers' role as the main decision-makers, and the Internet of Things' function as the decision support system within data-informed pedagogy. The conceptual framework of the IoT-based classroom management system is shown in Figure 3.

Figure 3.

Framework of the IoT-Based Classroom Management System

RQ 2 analysis results

The research findings at the development/prototyping and assessment phases showed that teachers' pedagogical decision-making is strongly determined by the integrated processes of data collection, data display, and data interpretation. The system was designed with integrated data flows, beginning with data acquisition from the environment through the IoT devices, continuing with data display on the website/dashboard, and completed with data interpretation based on the temporal patterns to manage Natural Science subject activities.

During the data acquisition phase, the system used IoT devices equipped with sensors for temperature, humidity, light intensity, and noise to collect real-time data on the classroom environment. The devices were installed in the classrooms and operated continuously throughout the learning process. The design and sensors integration illustrated in Figure 4 depicted how environmental data were obtained directly from the actual conditions of the classrooms without teachers' manual intervention. The automatic data acquisition ensures that the environmental information received by the teachers is objective and actual. The IoT prototype and sensor integration are illustrated in Figure 4.

Figure 4

IoT prototype with temperature, light intensity, humidity, and noise sensors

The environmental data were then displayed on a website/dashboard within the classroom management system, accessible in real-time by teachers, as shown in Figure 5.

Figure 5

Website/dashboard prototype of the classroom management system

The dashboard displays temperature, humidity, light intensity, and noise as numeric values, simple visualizations, and condition status indicators (normal, cautious, not optimal). The data display was designed to be simple and intuitive, allowing teachers to understand it without disrupting their instructional workflows. The teacher can immediately monitor classroom conditions and obtain a general assessment of the appropriateness of the environment and the Natural Science activities being implemented.

In addition to a concise display of current conditions, the system provides visualizations of temporary environmental data to support in-depth interpretation processes. Graphs of temperature, humidity, light intensity, and noise within the ten days of the learning activities help teachers identify the fluctuation patterns of the classroom conditions. The temporal visualization of environmental data is displayed in Figure 6.

Figure 6.

Average score of data interpretation of temperature, humidity, light, and noise sensors in 10 days at 9 schools

The environmental data visualization shows variation in parameters across days, influenced by time, learning activities, and external environmental conditions. The data displayed in the form of temporal graphs enables teachers to understand the dynamics of the classroom environment comprehensively, rather than a brief and current situation. The observation and teachers' reflection results indicated that data interpretation through the dashboards and graphs develops teachers' situational awareness that encourages adaptive pedagogical responses. Teachers adjusted their learning strategies in response to environmental conditions, such as reducing motor activities when temperature and noise levels increased, or increasing observation activities and discussion in appropriate conditions. The integration of environmental data into learning activity recommendations facilitates teachers in making pedagogical decisions. Structured and visualized real-time data display makes the IoT-based classroom management system a supporting tool for pedagogical decision-making, rather than a technical monitoring system.

RQ 3 analysis results

The testing results from the development/prototyping and assessment phases indicated that the real-time data display on the website/dashboard is essential for supporting teachers' pedagogical decision-making. The data from the temperature, humidity, light, and sound sensors were displayed in numeric indicators, a graphic visualization, and a condition status indicator. The display can be accessed and easily understood by teachers during the teaching process. The dashboard interface was designed to be concise and intuitive to minimize disruptions during the teaching process. The effectiveness of the IoT-based classroom management system is supported by teacher self-efficacy, technological acceptance, and system usefulness. The distribution of teacher self-efficacy scores is shown in Figure 7. Teachers' technology acceptance results are presented in Figure 8. The SUS score distribution is displayed in Figure 9..

Figure 7

Teacher self-efficacy

Based on Figure 7, teachers show relatively high self-confidence in using the system, especially in improving the learning quality and integrating environmental data into their teaching practices. The high score of self-efficacy indicates that teachers do not perceive the system as an additional burden. Instead, it is a relevant supporting aid for their professional duties. The findings are significant because teachers' internal readiness is the main prerequisite for adopting data-driven instructional technology, especially in the context of instructional decision-making. Figure 8 presents the measurement of the technology acceptance model (TAM) of teachers during the implementation.

Figure 8

Teachers' Technology Acceptance Model (TAM)

Figure 8 indicates that perceived usefulness and perceived ease of use fall within the fair category. Teachers assessed that the system is useful for their classroom management and relatively easy to use, although it received a score below the self-efficacy score. The differences indicate that although teachers believe they can use the system, they need more time and encouragement to adopt the technology. The lower score of the indicator of *intention to continue use* indicates that the sustainability of the system utilization is highly influenced by external factors, such as school support, system operational stability, integration level to the teachers' teaching practices. Further, the system's usefulness was measured using the System Usability Scale (SUS) (see Figure 9).

