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Encouraging Sustainable Choices Through Socially Engaged Persuasive Recycling Initiatives: A Participatory Action Design Research Study

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Abstract: Human-Computer Interaction (HCI) research has illuminated how technology can influence users' awareness of their environmental impact and the potential for mitigating these impacts. From hot water saving to food waste reduction, researchers have systematically and widely tried to find pathways to speed up achieving sustainable development goals through persuasive technology interventions. However, motivating users to adopt sustainable behaviors through interactive technologies presents significant psychological, cultural, and technical challenges in creating engaging and long-lasting experiences. Aligned with this perspective, there is a dearth of research and design solutions addressing the use of persuasive technology to promote sustainable recycling behavior. Guided by a participatory design approach, this investigation focuses on the design opportunities for leveraging persuasive and human-centered Internet of Things (IoT) applications to enhance user engagement in recycling activities. The assumption is that one pathway to achieve this goal is to adopt persuasive strategies that may be incorporated into the design of sustainable applications. The insights gained from this process can then be applied to various sustainable HCI scenarios and therefore contribute to HCI's limited understanding in this area by providing a series of design-oriented research recommendations for informing the development of persuasive and socially engaged recycling platforms. In particular, we advocate for the inclusion of educational content, real-time interactive feedback, and intuitive interfaces to actively engage users in recycling activities. Moreover, recognizing the cultural context in which the technology is socially situated becomes imperative for the effective implementation of smart devices to foster sustainable recycling practices. To this end, we present a case study that seeks to involve children and adolescents in pro-recycling activities within the school environment.

Keywords: community engagement; Internet of Things (IoT); participatory action design research; persuasive technology; recycling; smart bins; sustainable behavioral interventions

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1. Introduction

According to estimates by the Brazilian Institute of Applied Economic Research (IPEA), Brazil generates around 160,000 tons of urban solid waste per day, of which approximately 30% to 40% is considered recyclable. However, only 13% of this waste is sent for recycling. It can be seen that, due to the large volume of urban centers, planning, developing, and experiencing the various social and technological infrastructures of the city are increasingly complex [1]. Thus, such complexity requires a real-time examination of macro/microscopic perspectives to deal with the tangible and intangible constituents of the city as a "hybrid space" between the physical and the digital [2].

Given the increase in waste generation and disposal in cities and the emergence of regulations aimed at effective solid waste management in urban areas, we are witnessing a proliferation in the number of applications in this domain, with a notable increase in the quality and scale of data being generated and managed. This context then requires a new set of strategies incorporated into technologies and applications that promote changes in habitual behavior towards ecological sustainability [3]. Within the field of Human–Computer Interaction (HCI), waste management is an example of the socio-ecological relationship in which society's consumption and disposal habits can have negative environmental impacts [4,5]. In addition, other factors that have driven the growth of systems for effective waste management are linked to the innovation cycle, including the application of advanced data collection techniques combining big data, mobile devices and Internet of Things (IoT)-based technologies [6].

Recent studies suggest that persuasive technological interventions to improve sustainable behaviors are gaining traction [7]. For example, smart and mobile technologies have become attractive channels for delivering personalized and socially responsible interventions to challenge everyday habits [8]. Overall, such technology can help encourage positive individual and community actions to achieve the United Nations Sustainable Development Goals (SDGs), particularly with regard to environmental protection and the promotion of people's health and well-being [9,10]. Building on previous HCI work on persuasive displays for water conservation [11] and eco-friendly devices [12], recent research has focused on promoting sustainable lifestyles through food shopping apps [5] and gamified carbon emission reduction systems [8], just to cite a few.

Regarding the intersectional space between HCI and sustainability, some research works (e.g., [13–15]) have reported strategies that seek to involve citizens in solving non-trivial problems in the urban context (e.g., waste management). However, designers lack practical experience in collaboratively building systems of this nature. Seeking to explore the collaborative aspect, this study adopts a Participatory Action Design Research (PADR) methodology based on collaborative and community-based participatory design [16]. In particular, this work aims to examine how persuasive technologies for sustainability can be adapted to improve engagement in mobile and IoT-based waste management tools, contributing to research focused on user engagement in pro-recycling activities in specific contexts. Similar to the other literature addressing recycling behavior (e.g., [17]), this study considers recycling a fundamental behavior to be examined as it is directly linked to subsequent environmental effects.

This research captured insights into pro-recycling behaviors through a PADR process conducted with students from a public school in a peripheral neighborhood in northeastern Brazil. The school environment was selected as the specific context for examining persuasive technologies due to its implication in the development of habits and behaviors for future generations. On the other hand, we also analyzed innovations proposed in the literature regarding the role of digital technologies in organizing collective pro-environmental actions around waste management [18]. Given the limited understanding within the HCI field about the design of persuasive technology to encourage behavioral change towards recycling, this article contributes to the understanding of the role of the user in the infrastructure of waste management platforms with the school environment as the focus.

The PADR methodology is adopted as a means of understanding which persuasive tools should be prototyped. The choice of methodology was based on the social and community nature of recycling. However, our goal is not to investigate the effectiveness of the PADR methodology, as this will be the focus of future work. Instead, this study examines experiences and challenges in the Global South with a case study where a Web application and a persuasive smart trash bin were implemented and studied in situ using ethnomethodology together with participatory evaluation (see Randall and co-authors [19] for a brief discussion of how the participatory design community has effectively used ethnomethodological work in their research efforts). The school selected for the fieldwork was chosen because of the proximity of one of the researchers to the educational institution as a former student. The observations allowed us to assess how students interacted with persuasive technology, indicating a set of recommendations for design when considering its use to change environmental practices of specific users.

2. Background and Related Work on Persuasive System Design

Persuasive technology is characterized by using persuasive strategies to motivate behavior change. Some studies focus on how persuasive technology motivates behavior change and how to design systems to increase persuasiveness [20]. Traditional definitions limit the scope of persuasive technology to non-coercive and non-deceptive technologies. However, the persuasive influence of technology on society is often perceived negatively, as some applications use persuasive concepts for ethically questionable purposes [21]. There are thus many ethical and socio-technical challenges related to technologies that shape behavior and actions. Fogg [22] devoted efforts to studying how persuasive technology can influence human behavior, being one of the pioneers in the area. According to the author, behavior is a product of three factors: motivation, ability, and triggers. Thus, for a person to perform a target behavior, s/he must be sufficiently motivated, have the ability to perform the behavior, and be activated to perform the behavior through triggers (e.g., a text message that appears in the interface of a persuasive mobile application with an alert to a need for action). These three factors must co-occur; otherwise, the behavior will not manifest.

