DEVELOPING AN INTELLIGENT SYSTEM BASED ON MACHINE LEARNING TECHNOLOGY FOR ELECTRONIC WASTE MANAGEMENT IN THE FIELD OF EDUCATION

Amany Fathy Mohamed Ibrahim Metwaley [1], Elsaeed Elsaeed Mohamed Abd-ElRazik [2], Rasha Kandil Mohamed Kandil Arafa [2]

[1] Computer Teacher at Royal British School, Damietta, Egypt.
[2] Computer teacher preparation department, Damietta University, Egypt.
[3]

ABSTRACT

The rapid advancement of technology in recent years has led to its integration into all aspects of life, prompting the need to find solutions to mitigate its negative environmental impacts. Hence, Green computing aims to reduce the negative impacts of using computers and modern technology by reducing energy use, reducing carbon emissions, and disposing of digital waste in environmentally friendly ways.
The study aim to promote the culture of green computing in educational institutions by encouraging school students to adopt positive environmental behaviours and dispose of digital waste in environmentally friendly ways.

The system proposed in this study seeks to provide a practical model for electronic waste management in the field of education in educational institutions, contributing to a healthy learning environment for students, free from the negative environmental impacts resulting from the use of technology, The results indicated the effectiveness of the proposed system in managing electronic waste.

KEYWORDS

Green Computing, Electronic Waste, intelligent System, Machine Learning, Education

1. INTRODUCTION

By raising educational standards and giving students easier access to information through computers, tablets, and the Internet, technology has significantly contributed to the growth of the education sector.

Despite its significant contribution to the advancement of education, the direct use of data centres and electronic devices results in carbon emissions. In addition to the fact that computers and their continuous operation result in an increase in the consumption of electricity and energy, one of the most significant risks posed by technology is electronic waste and its detrimental effects on the environment and future generations.

The concept of green computing has emerged as a modern trend aimed at improving the efficiency of ICT resource use, reducing carbon emissions, and promoting environmental sustainability practices within institutions, including educational institutions.

Educational institutions encourage teachers and students to use the green computing resources by holding initiatives and seminars within schools to train ICT teachers and students on the use of energy-saving software, establishing policies for energy conservation in computer labs, and allocating bins for collecting electronic waste for recycling and reuse

Despite the importance of this trend, the implementation of green computing in the education sector still faces challenges related to a lack of environmental awareness and the absence of smart solutions that support effective resource and waste management.

The primary goal of green computing is to reduce energy consumption and limit the use of excessive resources that negatively impact the environment. Among the most important green computing technologies are virtualization and energy optimization [1] One of the main goals of green computing is energy efficiency, the environmentally friendly disposal of digital waste, and the use of eco-friendly software [2].

One of the key advantages of applying machine learning (ML) technologies in the field of environmental sustainability is their ability to rationalize energy consumption and improve the efficiency of resource use. AI also accelerates the process of developing electronic devices and disposing it in eco-friendly manner, AI is used in optimizing the design and manufacturing processes of electronic devices by enabling automated quality control, predictive maintenance of manufacturing equipment, and advanced data analysis to improve product performance and energy efficiency. This leads to producing devices that consume less power and have longer lifespans, thus supporting green computing practices.

These technologies are effectively used to support decisions related to environmental sustainability and to achieve a balance between economic and environmental requirements [3], machine learning applications in environmental management span a wide range of areas, including mitigating the impacts of climate change, improving agricultural production, monitoring ocean health, managing water resources, forecasting weather conditions, and responding to natural disasters. These applications also extend to improving energy efficiency in computers, managing sustainable resources to reduce waste [4].

2. LITERATURE REVIEW

Farismana et al. [5], It introduced the importance of green computing in education by developing a system to reduce paper consumption in schools and encouraging students to adopt a sustainable environment, Results show that the first step in implementing green computing should start in the education due to its significance in raising students' awareness of the importance of green computing and educating them on achieving higher efficiency at lower costs. This research can be further expanded by involving a group of students from private and public schools, not just vocational schools, with analysis using artificial intelligence techniques rather than just databases Trevisan et al. [6],This research focused on the importance of sustainable development in higher education. Moreover, given the sustainability challenges currently faced by humankind, higher education institutions (HEIs) have been considered key stakeholders in the education of responsible citizens and leaders. Therefore, providing students with sustainability skills with the support of technology is both an opportunity and a challenge for these institutions. The results show that linking digital transformation and sustainability activities to face global challenges, such as climate change, social inequality, energy, quality of education, responsible consumption and production, among others, through the education of responsible citizens and the dissemination of a sustainability culture throughout the university system.