Figure 9

System Usability Scale (SUS) score distribution

The score shown in Figure 9 means that the system is generally accepted by users and demonstrates an adequate level of usefulness for the teaching practices. Based on the adjective rating, the System Usability Scale (SUS) reached the good category, reflecting positive usability experiences, although it needs improvement. Meanwhile, on the grade scale, the average score was 75, categorized in grade C. It signifies that the system has fulfilled the functional usability standards and is feasible for use in the classroom management system. The findings revealed that the system has a strong foundation of usability and the potential to be developed further to improve the teachers' comfort and effectiveness.

The quantitative findings are confirmed in the interview and in the FGD results during the assistance processes. In other words, the system reduces teachers' workload by automating classroom condition monitoring and providing recommendations for instructional interventions. The teachers reported that real-time data availability allows them to adjust the learning strategies, pacing, and approaches, as well as to support differentiated learning and authentic assessment. Moreover, the system's assessment features help teachers write students' learning reports more systematically and align them with the school's learning objectives.

Discussions

The research indicates that the Internet of Things (IoT)-based classroom management system has significant pedagogical potential when the physical environment of the classrooms is treated as an integral part of the learning process, rather than a passive setting. The RQ 1 findings identifying the temperature, humidity, light intensity, and noise as the main parameters are in line with the study of indoor environmental quality, which indicates that the physical condition of a classroom directly influences the students' comfort, emotional regulations, and cognitive involvement (Borrallo-Jiménez et al., 2025; Fernández et al., 2019; Lan et al., 2020; Toyinbo, 2023). The studies claim that small variations in the environmental conditions can affect the learning performance, especially in science learning that requires students to concentrate and participate in high-order cognitive activities.

Further, the findings of RQ 2 revealed that real-time data display on the dashboards is essential in supporting teachers' instructional decision-making. The results support the research on learning analytics and teacher dashboards, emphasizing that data are meaningful only when they are displayed in simple visualizations and are relevant to the teaching practices (AlZoubi et al., 2024; Van Kessel et al., 2025). Data visualizations in the form of status indicators and temporal graphs allow teachers to develop situational awareness, a concept proposed in the studies of data-driven instructional decision-making (Ahn et al., 2021; Wiedbusch et al., 2021). The conceptual framework developed in the present study broadened the discourse on smart learning environments by integrating the physical environment, teachers' interpretation of data, and adaptive pedagogical responses. Unlike much of the research on smart classrooms that focuses on the efficiency and automation of technology (Quevedo Piratova et al., 2025; Truong et al., 2023), the present study treats teachers as the main actors in decision-making, while IoT and dashboards serve as the decision support system. The approach is in line with the views of human-centered learning analytics that emphasize the importance of teachers' role in interpreting the data and using them contextually (Li et al., 2021).

RQ 3 findings indicate that teacher self-efficacy, technological acceptance, and system usability are key factors in the successful implementation of an IoT-based classroom management system. High levels of teacher self-efficacy are consistent with previous findings that teacher self-efficacy plays a significant role in instructional technology adoption (Gomez et al., 2022; Ma et al., 2021). Meanwhile, the constructs of the Technology Acceptance Model (TAM) and the System Usability Scale (SUS) align with the studies claiming that the usability perception, ease of use, and system usefulness influence the sustainability of the utilization of technology at schools (Chuenyindee et al., 2022; Vlachogianni & Tselios, 2022).

The Educational Design Research (EDR) approach is also effective in providing a theoretically valid solution and a practically applicable solution. The iterative process that involves teachers from the preliminary to the assessment phases aligns with the principles of EDR that emphasize collaboration with practitioners and real context-based development (Plomp & Nieveen, 2013) (McKenney & Reeves, 2025). Therefore, the research provides empirical contributions to the EDR literature by demonstrating how IoT-based frameworks can be developed systematically to support classroom management and students' well-being. This study has several limitations. The implementation period was relatively short (10 days), and the sample size was limited to 23 teachers in nine schools within one regional context. Future research should examine long-term impacts on student academic performance and compare different subject contexts.