During the last decades, many persuasive applications have been proposed to encourage users to reduce carbon dioxide emissions [23], sedentary behavior [24], or even unhealthy gaming behavior [25]. According to Oinas-Kukkonen and Harjumaa [26], the development of persuasive systems requires a deep understanding of their fundamental issues a priori to their implementation. This can be any form of ethnographic fieldwork and other informative elements obtained from applying methods to inform system design based on empirical and experimental data. Therefore, it is necessary to examine the context of the application by recognizing the intention, events, and system-use strategies. Moreover, it is also crucial to define the actual qualities of the persuasive technology or evaluate the characteristics of an existing system. These steps are part of the Persuasive System Design (PSD) model, which has been widely used in the area of persuasive technology and applied across various sustainable use case scenarios.

In a broad sense, this model facilitates the development of systems tailored to users' needs and characteristics [27] and its proponents present 28 design principles divided into four categories. The present study primarily adopts Fogg's [22] definitions of persuasion and persuasive technologies in conjunction with the PSD model proposed by Oinas-Kukkonen and Harjumaa [26], as these studies have a complementary relationship. Our research focuses on persuasion in the context of platforms designed to engage users in recycling practices with a focus on sustainability. In taking this approach, we sought to apply a participatory design methodology to involve users in developing the proposed solution. The following section describes how we adapted the PADR methodology for application in the design and development of the persuasive technologies examined.

3. Methods

From a methodological perspective, the Participatory Action Design Research (PADR) approach actively involves end users in designing, developing, and evaluating systems to ensure that the solutions developed meet their needs and expectations. Given the demonstrated value of this participatory and integrative approach in HCI and related fields, the investigation presented here adopts the method proposed by Bilandzic and Venable [28] to meet the particularities of persuasive technology using continuous and iterative feedback based on community input. In line with this, a community-based participatory design approach [16] is taken to ensure that diverse voices are heard and considered in the design process. This is because community members can provide unique insights regarding the local context, culture, and social dynamics within which the technology is being situated, which can be used together to inform the design process and help create sustainable HCI solutions that are more contextually grounded. Figure 1 depicts the activities of the PADR methodology adapted to the research on persuasive technologies that served as the basis for this study. The highlighted activities were added to meet the needs of persuasive system design.

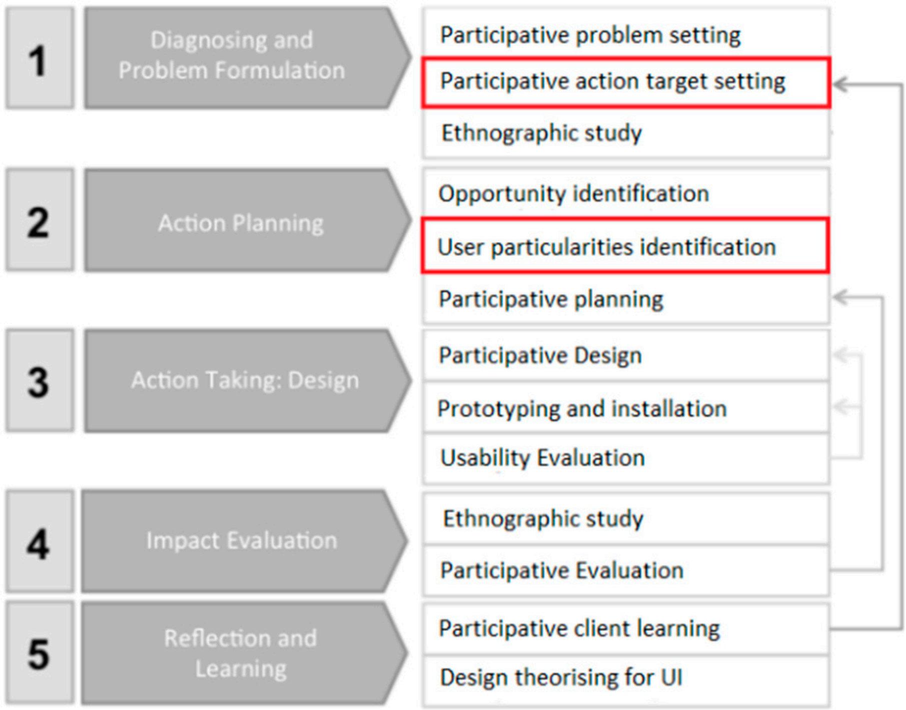

Figure 1. The PADR methodology adapted to the context of persuasive technology.

3.1. Diagnosing and Problem Formulation

This stage justifies the design of the technological artifact and is associated with an initial empirical investigation of the problem based on observations, ethnographies, questionnaires, interviews, document analyses, etc. The research problem may be anticipated by researchers or realized in practice, providing the impetus for formulating the research effort. As previously noted, understanding the fundamental issues behind the persuasive system before its implementation is basically a must in in this line of work. As a result, it was decided to add the participatory action target-setting activity at this research stage to underscore the need to analyze the application context while recognizing the intention, events, and strategies for using the system as recommended by the PSD model.

3.2. Action Planning

At this stage, researchers frame the problem to identify opportunities and engage in participatory planning for the solution. The aim of the research conducted in this context is not merely to technically solve the problem or intervene in the social context alone but to reconcile these two approaches [29]. We opted to include the activity of identifying user particularities at this stage, as it is a crucial step in co-creating persuasive systems. At this juncture, it is analyzed whether the target user of the system is sufficiently motivated and can perform the expected behavior so that appropriate triggers can be planned.

3.3. Action Taking: Design

In the third stage of the PADR methodological approach, the challenge lies in translating the design principles into an application while prototyping and implementing the participatory design solution. The artifact reflects the preliminary design and incorporates the participants' social shaping and perspectives through participatory design. At this point, the initial usability assessments of the proposed solution are carried out. If the usability results are unsatisfactory or below a certain threshold, it is recommended to rethink the design and make adaptations to the prototyping and implementation.

3.4. Impact Evaluation

The fourth stage of the PADR methodology relies on ethnographic fieldwork in conjunction with participatory evaluation to assess the impact of the artifact. The goal is to gather evidence indicating whether the new technology helps solve the relevant problem or achieves the desired improvements. If the impact evaluation is deemed insufficient—meaning that the original project goals are not met or new problems arise—a decision can be made (by mutual agreement) to iterate through the initial phase, replanning the research and subsequently redesigning and re-implementing the system [28].

3.5. Reflection and Learning

This stage involves formalizing the learning process. Participants must reflect on their experiences and discern key insights and takeaway lessons. Consequently, researchers articulate the project's outcomes to formalize learning. These outcomes may be materialized as design principles, recommendations or, in some cases, refinements of theories that informed the initial design. Collaborative reflection and learning enable stakeholders to take this knowledge forward for the broader community's benefit. This encompasses not only the sustained adoption and use of the current technological solution but also the continued development, usage, and adoption of new technologies in the future.

4. Research Setting and Results

The previous section outlined the phases of the PADR methodology adapted to the context of persuasive technology. This section aims to describe the research setting and the study outcomes based on the main activities undertaken in each project phase. Figure 2 presents a diagram with the main activities carried out and the expected result in each stage of the PADR. This approach enabled us to co-create persuasive solutions and enhance their effectiveness throughout the development cycles. In particular, this paper reports the outcomes of two design cycles that culminate in the implementation and evaluation of two technological artifacts.