Atadoga et al. [7],The research focus into the multifaceted dimensions of green computing, elucidating various practices and strategies that are instrumental in fostering environmental sustainability From optimizing code efficiency to embracing energy-efficient computing architectures, the review underscores the diverse approaches available to software developers in minimizing resource consumption and carbon emissions. Furthermore, it examines the broader ramifications of these practices, emphasizing their potential to reshape the software industry's ecological footprint and contribute to global efforts for environmental conservation. The results show that the symbiotic relationship between green computing and modern software development methodologies is very important to achieve the environmental sustainability.

Kushwaha & Waoo[8],This research highlight the significance of green computing for the preservation of the environment, The minimization of hazardous materials, the maximization of output from the product throughout its lifespan while simultaneously minimizing energy consumption, as well as the reusability or recyclability of old products and wastes, and the biodegradability of wastes and waste products are all , research implementing various programmers in order to lessen the negative effects have on the surrounding environment ,results show that the green computing aims to preservation of the environment from Educating students in schools about its importance and the importance of disposing of leftover electronic devices in an environmentally friendly manner.

Tobel, I. [9],The research explores the integration of digital education within the green campus initiatives, adding emphasis on reducing energy consumption and achieving sustainability in the institution of higher learning. This study frames a broad overview of how online education, digital tools, and virtual resources help make campuses sustainable by lessening the authorized use of physical resources, increasing energy efficiency, bringing down carbon footprints, etc.. The findings bring out the role of digital education in promoting sustainability by giving actionable insights for education institutions in the strive towards a green campus.

Ahmad, S., Mishra, S., & Sharma, V. [10], It introduced the impact of green computing in every area of life especially in the field of achieving a sustainable future So, the study uses a qualitative method of collecting resources and data to address the opportunities, challenges, and future trends in green computing for Sustainable Future Technologies. Research results show that green computing is an upcoming and most promising area. The number of resources employed for green computing can be beneficial for lowering E-waste so that computing can be environmentally friendly and self-sustainable, It can be added that to achieve sustainable development, it is necessary to dispose of waste, especially computer remnants, in an environmentally friendly manner to reduce negative impacts on future generations.

Shrotriya et al. [11], It discussed the importance of responsible e-waste management, recycling, and disposal of electronic devices. The study highlights the significance of sustainable practices such as server consolidation, data centre design, and circular economy in promoting green computing. Results show that examines the various policies and regulations governing green computing practices and the impact they have on creating eco-friendly IT solutions.

Haque et al. [12], It presented the critical topic of green computing and looks at the importance of reducing the damage that uses too much energy, electronic waste, and the disposal of outdated technology in the environment, the result highlights how important it has become to manage global efforts by adjusting to new technological advancements and developing a shared commitment for creating a sustainable and ecological friendly future.

Nyabuto, G. M. [13], This study explores various aspects of green computing based on the latest research published in high-level scientific journals such as IEEE. The study also includes

comparisons between countries where the research was conducted and the years in which it was completed and published, Green computing, or green ICT, in the field of information and communication technology, aims to mitigate the negative environmental impact of computing technologies. With continuous technological advancements, new devices vary in their environmental footprint. results show that the green computing is important in disposal electronic waste, and the disposal of outdated technology in the environment.

Rathi,P. [14], The research offers a solution to problems such as greenhouse gas emissions, the growing volume of waste, the continued burning of fossil fuels, and the depletion of natural resources. As a result, it becomes the imperative of both companies and individuals to take responsibility for minimizing power consumption while incorporating environmentally friendly practices into their operations and waste management, The research focused on the importance of disposing of waste in an environmentally friendly manner so as not to affect future generations and reduce the negative effects on the atmosphere. It can be added that using machine learning techniques, some auxiliary programs can be created to reduce energy in computers.

Ugonnia et al. [15], This research examines the integration of green computing practices within data warehousing and big data technologies, focusing on their effects on organizational efficiency and environmental responsibility. This study explores how sustainable IT practices, specifically green computing, can be effectively integrated with data warehouses and big data technologies to address these challenges. A quantitative research methodology was employed, utilizing a structured questionnaire distributed among 389 IT professionals selected through purposive sampling. Results from the study indicate a significant negative relationship between green computing practices and energy consumption and emissions, suggesting that integrating green computing can substantially reduce environmental impacts.

Biswas et al. [16], This study discussed the importance of using green computing to reduce energy consumption in computer resources and decrease carbon emissions, which could affect the environment and the health of future generations. The study's results highlighted the importance of supporting and utilizing green computing technology in manufacturing plants and computer hardware companies to minimize the environmental impact of their waste. The study also emphasized that the commitment of these companies represents a significant step toward achieving Egypt’s Vision 2030 by promoting a clean, sustainable environment and rationalizing energy consumption, which in turn leads to significant cost savings for business and factory owners.

Oliver, A. S., et al. [17], It proposed novel technique in energy management with security enhancement based on heuristic green computing technique and optimized routing protocol. Results show that how green computing can reduce electronic waste and the release of dangerous gases when a system is in operation. Green computing helps to limit the emission of dangerous gases from the computer components, study of this research can be extended based on real time dataset with computer aided analysis and artificial intelligence.