Conclusions and Implications

The research concluded that the IoT-based classroom management system links classroom environmental conditions to teachers' pedagogical responses in the Natural Science subject. By integrating the data of the temperature, humidity, light intensity, and noise in the dashboard, the system allows teachers to make classroom management decisions contextually and adaptively. The conceptual framework confirms that the environmental data functions as a pedagogical trigger that supports

science learning that is more responsive to the actual classroom conditions and strengthens students' well-being and positive school climate. Theoretically, the research contributes to the development of smart learning environments by treating teachers as the main decision-makers and IoT as the pedagogical support system, rather than a technical monitoring tool. The framework proposed in the research enriches data-informed pedagogical approaches by integrating the physical environment dimensions as integral parts of learning. Practically, the research findings imply that teachers, schools, and decision-makers in education utilize IoT meaningfully in classroom management. Therefore, the IoT-based classroom management system has the potential to ensure sustainable learning quality and student well-being. By repositioning environmental data as a pedagogical trigger, this study reframes smart classroom technology as a human-centered instructional support system rather than an automation mechanism.

Declarations

Participant Consent Statement: All participants involved in this study voluntarily agreed to participate in the research. Informed consent was obtained from the participants prior to their involvement in the study. Participants were informed about the purpose of the research, the procedures involved, and their right to withdraw at any time without any consequences.