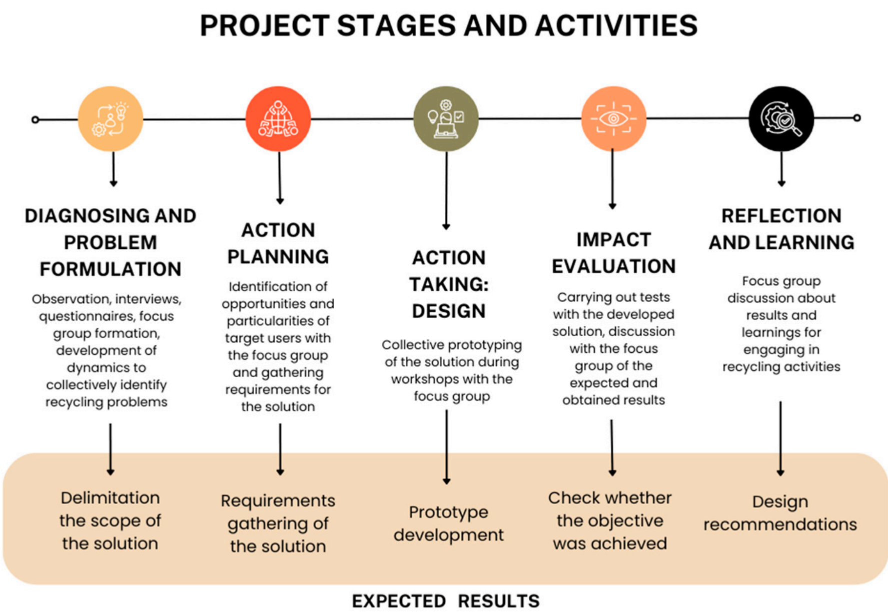

Figure 2. The activities and expected outcomes from each stage of the PADR methodology.

4.1. Design Cycle 1—Web Application

Following the PADR methodology, the activities that encompass problem formulation, action planning, design and prototyping, and impact assessment of the Web application were carried out during the first design cycle. Most of the activities in Cycle 1 were carried out with a focus group consisting of eight students aged between 14 and 16, from the Juscelino Kubitschek Municipal Elementary School, located in the Coroa do Meio neighborhood in the city of Aracaju, Brazil. The focus group was formed at the request of the school administration and included 9th grade elementary school students who were taking the extracurricular course “Introduction to Informatics” in partnership with the João Carlos Paes Mendonça (JCPM) Institute of Social Commitment. In view of this, the school coordinators formally invited the students to participate in the focus group meetings outside of class time to develop and analyze a technological solution aimed at engaging the school community in recycling activities. Out of an approximate total of 15 students taking the extracurricular course, 8 students accepted the invitation to be part of the focus group. The focus group meetings took place once a week for a period of 6 months in 2022. Below is a description of the main activities conducted in Cycle 1.

4.1.1. Diagnosing and Problem Formulation (Cycle 1)

Our initial design problem involved creating a persuasive solution to engage users in recycling activities with a focus on the school environment. Therefore, the focus group sessions were aligned with the interests of the present investigation, which emerged from field observations conducted during an ethnographic study by the lead researcher. After a few weeks of initial ethnographic observations, a recurring issue emerged: the inappropriate disposal of recyclable materials. Despite the presence of an Ecopoint in the neighborhood—a specialized facility for collecting recyclable materials—many residents claimed to be unaware of its existence and, consequently, disposed of recyclable materials together with regular trash. Furthermore, the school did not have a selective collection service, which meant that all waste was indiscriminately deposited in a regular trash container. Through unstructured interviews with neighborhood residents, professionals, and students, it became evident that waste disposal is often performed thoughtlessly, as many interviewees claimed not to consider the consequences of their actions when disposing of waste.

According to Culiberg and Elgaaied-Gambier [30], social norms play an important role in adopting sustainable behaviors. Therefore, recycling behaviors should not be analyzed considering individual predispositions alone. The authors suggested considering the social factors that influence sustainable behaviors, distinguishing between injunctive norms (representing a socially shared rule of conduct) and descriptive norms (which reflect people's visible behavior), since both types of norms represent separate sources of motivation. Seeking to identify social factors that could influence participation in recycling, a questionnaire was developed by the researcher in charge and was applied to several classes of 9th grade elementary school students, with approximately 110 respondents. Among the questions raised, students were asked about their waste disposal practices at home and at school to discern any differences in disposal behavior that the social environment could influence.

The results revealed that students perceive themselves as more actively involved in recycling within the school environment. As illustrated in Figure 3, while 18.7% of students reported separating their household waste for recycling, 47.6% indicated that they separate waste generated at school for recycling. Regarding injunctive norms, there is a socially shared conduct at school regarding waste disposal, likely influenced by the presence of colorful bins for selective disposal within the school premises, even though the waste is ultimately disposed of in common trash bins.

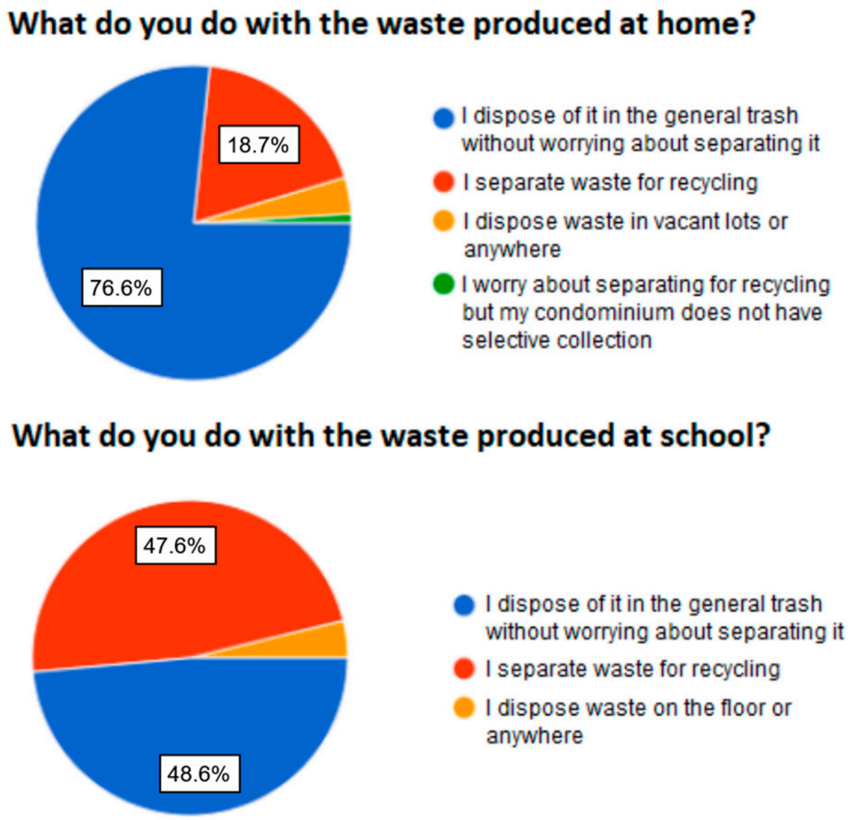

Figure 3. Waste disposal behavioral choices in school and home environments.