Choudhury et al. [18],It discussed the importance of combining artificial intelligence techniques, including machine learning, with green computing to reduce energy consumption and enhance environmental sustainability. It presented a proposed system to reduce carbon emissions. The system used advanced techniques from machine learning and deep learning to improve the allocation of resources at the present time, and the results show that This approach uses methods like convolutional and recurrent neural networks to enhance architectural efficiency, It can be added that artificial intelligence techniques can be combined to accurately predict temperatures.

Barbierato & Gatti [19], The research discusses the evolution of machine learning as a branch of artificial intelligence, focusing on artificial neural networks that have made remarkable advances in complex problems such as computer vision and natural language recognition. The paper notes that these models, while powerful in prediction, suffer from a lack of transparency, as it is not possible to explain how they arrived at their decisions due to their "black box" nature. The paper also criticizes the belief that machine learning can only be effective through statistical methods, and suggests that learning is more complex and includes elements of human learning such as reinforcement learning and imitation learning.

Verma et al. [20], The research explores the potential environmental impacts of technology and compares the associated benefits and challenges, providing real-world examples of how digital technology can be both a barrier and an opportunity for global sustainability. The research focuses on how digital technologies, including cloud computing, block chain, the Internet of Things, big data analytics, and artificial intelligence, can be key elements in achieving sustainability.

Dahmani, S. [21], The research focus environmental protection, Sustainable Development Goals, and the role of information technology (IT) is to foster it. The research focus on Artificial intelligence addresses environmental challenges, offering solutions such as emissions reduction, cost savings, legal compliance, HR attraction, optimized investments, and waste management. Green IT aligns with broad sustainability and ESG standards and is fostered with innovative AI solutions to integrate and optimize AI-based green computing algorithms which address environmental impacts and data utilization strategies, optimizing energy consumption, and mitigating digital waste and carbon footprint. The conclusion advocates increased use of AI-built technologies for the adoption of renewable energy sources, energy-efficient hardware, hardware optimization, and exploration of external cloud solutions for a more sustainable future.

Lokesh et al. [22], The research explores the relationship between the Internet of Things (IOT) and green IT, examining how environmental sustainability can be enhanced by integrating sustainable design principles with IOT technologies. It highlights that the development of IOT technologies has raised environmental concerns that require innovative solutions to mitigate negative impacts. The research presents green IT as a strategy for designing technological solutions that reduce or eliminate the environmental effects of IOT. The result includes a comprehensive analysis of various proposals to identify the best sustainable IOT frameworks and discusses how to implement these green designs as effective environmental solutions.

Verdecchia, R., Sallou, J., & Cruz, L.Besides[23], it presented in this paper the relation between the AI techniques and environmental sustainability AI affordances" are introduced as the possible actions offered by AI to an organizational actor whose goal is to achieve environmental sustainability, results show that " AI practices aimed at to mitigate the impact that humans have on the natural environment in terms of natural resources utilized, and recycling some remnants of computer devices. The study also highlighted the importance of encouraging factories and companies to use green resources and devices to save energy.

3. THE PROPOSED MODEL

The proposed system is an integrated system aimed at promoting sustainable environmental practices in educational institutions by utilizing modern technologies such as machine learning and facial recognition. The system focuses on motivating students to participate in environmental activities and proper waste disposal using innovative technical tools.

The proposed system aims to enhancing Environmental Awareness and raise students' awareness of the importance of proper environmental practices such as correct waste disposal.

The proposed system aims to encouraging Positive Environmental Behaviour: Through a point-based reward system, students are encouraged to participate in environmental activities and dispose of waste in eco-friendly ways.

3.1. System Workflow

Students register for the application by creating a new account using their email, password, class, and name, and uploading a facial image for identity verification then Data is stored in the system's database.

When a student disposes of waste in a smart trash bin equipped with a camera, the system captures an image of the student, the image is compared with the stored facial images in the application to verify the student's identity.

The waste that attach from the camera during the student throw it , the camera attach it and classify it by using the machine learning model and give the points based on the type of the waste.

Once identity is verified, a machine learning model is used to classify the type of waste, Points are awarded based on the waste type (e.g., 5 points for a mouse, 10 points for a keyboard, etc.).
The teacher monitors student performance through a dashboard, identifies top-performing students based on points, and provides appropriate encouragement.

3.2. Key Components of the Proposed Model

3.2.1. Application Mobile Phone

The application consists of (input & output screens)

The input screens consist of (Select language screen) This is the first screen that appears when the user opens the app. It is used to select the preferred language for use, either Arabic or English, to provide a multilingual interface that accommodates all users, enhancing usability and expanding the system's applicability in different environments.

Once the language is selected, the entire app interface switches to the chosen language, and the user is directed to the Select User Screen.