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Tables

Tables 1 and 2 are available in the supplementary files section

Figures

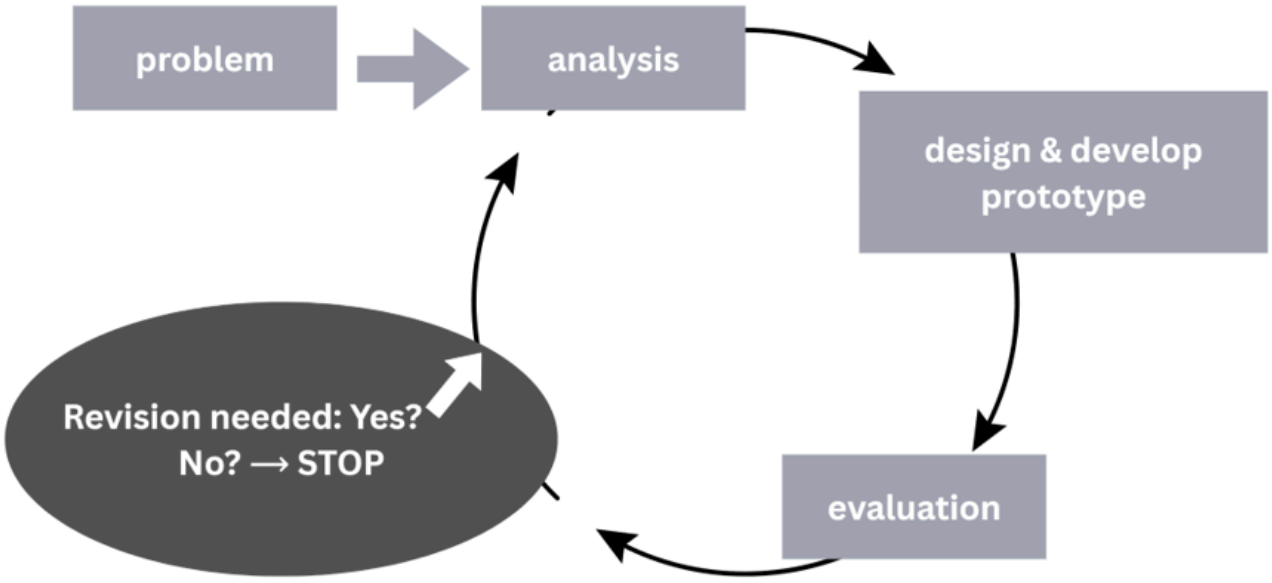


Figure 1

Iterations of systematic design cycles by Plomp

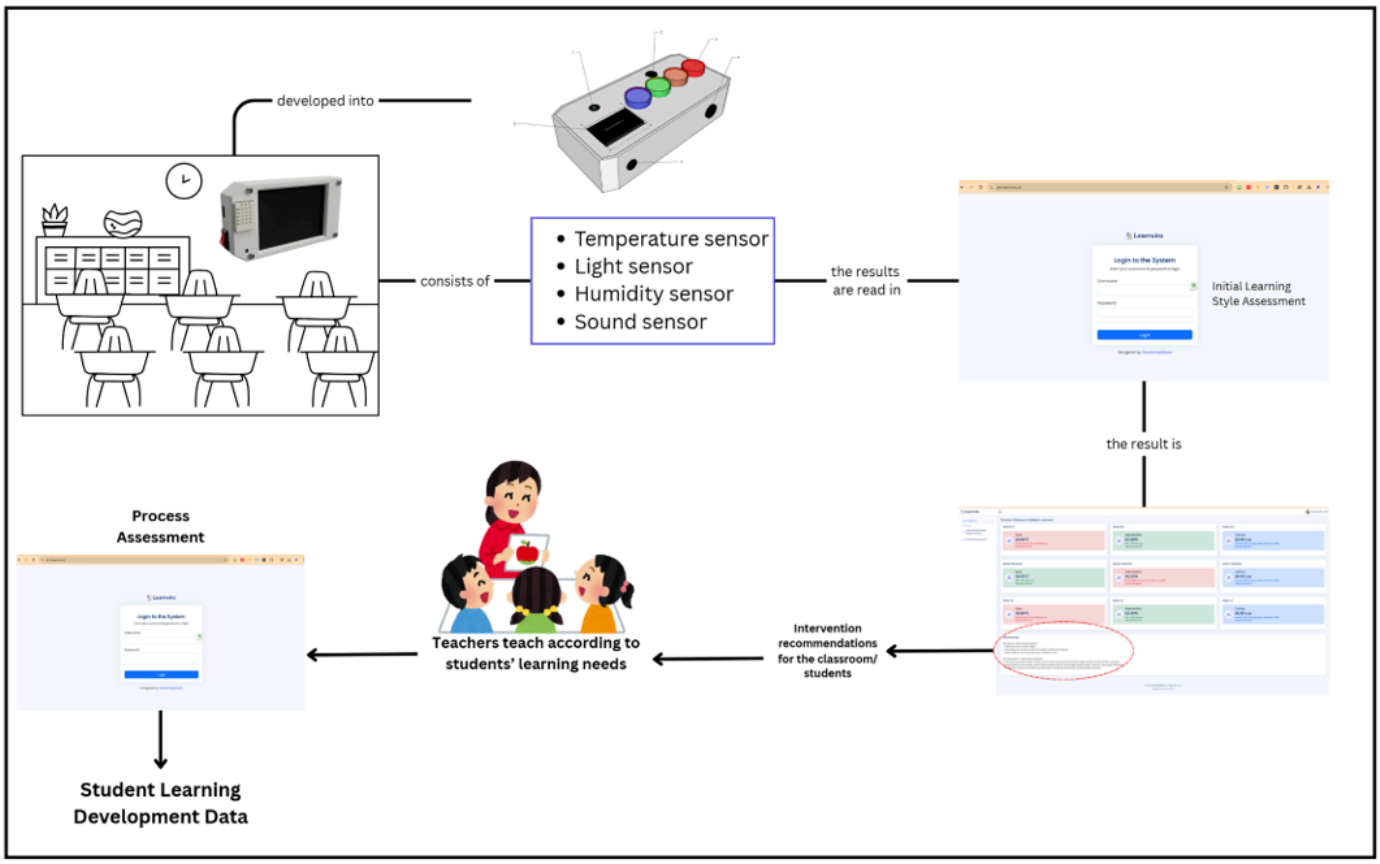


Figure 2

Initial design and operational workflow of the IoT-based classroom management system