The questionnaire developed also included a question related to the main reasons that hinder participation in recycling, which assessed the respondent's agreement with statements about existing barriers to sustainable behavior found in the literature [31]. As depicted in Figure 4, the primary causes affecting recycling behavior were the lack of expertise about where to dispose of recyclable materials, followed by the lack of knowledge about waste separation.

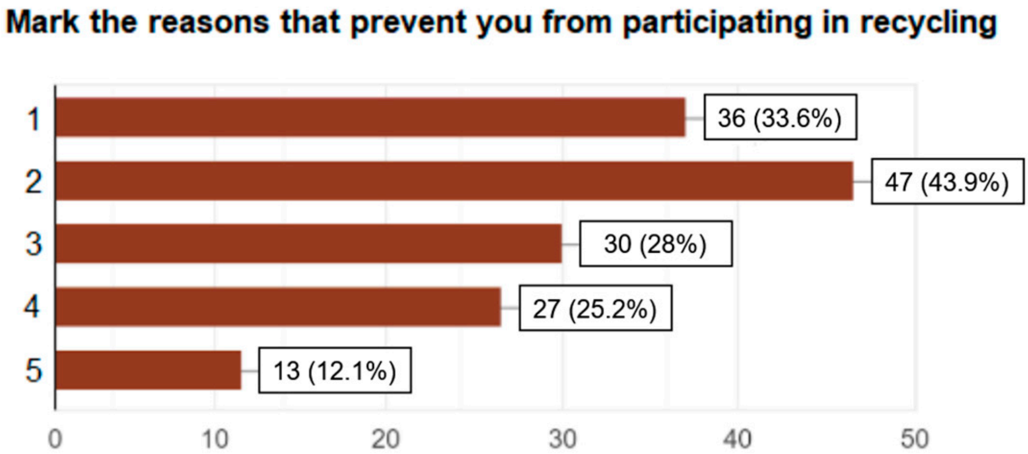

Figure 4. Main reasons that prevent engagement in recycling. (1) Lack of knowledge on how to separate waste; (2) lack of expertise on where to dispose of recyclable materials; (3) lack of will, as recycling requires significant effort; (4) lack of space at home to store materials before handing them over for recycling; and (5) lack of hope, as some believe that recycling makes no difference to environmental preservation.

After collecting the initial data through an ethnographic study and a questionnaire-based survey, the focus group sessions began with the presentation of the data collected and the implementation of a dynamic focused on the topic of recycling using the Matrix of "Certainties, Assumptions and Doubts" (MSC), a User Experience (UX) tool that consists of surveying certainties, assumptions, and doubts about a problem [32]. During the development of this focus group dynamic, two issues stood out from the research carried out: younger people recycle less than middle-aged adults, and the costs of transporting and collecting recyclable materials make it difficult to adhere to recycling. In light of these findings, the scope of the investigation was limited to developing a personalized solution for children and adolescents to raise awareness about recycling, making separation and disposal more appealing. In the background, there was an underlying interest in developing a solution to make the transportation of recyclable materials more efficient.

4.1.2. Action Planning (Cycle 1)

Upon delineating the research problem, the lead researcher, along with the focus group, sought to identify potential opportunities by reviewing solutions aimed at waste management. The first requirement established by the group was the creation of a Web application to raise awareness about recycling. This decision stemmed from the fact that many students have devices with limited memory capacity, thereby hindering them from installing applications that are deemed non-essential. Another critical point the group raised concerns the Web application's content. Participants reported that the way the content is transmitted serves as a differentiator for the students within this age group.

Given the above observations, the Internet meme emerged as a language shared by the target audience, which can transmit a serious message in a relaxed and fun way while making the system more attractive to children and teenagers. This is in line with previous studies focused on platform infrastructure (e.g., [33]), which stressed the process of meme generation as a basis of sociality. That is, the social aspect of memes makes them a way of communicating. By considering memes as a form of language, we can imagine the existence of "speakers" of this language. In other words, using memes as a language can collectively guide conceptions about the world, delimiting an interpretative linguistic community that, inserted in a cultural context, comprises texts produced in communicative dynamics mediated by the Internet [34]. In our study, participants demonstrated a very favorable opinion about using memes to transmit awareness content, so we started workshops to produce memes about recycling.

Considering that the main barriers to recycling activities are the lack of expertise about where to dispose of recyclable materials and the lack of knowledge about how to separate waste, it was agreed among the group participants that this information should be presented in the app. At this point, the group raised another important requirement: in principle, the application would only be informative, not collecting and processing data. As a result, there was no need for user registration, as it was also unanimous among participants that requiring registration would discourage users from the system.

In addition, some opportunities were identified through non-systematic searches for similar solutions in app stores and the academic literature, carried out during tabletop collaboration by the lead researcher and participants. The solutions found were then discussed in focus group meetings. Requirements were raised during the planning activity, and user particularities were identified during focus group discussions based on data collected through the ethnographic study, the questionnaire, and tabletop research guided by the researcher in charge.

4.1.3. Action Taking: Design (Cycle 1)

Based on the research context presented, we conducted a preliminary design of Reciclaju's prototype, a Web application intended to raise awareness about recycling. The term Reciclaju was formed by combining the words "reciclar" ("recycling" in Portuguese) and "Aracaju" (the Brazilian city where the participatory design project took place). Initially, the focus group participants were instructed to develop screen prototypes using the Adobe XD vector-based design tool. The screens were designed collaboratively through the sharing of ideas during the focus group meetings. Based on the data collected in the previous activities conducted by the focus group, it was agreed that the platform should mainly contain information about the 5Rs policy (Rethink, Refuse, Reduce, Reuse, and Recycle), types of Municipal Solid Waste (MSW), separation of materials, and a map with the location of Ecopoints spread across the city (i.e., designated sites for recycling disposal).

Based on this, the first Reciclaju prototype was designed and made available online. For more details about the prototype's source code and the data used in this research, the Reciclaju application repository can be accessed at the following link: https://github.com/emillymar/reciclaju.git. The prototype was developed during introductory Web programming classes attended by students who participated in the focus group. These classes were held in the computer laboratory of the JCPM Institute of Social Commitment through a partnership between the Institute, the school, and the lead researcher. Figure 5 depicts a screen of the Reciclaju application and shows the side menu open with the information topics presented by the application.