(Select User Screen) This screen appears immediately after language selection and is used to determine the user type: Student or Teacher, to differentiate app jobs based on user type, as each category (student and teacher) has different interfaces and tasks within the system.

If Student is selected: The user is taken to the Objective Screen, If Teacher is selected: The user is taken directly to the Create new account screen for teacher, It also includes a button for logging in if the user already has an existing account registered in the database.

(Objective Screen) This screen displays the purpose of creating the application, which is to promote green computing culture in educational institutions. It also includes a section explaining the application's problem, focusing on environmentally friendly waste disposal. It presents the tools used to design the application, including the Dart programming language.

(Create New Account Screen for Students) Allows students to register using their name, class, email, password, and facial recognition. After the student registers for the first time, the data is saved in the database for future image comparisons. If the student does not provide any required data (name, email, password, class, or facial recognition), an alert message appears prompting them to complete the necessary information. The student cannot proceed to the next screen until all required fields are filled in and the facial recognition image is successfully captured.

A camera is mounted on the trash bin inside the computer lab. The camera captures an image of the student while disposing of waste and compares it with the image previously saved during registration. If the images match, a Statistics Screen (an output screen) appears showing the type of waste, time of disposal, and points earned. This data is saved in the pre-prepared database along with the student's information for future reference.

(Student Login Screen) Students log in using their email and password. If the credentials are already stored in the database, a "Verified" status is displayed.

(Student Thanks Screen) Displays a thank-you message from the teacher to students who earned the highest points. This screen aims to boost students' motivation to maintain their positive behaviour and commitment to green computing goals, and to enhance their sense of achievement and recognition.

(Application Capabilities Screen): Presents a list of the application's features and capabilities.
(Create new account screen for teacher): Allows teachers to register using their name, email, and password. After registration, the data is saved in the database.

(Teacher Login Screen) Teachers log in using their email and password. If their data already exists in the database, a "Verified" status is shown, allowing them to monitor student progress.
From the output screens (Student Statistics Screen): This screen is linked to the Student Login Screen. After the student logs in and their facial image is verified by comparing the one captured during waste disposal with the one stored during registration, the following data is retrieved from the database and displayed on this screen: the student's name, class, email, password, date of waste disposal, and the points earned, The type of waste.

(Top Students in the Class Screen): Displays the names of students who actively participated in the app and properly disposed of waste, earning the highest points. Based on the data entered through the Student Login Screen, students are ranked according to the number of points they earned for disposing of waste.

(Teacher Dashboard Screen): Displays the total number of students registered in the app and the total number of points earned. A dropdown list shows the names of all registered students. When a teacher selects a student from the list, the following data is displayed: full name, registered class, type of waste, time of disposal, and points earned. It also shows the top student with the highest points and their class.

- The teacher's dashboard is an essential tool that allows the teacher to monitor student performance in the "Green Computing" application and assess their interaction with the system. This dashboard enables the teacher to track points and student activities.
- View Student Information: The teacher can view student details registered in the app, such as name, email, class, and points earned and Monitor Performance: The teacher can see how many points each student has earned based on their behaviour in waste disposal, track their progress in collecting points, and evaluate their environmental

behaviour.

- View Waste Record: Shows an updated log of the types of waste disposed of by students (e.g., mouse, keyboard, etc.),The Waste Record also includes additional details such as the disposal date and the type of point associated with it.
- Display Student Rankings: Displays the students' rankings in the class based on the points earned. The teacher can identify top-performing students and reward them.

3.2.2. Database of the Proposed System

The database in this application contains three main records: **Students Record (students)- Waste Records (waste records) - Teachers Record (teachers)**

Figure 1 illustrates the structure of the student records stored in the Firebase Fire store database for the proposed application. Each student document contains personal and login information, including the student's name, registered class, email address, password, and a facial image encoded in Base64 format. This data structure enables secure user authentication and supports the facial recognition functionality used within the application.

Base64 is a binary-to-text encoding scheme that converts image data into a text string, allowing it to be stored efficiently in the database and easily retrieved for processing. This encoded string can be decoded within the application to display the image as needed for facial recognition and student verification processes.