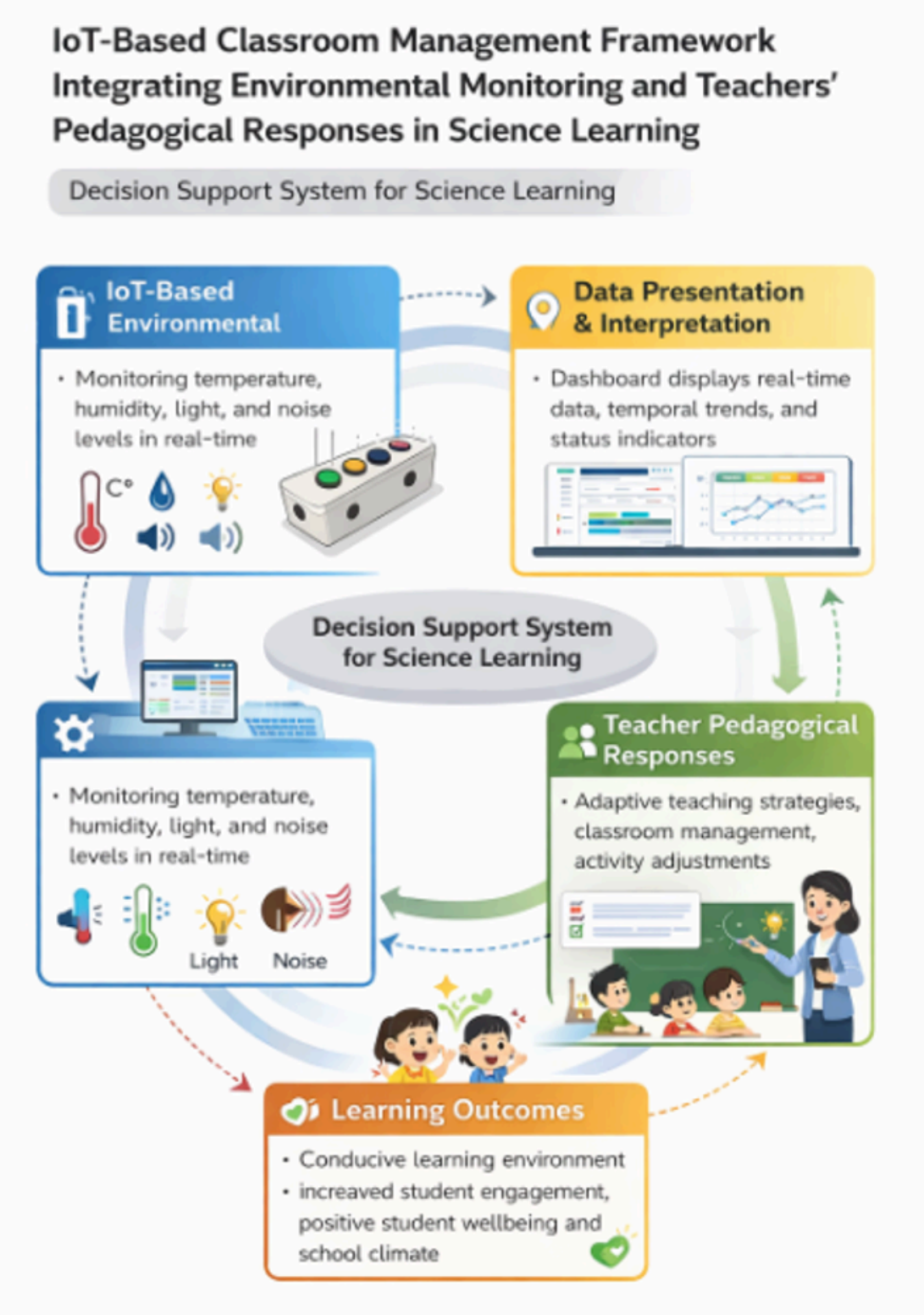


Figure 3

Framework of the IoT-Based Classroom Management System



Figure 4

IoT prototype with temperature, light intensity, humidity, and noise sensors

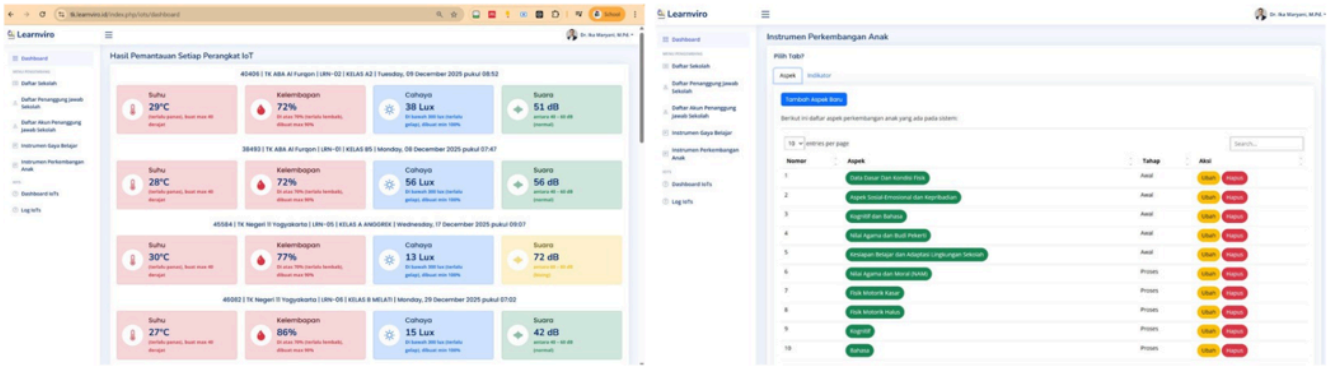