The prototyping occurred in conjunction with the meme production workshops, both held during the focus group sessions, so that the content of the memes would dialogue with the information presented in the Web application. Memes are generally created from images, photographs, music, song lyrics, excerpts from films/series, paintings, etc. Thus, during the meme production workshops, the students used some "famous memes" already consolidated on the Internet, replacing only the message to be conveyed. An online tool automatically generating memes from an image bank was also used. Additionally, some memes were created from scratch. After prototyping the solution, we moved on to the impact assessment.

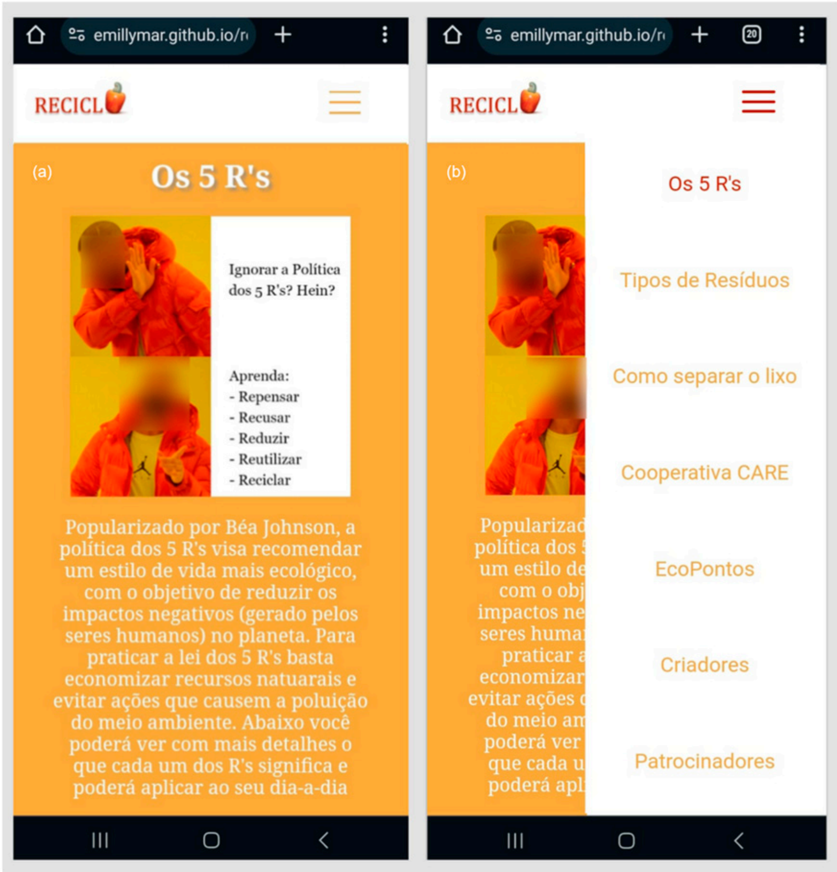

Figure 5. Two screenshots of Reciclaju. (**a**) Left: the 5Rs interface. (**b**) Right: interface with the side menu open.

4.1.4. Impact Evaluation (Cycle 1)

Impact evaluation is an integral part of the PADR methodology, playing a crucial role in assisting the project in achieving its goals and generating a positive impact on the involved community. The data collection methods employed in this study included focus groups, questionnaires, ethnographic study, and tabletop research with UX design dynamics. Before carrying out the impact assessment, it was necessary to define the project goals, which included the expected results and the impact that the project should have on the community, such as changes in practices, behaviors, knowledge, skills, and values of the participants.

By creating a personalized solution for children and adolescents, the aim of this study was to make users consciously reflect on their waste disposal behavior and improve recycling rates in the school. During the focus group meetings, participants reported a change in values regarding the disposal of recyclable materials, indicating an increased awareness of disposal actions. According to the reports of some participants, they began to identify in their routine which materials could be sent for recycling and which should be disposed in common trash so that the very act of disposal began to be questioned. Thus, what was previously an unreflective action became an object of reflection and consideration.

In general, the first goal of the project, which aimed to foster conscious reflection among students regarding their waste disposal behavior, was successfully achieved among the students who participated in the focus group. To evaluate the system's usability, the questionnaire utilized was the System Usability Scale (SUS) [35]. The SUS comprises ten statements on a Likert scale, from 1 (totally disagree) to 5 points (totally agree), allowing participants to assess their level of agreement with the system. In this usability study, the

Web application was presented to 20 students who did not participate in the focus group meetings. However, one questionnaire was incomplete and consequently excluded from the analysis, resulting in 19 valid questionnaires. According to Tullis and Stetson [36], the SUS yields highly reliable results with around 75% accuracy in identifying preferences and problems, even with reduced sample sizes. The authors suggest that sample sizes of at least 12–14 participants are necessary to obtain reasonably reliable results. Therefore, our sample of 19 participants can be considered to be acceptable.

Once data collection through the SUS questionnaire was completed, the information was selected and tabulated by the researcher in charge according to the SUS methodological procedures. The analysis consisted of a specific score calculation that reflected the user satisfaction index regarding the system's usability. A SUS score exceeding 68 is considered above average, indicating good perceived usability, while scores below 68 suggest areas for usability improvement. Besides the overall score, it is recommended that individual responses be analyzed to understand the strengths and weaknesses of the system under evaluation. The overall average score for the Reciclaju application evaluation was 73.2, indicating a good perceived usability.

Among the questions that highlight weaknesses in the Web application, a question that stands out addresses the frequency of use of the application. The majority of participants evaluated it neutrally, neither agreeing nor disagreeing with this statement. This result was expected because it is an awareness application without features for continuous and frequent use. Most respondents agreed that people would quickly learn to use the Web application and that the system is easy to use. However, it was realized during the discussions held in the focus group meetings that the objective of improving recycling rates in the school community could not be achieved with the prototype since it only aims to raise awareness. Given that this objective of the original study was not achieved, a decision was made (by mutual agreement between the researcher and the group participants) to iterate until the initial phase of redesigning the research. Therefore, the focus group proposed the development of a smart trash bin for recyclable materials capable of communicating with waste collectors. Finally, we realized that using the textual genre of memes as a persuasive strategy can make the disposal activity more engaging and enjoyable, a strategy also addressed in Cycle 2.

4.2. Design Cycle 2—Smart Trash Bin

This section describes the study's second design cycle, which involved developing the smart trash bin. Based on the PADR methodology, the activities underlying the problem formulation, action planning, design and prototyping, and impact evaluation were conducted during both design cycles. During Cycle 2, the activities were conducted both by the lead researcher and in conjunction with the previously formed focus group. The primary activities conducted in the second design cycle are outlined and further detailed below.