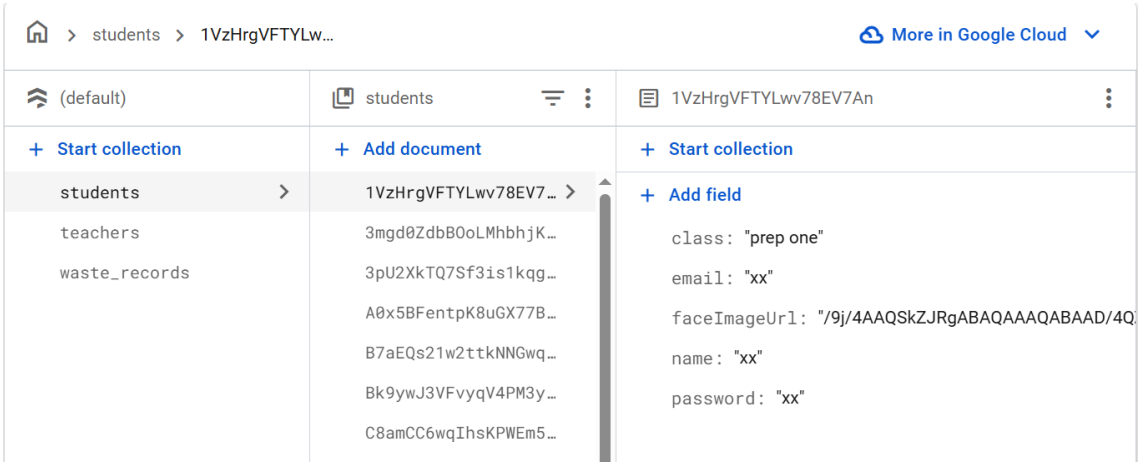

Figure 1: shows the student data record in the database.

In (Figure 2) The waste record contains data on every waste disposal action performed by students. It logs the confidence level (based on waste type), points awarded, the student's ID, an image of the waste, date of disposal, and type of waste, the students table is linked to the waste records table through the student_id, allowing each waste record to be associated with a specific student.

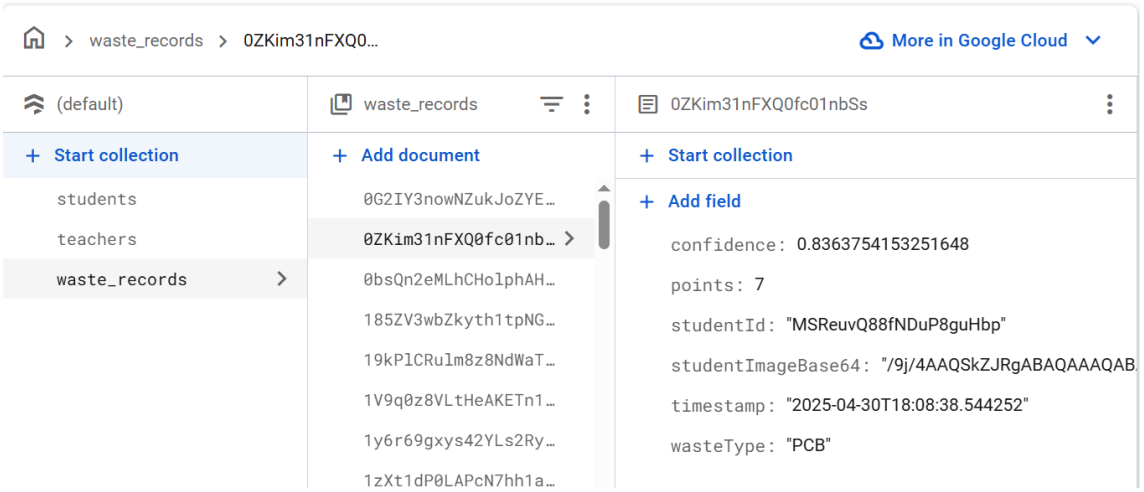

Figure2 : shows the waste records in the database

In (Figure3) Teachers Record (teachers)This record contains the data of teachers who have the authority to monitor students through the application.

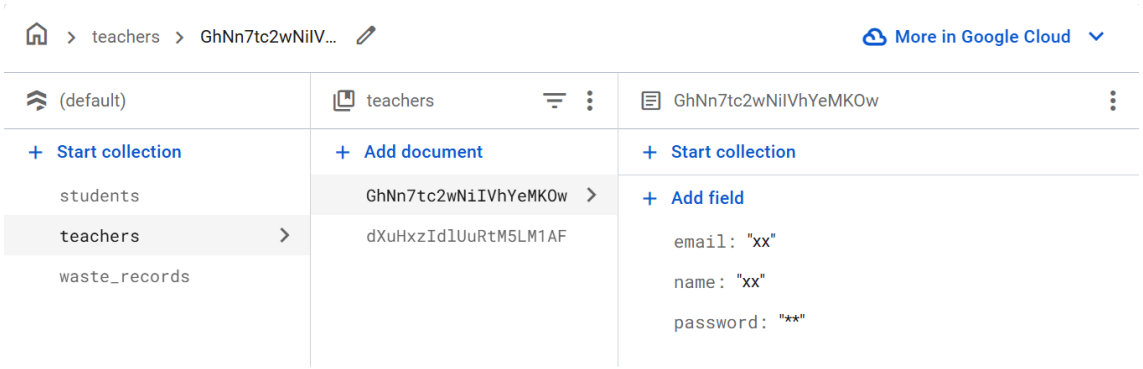

Figure 3 : shows the teachers' record in the database.