Figure 5

Website/dashboard prototype of the classroom management system

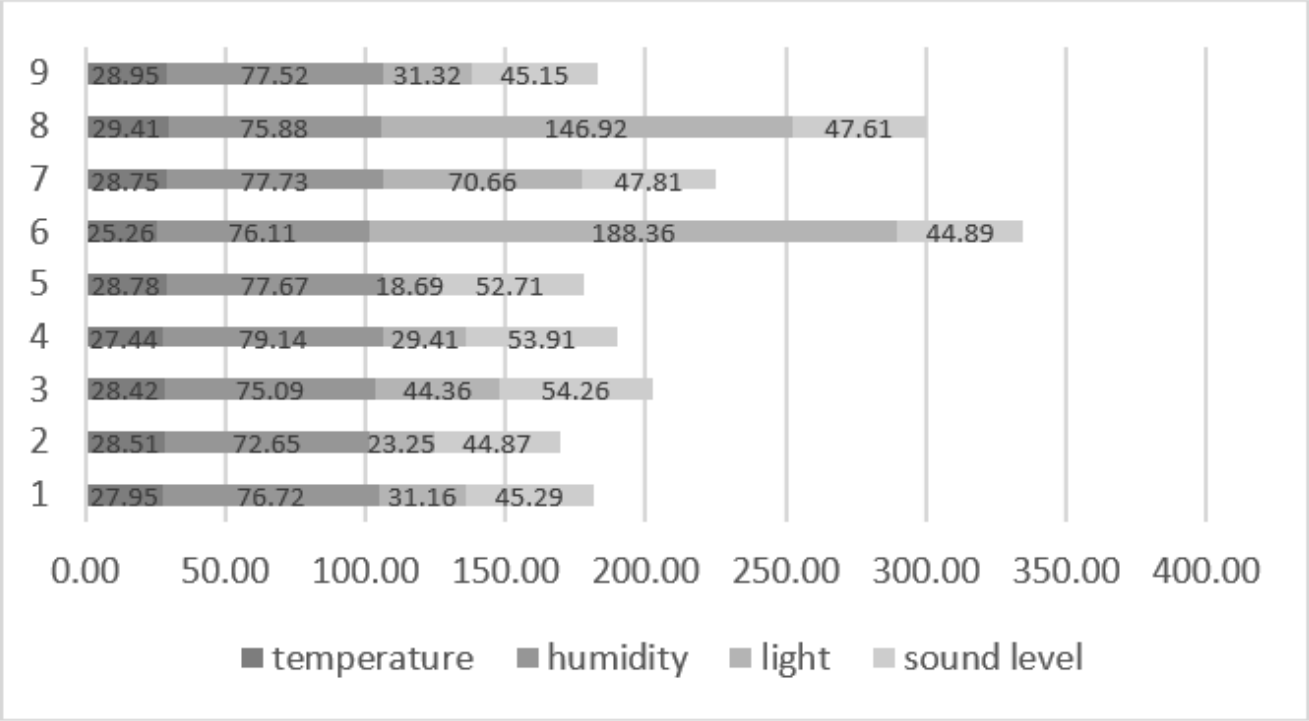


Figure 6

Average score of data interpretation of temperature, humidity, light, and noise sensors in 10 days at 9 schools