4.2.1. Diagnosing and Problem Formulation (Cycle 2)

As mentioned before, our initial design problem involved creating a solution to engage the school organization in the selective waste collection process. Considering that Cycle 1 did not achieve the goal of improving recycling rates at the school, we expanded the focus of this study to develop a solution that would facilitate the collection and proper disposal of recyclable materials at the school. This was conducted after extensive discussion during focus group meetings and based on the data collected in the first cycle through questionnaires and ethnographic fieldwork. Seeking to bring the process of collecting recyclable materials to the forefront, the action target for Cycle 2 was delimited to the development of a personalized solution for children and adolescents that could make the task of separation and disposal of waste more attractive, aiming to improve recycling rates while also considering the costs of transport and collection of recyclable materials. Therefore, developing a persuasive smart trash bin was the solution raised for waste disposal.

4.2.2. Action Planning (Cycle 2)

After defining the new action target, we conducted a scoping review to investigate the main persuasive principles used in smart bin projects [37]. Such a review helped identify the breadth and diversity of studies on the topic. Understanding how persuasive smart trash bin designs are being developed helped us create a personalized and efficient solution. According to the review results, the persuasive strategies of the PSD model most frequently used in persuasive smart bin projects were normative influence, surface credibility, tunneling, appearance, adaptation, self-monitoring, and praise. Using this information, we sought to adapt these strategies to our prototype, listing requirements based on the solutions analyzed during the focus group meetings.

The first requirement was to automate communication between smart bins and the trash collectors to improve the efficiency of recycling pickup by giving them real-time updates on bin fullness. This requirement mobilizes the strategies of superficial credibility and tunneling simultaneously, while the surface credibility strategy is based on demonstrating a competent appearance through process automation by facilitating activities and providing information and immediate feedback. In this sense, automating communication between the smart trash bin and the trash collectors facilitates the collection activity, which is only carried out when necessary, and provides information on the status of the bin immediately. The tunneling strategy, in turn, aims to guide users in carrying out activities. Hence, providing information about the smart trash bin's filling level assists the trash collectors in completing the recycling pickup task while reducing periodic transportation costs.

Following the previous requirement elicitation process, the group established a second requirement based on the presentation of memes through a screen with messages encouraging the disposal of materials in the smart trash bin and providing positive feedback. This requirement mobilizes the strategies of superficial credibility, appearance, and praise simultaneously. The superficial credibility strategy is enacted through immediate feedback related to waste disposal, suggesting a competent appearance. Concerning the system's design, the smart trash bin becomes visually appealing due to the drawings and animations presented in the memes. Finally, the praise strategy is activated through the use of memes which offer praise as feedback to encourage recycling behavior.

After a few focus group sessions, the planning phase of Cycle 2 was completed and we started designing the solution. Despite identifying several vital strategies in the scoping review, some were not translated into requirements and incorporated into the prototype due to project constraints such as time limitations, lack of expertise, and technical resource constraints. However, these strategies studied during the scoping review hold significant potential for future exploration. That said, the next subsection presents more details on the design activity of the persuasive smart trash bin prototype.

4.2.3. Action Taking: Design (Cycle 2)

Building upon the research context provided, the focus group developed the preliminary design of the first prototype of the smart trash bin integrating IoT-based persuasive technologies. The initial design was informed by the questionnaire, scoping review, and workshops held with the focus groups. Using a community-based participatory design approach, the design of the smart trash bin was collectively conceived through sharing ideas during focus group meetings. As can be seen in Figure 6, it is a substantial bin with a monitor installed on the upper surface, a small hole through which the materials must be disposed, and some drawings to draw attention to the bin. In general, the main goal of the smart trash bin is to detect the disposal of materials and provide feedback in the form of a thank you meme.

Figure 6. Persuasive smart trash bin.

Consequently, one key question was how the disposal process would be detected. After considering the available sensors at the Network and Multimedia Laboratory (LabNet), where this research phase was conducted by the lead researcher, it was decided to utilize a laser sensor in conjunction with a Light Dependent Resistor (LDR) sensor. In this setup, the laser is directed at the LDR sensor and, when the beam of light is interrupted by the passage of material, it triggers the presentation of the thank you meme.

Another requirement raised in the previous step concerns detecting the bin's filling level. It was decided to use an ultrasonic sensor to measure the distance between the top of the bin, where the sensor is installed, and the trash level. The ultrasonic sensor is commonly used in the literature on smart trash bins. Therefore, when a certain level of waste is detected, the bin is considered to be full, requiring the collection of materials inside. The project used the Raspberry Pi 3 Model B+ microcomputer, chosen due to its ease of connecting to the Internet via Wi-Fi and the USB and HDMI inputs, enabling the connection of peripherals such as keyboards and webcams.

During this study, a Telegram chatbot was also used to communicate between the smart trash bin and the trash collectors. As Figure 7 shows, the chatbot has two commands for communicating with the trash bin: an initial greeting command and a command to request information about the bin's status. The bot replies to the greeting command with a greeting-ready message, while the request command elicits information about the bin's filling level. For more details about the prototype's source code and the data used in this study, the reader can access the smart bin repository at the following link: https://github.com/emillymar/SmartBin.git.

Figure 7. Chatbot used to alert users about the filling status of the smart trash bin.

At the same time, workshops were held with the focus group to develop the memes that the smart trash bin would present. During the workshops, it was decided that there would be two types of memes: "default memes", which would be presented constantly, and "feedback memes", which would be presented upon detecting waste disposal. In this way, the system starts with a default meme on the screen, randomly selected from the list of default memes. After the detection of disposed materials, a feedback meme is randomly selected from the list and presented on the screen for 5 s. Subsequently, a new default meme is randomly chosen to remain on the screen until the next interaction. We proceeded to the impact assessment after completing the smart trash bin prototyping.

4.2.4. Impact Evaluation (Cycle 2)

The data collection methods used in design Cycle 2 included focus groups, questionnaires, user interviews, and participant observation. During the focus group meetings, participants had already reported a shift in values concerning the disposal of recyclable materials during Cycle 1. With the prototype of the smart trash bin in Cycle 2, students reported that the action of reflecting on the waste they produce intensified, as they could put into practice the recycling of materials. Another critical aspect mentioned by the students is that the smart trash bin facilitates disposal, as many were previously unsure of where to dispose of the materials properly. In addition, the fact that the smart bin is fun and provides a good example to be followed was widely discussed among the students.

Usability testing of the smart bin took place over a 4-week period. During the first 2-week period, the bin was placed in the school without interactive features. Later, during the following 2 weeks, interactive tools were integrated into the smart trash bin to assess whether interactivity and communication through memes could increase community engagement during the recycling activity. Participant observation carried out by the researcher in charge was used as a data collection technique during the tests. In addition, the amount of waste collected in each period was recorded.

The first noteworthy observation is that students from the early elementary level were more engaged in the proposed activity, regardless of the presence of interactivity tools. Specifically, students from the 1st to the 5th year were the most active group in bringing materials from home to dispose of in the trash. Conversely, students in the later elementary school years did not participate with the same assiduity in this study.