When a new student registers → their data is added to the students table, When logging in → the system searches for the email and password in the students table. If correct, a "Verified" notification appears, and the student proceeds to the student statistics screen, When disposing of waste → the information is stored in the waste records table and linked to the student via student_id and When a teacher logs in → the system searches their credentials in the teachers table. If valid, they are granted access to the control panel to monitor student progress.

3.2.3. Waste Classification Model

The model consists of Several convolutional layers for extracting visual features from images, pooling layers to reduce data dimensions, fully connected layers that make the final waste classification decision.

This model relies on Convolutional Neural Networks (CNNs), which have proven highly effective in image classification.

From the advantages of the model High Classification Accuracy: The model is based on CNNs, one of the most advanced image classification technologies and Tests showed it can accurately

classify waste types, which helps validate the waste disposed of by students.

Real-Time Performance and Speed: The model processes and classifies images quickly—in a matter of seconds. And Enables immediate point assignment to students upon waste disposal in the smart bin.

Customizability: The model can be fine-tuned with local data to improve its accuracy for Egyptian school environments and common waste types. And It was tested on real waste samples and performed accurate classifications.

Support for a Wide Range of Digital Waste Types: Such as mouse, keyboards, batteries, cables, motherboards, electronic boards, storage media (USBs, CDs), printers, and ink cartridges.

Enhanced User Experience: Provides a smooth experience for students as it automatically recognizes waste types without manual data input and Increases student awareness of eco-friendly waste disposal by awarding points for correct behaviour.

4. EXPERIMENT AND EVALUATION

- **Sample Study**

The study sample consisted of (25) student from the preparatory stage at the Royal British School in New Damietta City, during the second semester of the academic year 2024-2025 AD. This sample was selected due to the relevance of the ICT curriculum content in this educational stage to the study's topic, which covers the importance of green computing and methods of environmentally friendly disposal of electronic waste.

Pre- and post-assessment tools were applied to the same sample to measure the impact of the proposed system on students' awareness and behavior towards disposing the electronic waste.

The experiment aimed to measure the impact of the proposed system on encouraging students to adopt positive environmental behaviours and dispose of electronic waste in an environmentally friendly manner, contributing to reduced harm for future generations.

- **Data Collection**

A list of e-waste was collected from the education sector, and a list of 76 e-waste items was created and presented to a group of experts to determine the extent to which this waste was harmful to the environment. Based on this list, After analysing the opinions, points were assigned according to the waste type such as the keyboard was rated **10 out of 10** in terms of harmfulness according to the experts' opinions.

This points put in the designing the model to classify the e-waste. The following figure 4 shows the points students received based on the type of waste dumped, Student 1, Student 2 achieved 800 points in the application by disposing of high-impact e-waste items.

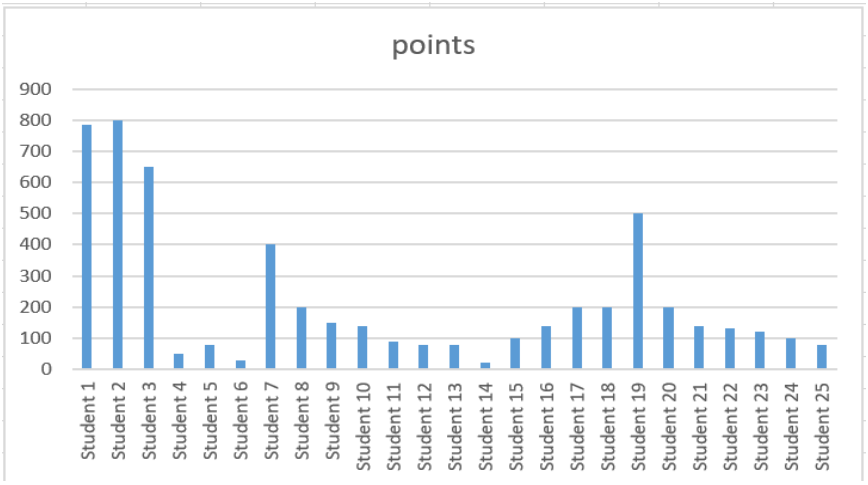

Figure 4 : shows Points Earned by Students for Waste Disposal

- **System Experiment**

An observation card consisting of a set of skills was prepared and applied to the sample before and after implementing the proposed system and consists of 9 skills. It became clear that the system had an effective impact on the students' behaviour.

In figure 5 shows behaviours the students per- apply the system Thus, the proposed system had a clear effect on enhancing students' environmental behaviours.