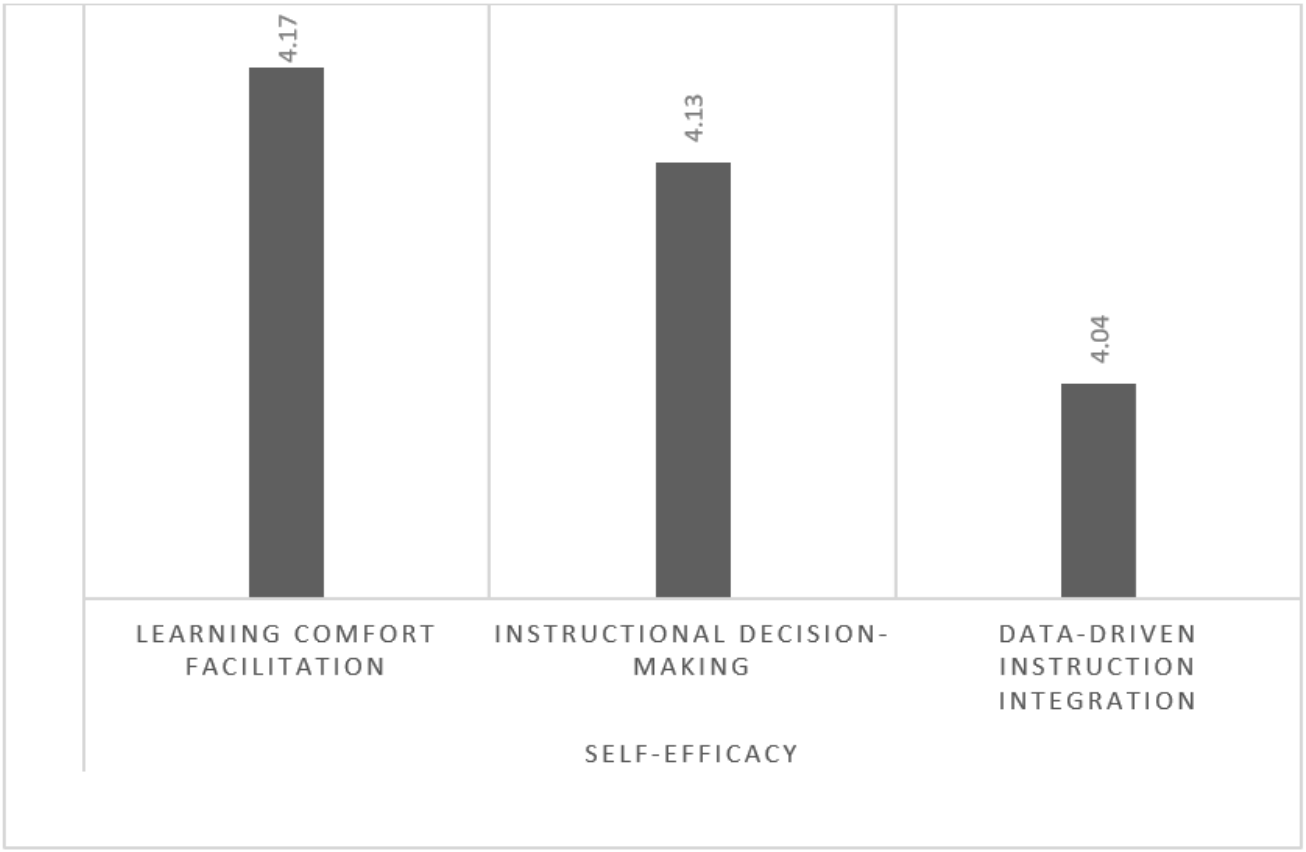


Figure 7

Teacher self-efficacy

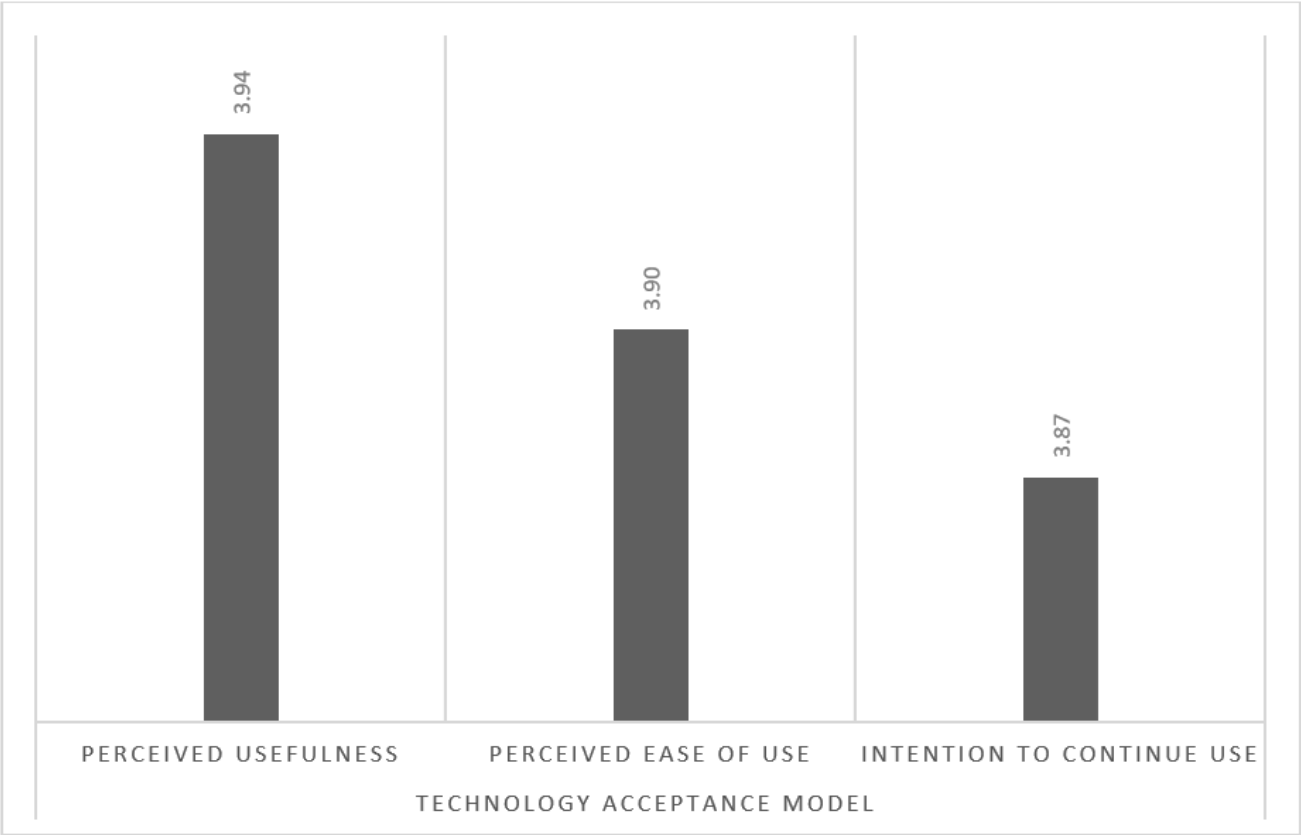


Figure 8

Teachers' Technology Acceptance Model (TAM)