Another factor that deserves to be highlighted is that some teachers became involved in this study and brought recyclable materials from home to dispose of in the smart trash bin. The project gave the entire school community a new look at the waste generated. For example, during the first week of testing with the smart trash bin, the teachers had a get-together. Even without the researcher being present at the event, the teachers disposed of plastic bottles in the smart trash bin. Due to the large amount of waste generated at the event, the bin filled quickly but the teachers still separated the waste into 100 L plastic bags so that selective collection could be carried out. This event generated an unusually high amount of waste, compromising the accounting of materials collected in both bin test periods. However, considering that the event occurred when the bin lacked interactivity tools and the amount of materials collected during the two periods was practically the same, it can be deduced that the amount of waste collected in the bin using interactivity tools would be greater under normal conditions.

As a new data source, a survey was administered to a total of 35 9th grade students who were not involved in the development of the solution during the focus group meetings. The first question on the survey asked if the respondent had used the smart bin at any point during this study. As shown in Figure 8, 42% of participants said they had used the smart trash bin at least once to dispose of recyclable materials, while 34% reported using it twice or more. A total of 20% of participants reported that they did not use the smart trash bin at any time. Only one student mentioned using the interactive smart bin just for fun (without disposing of recyclable materials) by simply activating the sensor to watch the memes change on the screen.

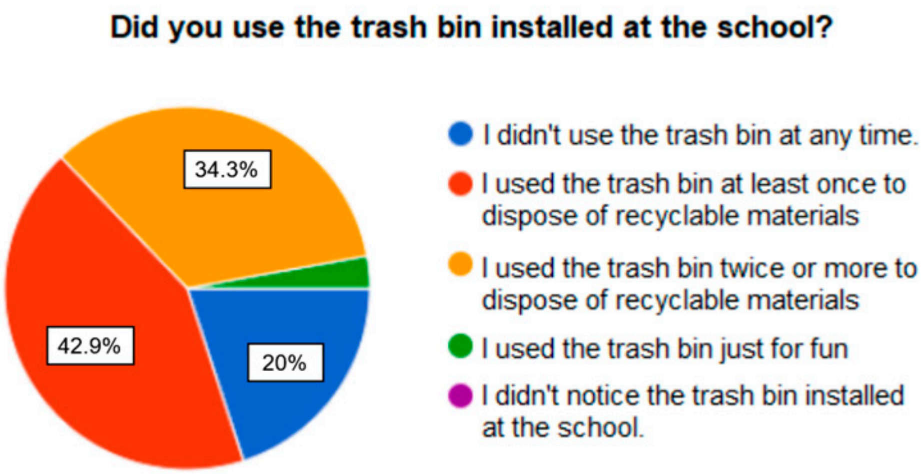

Figure 8. Results of the questionnaire data on the usage of the smart trash bin.

Another intriguing aspect noticed through the questionnaire concerns using the Web application developed in Cycle 1 in conjunction with the smart trash bin developed in Cycle 2. Out of the total of 35 students who responded to the questionnaire on using the smart trash bin, 19 students who had previously been exposed to the Web application also participated in the usability test of Cycle 1. By analyzing the results of the questionnaire, evidence suggests that utilizing the Web application can lead to increased usage of the smart trash bin, indicating promising potential for the joint use of these two solutions.

Generally, observations during the 4-week trial period indicated increased activity around the bin when equipped with interactive tools. As shown in Figure 8, the presentation of memes on the screen next to the smart trash bin aroused much interest among students, especially younger children in the early years of elementary school. As depicted in Figure 9 (Inform Consent see Supplementary Materials: File S1), the vast majority of interactions occurred without any disposal of recyclable materials because the students began to place and remove their hands and other objects in the hole to view the thank you memes upon realizing that the screen displayed feedback memes when capturing the passage of materials through the disposal hole.

Figure 9. Students in the early years of elementary school interacting with the smart trash bin.

Regarding the IoT communication module, a Telegram chatbot was chosen to communicate the status of the smart trash bin to the person responsible for collection due to its ease of implementation. However, it was noticed that the trash collectors did not accept Telegram as a means of communication. Furthermore, as a prototype, the smart trash bin is filled quickly with a reduced volume. In this sense, the trash collectors were not available to collect it daily; rather, the trash was only collected on specific days of the week. Therefore, it was necessary for the smart trash bin to be emptied by the school staff and the waste stored elsewhere to await collection by trash collectors on the scheduled days.

Consequently, the IoT tool did not prove to be effective in solving the intended problem of making the process of collecting recyclable materials more efficient, as the trash collectors did not reduce visits to the school to carry out the collection, considering that the bin was always full of waste on the predetermined collection days. Another potential use for the IoT tool could be to alert school staff when the bin needs to be emptied. However, since cleaning staff regularly check and empty all school bins, implementing an additional method specifically for the smart trash bin would be redundant.

5. Discussion and Formalization of Learning

The Brazilian scenario presents some particularities regarding waste disposal. Specifically, Brazil is a country of continental dimensions, resulting in significant waste production alongside large regional disparities. This impacts waste management as different regions have varying infrastructures and capacities to handle waste disposal. These particularities highlight the importance of waste management solutions tailored to specific individuals in efficient and sustainable environments, including investments in appropriate solutions and public awareness to engage in waste recycling activities. The objective of this research is to contribute to this scenario by examining the use of persuasive technologies to involve users in pro-recycling activities, with the school environment as the target scene.

Considering the study's short duration as a limitation, the amount of waste collected during the study period was still significantly large. However, more tests need to be carried out for longer periods, as maintaining sustainable behavior over the long term is one of the most prevalent challenges in the area of sustainable technologies [38]. Without the novelty factor, the quantity of materials collected may decrease, and the rate at which the bin fills may slow down, thus justifying the use of the IoT tool. Therefore, the short duration of the tests, which took place over a period of 4 weeks, appears as a limitation of the research.

In addition to the short duration of the study, methodological concerns associated with the scope of the research conducted have also impacted the generalizability of the results. The research mainly used focus groups, questionnaires, participant observation, and ethnographic fieldwork. While these methods provide a contextualized understanding of user interactions, they can be influenced by participant and researcher biases. Furthermore, the sample of 8 participants involved in the focus group and the tests carried out with 35 respondents present small numbers to statistically represent the student population or to generalize the findings to other school contexts. These limitations indicate that, although this study brings important insights into the use of persuasive technology in educational contexts, it is necessary to carry out future work with larger and more diverse samples, along with long-term evaluations to verify the durability of changes in behavior.

Overall, the interactive smart trash bin prototype achieved the goal of improving recycling rates within the school community. The persuasive strategies integrated into the interactive tools supported engagement in recycling activities, as the period during which the trash bin was equipped with these tools led to increased user interaction with the trash bin. Furthermore, there is evidence that the use of the Web application developed in Cycle 1 in conjunction with the smart trash bin developed in Cycle 2 may be effective, as evidence suggests that the former encourages deeper reflection on selective waste disposal, consequently promoting the increased use of the smart trash bin. Therefore, developing mechanisms to integrate these two tools is a promising avenue for future research.