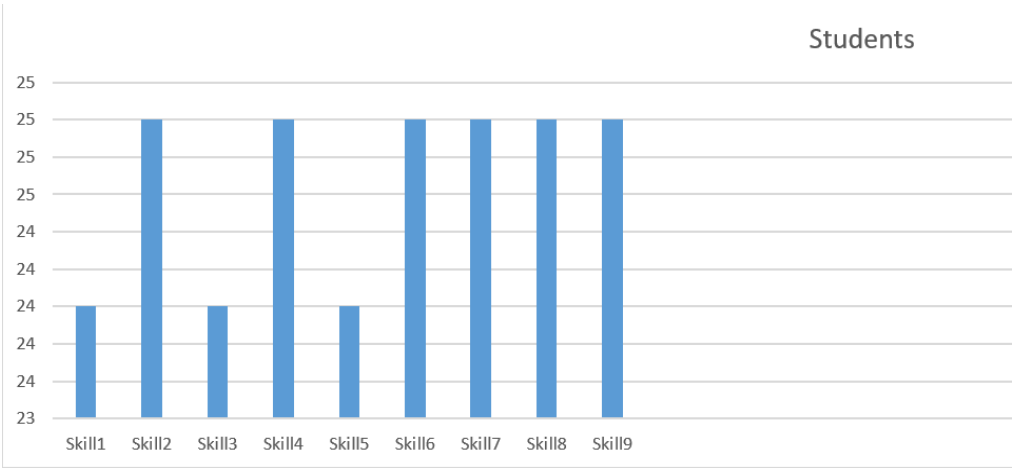

Figure 5 : shows behaviors the students per- apply the system

- **Observations and Results**

These differences were measured using the T-Test for paired samples, and the results were as follows:

The T value for the all skills was (-35.67) at a significance level of < 0.001, which is less than 0.05, indicating a statistically significant difference in favor of the post-test.

The mean score before application was (0.12), while the mean after application was (0.90),

indicating a clear improvement in student performance after using the proposed system.

The effect size (η^2) was calculated to be 0.9815, indicating that 98.15% of the performance change is attributed to the impact of the proposed system. This is considered a large effect size according to established statistical standards.

- **Summary of Results**

The results clearly indicate that the proposed system effectively contributed to enhancing students' awareness and behaviours related to applying green computing principles within the educational environment. This supports the effectiveness of integrating machine learning technologies in developing sustainable environmental practices in schools.

- **General Comment on the Results**

These results are consistent with recent studies in the field of green computing, such as Jaber et al. [24], The study demonstrated the extent to which AI technologies can be leveraged to achieve an efficient, sustainable environment with low carbon emissions. These technologies can also be used to reduce energy and electricity consumption, rationalize consumption, and recycle computer waste.

Furthermore, the result support in "A Focus on Green Computing", from the book Promoting Sustainable Practices in Emerging IT Technologies, which emphasized that raising students' awareness of green computing through intelligent and interactive systems directly impacts their daily practices regarding electronic waste management and participation in recycling initiatives.

Accordingly, this study contributes to filling a research gap in the Arabic literature by presenting a practical model for implementing green computing in schools using machine learning technologies, in line with modern global trends aimed at achieving Green Computing goals.

5. FUTURE WORK

The researcher recommends the following further research in view of the findings of the current study and the proven efficacy of the suggested system in encouraging green computing practices:

- ✓ An expert system based on artificial intelligence techniques to raise teachers' awareness of environmental issues.
- ✓ An expert system that supports virtual reality and augmented reality technologies to teach students to dispose of electronic waste in an environmentally friendly manner.
- ✓ A proposed system based on the Internet of Things to track students' classroom behaviour in a computer lab.
- ✓ An expert system to clarify the relationship between elementary school students' achievement and their awareness of the importance of green computing.

6. CONCLUSIONS

In conclusion, this study aimed to develop an intelligent system based on machine learning technology for electronic waste management within the educational field to promote green computing practices. The results demonstrated that the proposed system was effective in

enhancing students' environmental awareness, encouraging proper e-waste disposal, and fostering sustainable behaviours.

The integration of facial recognition and waste classification models allowed accurate monitoring of student participation, and the points-based reward system motivated students to adopt eco-friendly actions.

This research contributes to bridging the gap between artificial intelligence applications and environmental sustainability in education by providing a practical model that can be implemented in schools and universities to manage e-waste efficiently while raising environmental consciousness among students. Future studies may explore expanding the system's functionality to include broader waste types, integrating with smart campus infrastructures, and evaluating long-term behavioural impacts on larger student populations.

REFERENCES

[1] Mall, P., & Gupta, S. (2024). Green cloud computing. IBM Cloud Education. Retrieved from https://www.ibm.com/cloud/blog/green-computing

[2] Rathi, P. (2024). Promoting sustainable practices in greening the future: A roadmap sustainability.

[3] Verma, R., Gautam, S., & Sahu, S. (2024). Introduction to Green Computing for Smart Cities. In Green Computing for Sustainable Smart Cities (pp. 1-19). CRC Press.