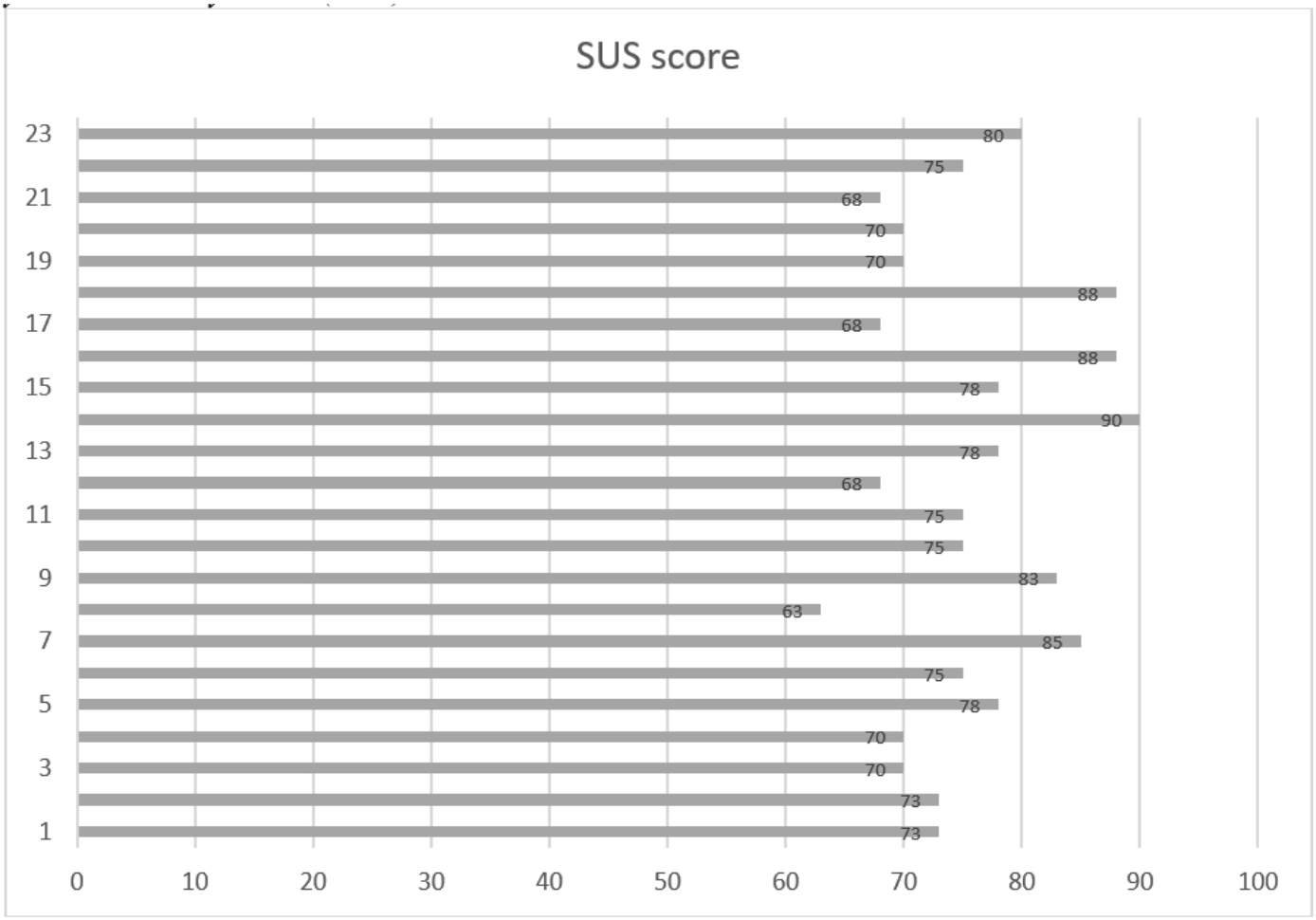


Figure 9

System Usability Scale (SUS) score distribution

Supplementary Files

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- TABLES.docx