In line with the above considerations, and seeking to formalize the knowledge learned throughout the process during the focus group meetings, we articulate a set of design recommendations (DRs) for creating persuasive technologies aimed at changing sustainable behaviors around waste recycling, reflecting the knowledge acquired throughout the different design cycles of the project. We conclude this section by describing and discussing a set of design recommendations for smart waste disposal platforms through persuasive strategies, a concept explored in previous sustainable HCI research (e.g., [18]). These recommendations are the main results of the research presented here and were consolidated during design Cycles 1 and 2 as part of the reflection and learning activities within the PADR methodology, which involves the formalization of the lessons learned.

5.1. Presentation of Educational Information (DR1)

Incorporating educational information into platforms designed to engage users in recycling activities is crucial to raising awareness and promoting sustainable practices. This information can take different forms, from informative texts to visual and interactive elements. Presenting information in a clear and simple format is seen as a solution to mitigate problems related to complex technical language. This study provided evidence that incorporating educational information into the Web application can help raise awareness, encourage greater use of the persuasive smart trash bin, and foster conscious reflection on the processes of identification, selection, and disposal. Some important aspects to be covered include but are not limited to an explanation of the benefits of recycling, presentation of consolidated themes in the area (e.g., the 5Rs policy), and guides on how to classify different materials by highlighting which items are recyclable and how to dispose of them correctly. Other areas of informational need include the presentation of nearby collection sites and addressing the work of trash collection companies and non-governmental organizations (NGOs) that operate in the sector. As stressed by Biørn-Hansen and co-authors [8], this way of incorporating information by designing beyond waste disposal habits can contribute to raising awareness of climate impact and planetary well-being.

5.2. Real-Time and Interactive Feedback (DR2)

Real-time feedback is a design strategy that provides users with immediate information about their actions or behaviors. In the context of platforms to engage users in recycling activities, real-time feedback plays a key role by creating an immediate connection between user actions and the positive consequences of recycling. Participants in this study emphasized the importance of the persuasive technology presenting immediate feedback and visual rewards whenever users perform the targeted action. However, there are many ways to present immediate feedback beyond the visual effects as designed in the present study. Alternative methods to implement real-time feedback include sound or haptic effects such as playful sounds or subtle vibrations on the device. Scoring systems and gamification elements that reward users with points for each recycling action also serve as effective methods for providing real-time feedback by enabling them to advance levels. However, such mechanisms were not the focus of this study, although they deserve attention in future studies.

5.3. Intuitive and Attractive Interface (DR3)

An intuitive and attractive interface is essential for persuasive technologies intended to engage users in recycling activities, as it helps make the user experience more enjoyable. An intuitive and visually appealing interface not only makes the system easier to navigate and use but also contributes to increased user satisfaction, thereby enhancing the effectiveness of recycling initiatives. The user experience must be designed to consider the particularities of each target user taking into account their context, age group, gender, ethnicity, physical and cognitive abilities, as well as the cultural aspects that influence their preferences and behaviors. This study addressed this issue using memes as a language that collectively guides conceptions about the world within a youth cultural context. In this regard, our study makes it possible to demonstrate that the processes of creating knowledge within the scope of digital culture have great potential to be explored in the environmental education of children and teenagers when connected to sustainability themes.

5.4. Smart Collection Devices (DR4)

Smart collection devices refer to technological solutions that use resources often linked to IoT, which can be used to improve the waste collection process and encourage recycling. These devices are designed to make waste collection more efficient and sustainable while engaging users in more conscious practices, as carefully documented in other ethnographically-informed sustainable HCI research integrating digital and physical components for smart waste recycling (e.g., [17]). Smart collection devices are equipped with IoT sensors capable of monitoring various variables in real time, including the container's storage capacity, the weight of the waste, and even the type of waste deposited. However, one of the study's findings revealed that the IoT tool implemented in the project did not effectively improve the efficiency of collecting recyclable materials. This was evident because the trash collectors did not reduce their visits to the school and the bins were consistently full of waste on the already scheduled waste collection days due to their limited capacity and heavy use, as it was a novelty for the school community. Furthermore, the Telegram chatbot was not well accepted by the work dynamics of the trash collectors, as it was not their standard means of communication. Therefore, understanding the organizational culture becomes essential for the successful adoption of smart devices by organizations, as culture sets the stage by defining shared norms and perceptions, customs, patterns of behavior, and ways of acting among community members.

6. Conclusions

This paper highlights the critical role of persuasive technology in fostering sustainable recycling behaviors and contributes to the growing body of knowledge on sustainable HCI by providing actionable design recommendations for future research and development. While previous studies have explored sustainable HCI in domains like energy and food waste, research on recycling remains relatively limited. Through the PADR methodology, we were able to prototype tools and analyze the potential of integrating persuasive elements into IoT applications to enhance user engagement in recycling activities. By emphasizing educational content, real-time feedback, and intuitive interfaces, we propose recommendations for designing effective persuasive recycling technologies. Recognizing the importance of cultural context is essential to successfully implementing such systems.

The research limitations include methodological challenges and limitations associated with the scope of this study. Although the research work presented here brings important insights into the use of persuasive technology in educational contexts, it is necessary to carry out long-term evaluations with larger and more diverse samples to verify the durability of the behavioral changes. The novelty factor is expected to see a decrease in user engagement with systems for sustainability. For future work, it is expected to conduct new systematic tests with the proposed prototypes involving a larger sample of students so that their results can be generalizable.

In addition, potential directions for future work arising from this study include combining the two solutions designed separately into a single integrated platform to explore persuasive strategies not addressed in the present study. Such strategies may include tracking individual disposal to personalize information and improve the user experience and providing feedback and rewards generated by the system. In this sense, the concept of gamification can be further explored in future investigations. In addition, it is expected to carry out a systematic evaluation of the PADR methodology, which can serve to demonstrate its effectiveness in the context of sustainable HCI interventions adapted to persuasive technology. Such an evaluation was not carried out in the present work since the main focus was to provide an insight into the potential application of persuasive technologies to the context of pro-recycling platforms, presenting as a result a set of design recommendations for the development of similar technologies.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/informatics12010005/s1, File S1: Informed Consent.

Author Contributions: C.M. and D.S. supervised E.M.d.S.'s master's research. All authors were actively involved in the research process, contributing to the qualification exam and final defense. All authors participated in comprehensive manuscript editing and review. D.S. and A.C. led the final manuscript preparation. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: All participants accepted the invitation to join the focus group after a brief explanation of the research objectives, following the precepts of the Declaration of Helsinki. Both oral and written explanations of the research project were provided. Consent for the participation of minors in the guided activities was obtained from their parents/guardians through project-specific authorization forms, which included detailed information about the dates and locations of participation. Given that the research involved multiple stages conducted at different times and locations, distinct authorization forms were required for each stage. In addition, an authorization form for the use of images of minor participants was distributed to parents/guardians. Inform Consent see Supplementary Materials, File S1.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors upon request.

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