[4] Alsharif, A., Alsharif, M. T., Samman, M., Binmadi, N., Kassim, S., Mourad, S., & Warnakulasuriya, S. (2023). Forecasting head and neck cancer trends in GCC countries: Implications for public health policy and strategy. Risk Management and Healthcare Policy, 16, 2943-2952.

[5] Master of Project Academy. (2025, January 25). The future of project management: Embracing AI-augmented work by 2030. Retrieved from https://blog.masterofproject.com/aidrivenprojectmananagement/

[6] Farismana, R., Amalia, D. R., & Darsih, D. (2024). Implementation of a monitoring information system for student field work practices to support green computing: Case study of the Kertasemaya Teladan Vocational School. Rekayasa Hijab: Journal Technology Ramah Lingkungan, 8(1), 25-37.

[7] Trevisan, L. V., Eustachio, J. H. P. P., Dias, B. G., Filho, W. L., & Pedrozo, E. Á. (2024). Digital transformation towards sustainability in higher education: State-of-the-art and future research insights. Environment, Development and Sustainability, 26(2), 2789-2810.

[8] Atadoga, A., Umoga, U. J., Lottu, O. A., & Sodiya, E. O. (2024). Advancing green computing: Practices, strategies, and impact in modern software development for environmental sustainability. World Journal of Advanced Engineering Technology and Sciences, 11(1), 220-230

[9] Kushwaha, N., & Waoo, A. A. 2024 Green Computing On Energy Savings.

[10] Tobel, I. (2024). The Role of Digital Education in Achieving Sustainable Green Campuse Journal of Applied Technical and Educational Sciences, 14(1), No-372.

[11] Ahmad, S., Mishra, S., & Sharma, V. (2023). Green computing for sustainable future and its applications. In Contemporary Studies of Risks in Emerging Technology, Part A (pp. 241-256). Emerald Publishing Limited.

[12] Shrotriya, N., Thakore, P., & Khang, A. (2024). Sustainable IT: A comprehensive guide to green computing and green Internet of Things (IoT) technologies. In Advanced IoT technologies and applications in the Industry 4.0 digital economy (pp. 82-108). CRC Press.

[13] Haque, S., Towfiq, K., Rahman, K. M., & Zafor, A. (n.d.). Green computing policies and regulations

[14] Nyabuto, G. M. (2024). A Review of Current Research Trends in Green Computing. East African Journal of Information Technology, 7(1), 51-59..

[15] Ugonnia, J. C., Olaniyi, O. O., Olaniyi, F. G., Arigbabu, A. A., & Oladoyinbo, T. O (2024). Towards sustainable it infrastructure: Integrating green computing with data warehouse and big data technologies to enhance efficiency and environmental responsibility. Journal of Engineering Research and Reports, 26(5), 247-261.

[16] Biswas, P., Rashid, A., Biswas, A., Al Nasim, M. A., Datta Gupta, K., & George, R. (2024). AI-driven approaches for optimizing power consumption: A comprehensive survey. Discover Intelligence, 4(1), 116. https://doi.org/10.1007/s44163-024-00211-7

[17] Oliver, A. S., Ravi, B., Manikandan, R., Sharma, A., & Kim, B. G. (2023). Heuristic green computing-based energy management with security enhancement using hybrid greedy secure optimal routing protocol. Energy Reports, 9, 2494-2505.

[18] Chowdhury, M. S. (2024). Comparison of accuracy and reliability of random forest, support vector machine, artificial neural network, and maximum likelihood method in land use/cover classification of urban setting. Environmental Challenges, 14, 100800

[19] Barbierato, E., & Gatti, A. (2024). Toward Green AI: A Methodological Survey of the Scientific Literature. IEEE Access,12(1), 23989–24013. https://doi.org/10.1109/ACCESS.2024.3360705

[20] Verma, R., Gautam, S., & Sahu, S. (2024). Introduction to Green Computing for Smart Cities. In Green Computing for Sustainable Smart Cities (pp. 1-19). CRC Press.

[21] Dahmani, S. (2024). Computational intelligence for green cloud computing and digital waste management. In Computational intelligence for green cloud computing and digital waste management (pp. 248-266). IGI Global.

[22] Lokesh, G., Devi, B. R., Badrinath, N., Anjaiah, P., & Kumar, T. R. (2024). Green Computing and the Quest for Sustainable Solutions. In Computational Intelligence for Green Cloud Computing and Digital Waste Management (pp. 24-41). IGI Global.

[23] Verdecchia, R., Sallou, J., & Cruz, L. (2023). A systematic review of Green AI. WIREs Data Mining and Knowledge Discovery, 13(4), e1507. https://doi.org/10.1002/widm.1507

[24] Jaber, M. M., Yussof, S., Ali, M. H., Abd, S. K., Jassim, M. M., Alkhayyat, A., & Mubarak, H. (2024). PPDA-FAF: Maintaining data security and privacy in green IoT-based agriculture International Journal of Cooperative Information Systems, 33(01), 2250007.