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ELECTRONIC WASTE: PERCEPTIONS, HABITS, AND DISPOSAL PRACTICES WITHIN A UNIVERSITY COMMUNITY

RESÍDUOS ELETRÔNICOS: PERCEPÇÕES, HÁBITOS E PRÁTICAS DE DESCARTE EM UMA COMUNIDADE UNIVERSITÁRIA

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Abstract

Brazil ranks as the fifth-largest producer of electronic waste (e-waste) and faces challenges regarding its improper disposal. This study assessed the awareness and practices related to e-waste disposal among members of an academic community. A total of 648 individuals participated in the study by responding to an online questionnaire; 61.0% of them reported awareness of the environmental risks associated with improper e-waste disposal, and 57.3% still disposed of their mobile phones improperly. Among those reporting improper disposal practices, 25.0% stored old mobile phones at home, which hampers material recovery, reuse, or recycling, resulting in economic losses and environmental harm. Furthermore, the analysis of disposal practices showed that the presence of disposal points is not directly linked to the habit of correct disposal. Most individuals (75.0%) were unaware of reverse logistics mechanisms and the Brazilian National Solid Waste Policy. These findings underscore the urgent need for awareness-raising strategies to emphasize the individual responsibility in the proper disposal of e-waste.
Keywords: Environmental education, Solid waste, Waste electrical and electronic equipment.

Resumo

O Brasil é o 5º maior produtor de e-lixo e enfrenta problemas com o descarte inadequado destes resíduos. Este estudo avaliou o conhecimento de comunidade universitária em relação ao descarte de lixo eletrônico. Foram entrevistadas 648 pessoas por meio de questionário online. Como resultado, 61% dos entrevistados afirmam conhecer os riscos ambientais do descarte inadequado do e-lixo, porém 57,3% descartam seus celulares de forma inadequada. Dentre os descartes inadequados, 25% dos participantes acumulam os celulares antigos em sua residência, que dificulta a recuperação, reutilização ou reciclagem de matéria prima sendo um desperdício econômico e um prejuízo ambiental. Além disso, ao analisar os hábitos de descarte, a pesquisa revelou que, embora existam pontos de coleta disponíveis, sua presença não está diretamente relacionada ao comportamento de descarte adequado. A maioria dos entrevistados (75%) declara não conhecer a logística reversa e Política Nacional de Resíduos Sólidos. Nossos resultados mostram que são necessárias e urgentes estratégias para conscientização da responsabilidade que cada cidadão tem em relação ao descarte correto dos seus resíduos.
Palavras-Chave: Educação ambiental, Resíduo sólido, Resíduo de equipamento eletrônico.

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Introduction

About 53,6 Mt of electronic waste (e-waste) was generated globally in 2019, with a potential increase to 74.7 Mt by 2030 (FORTI et al., 2020). These data highlight the critical challenges faced by society in managing e-waste generation. Planned obsolescence refers to the intentional design of products with a limited functional lifespan, promoting their replacement within a short period, even while they are still operational. Ardenghi et al. (2025) stated that this practice is strongly driven by marketing strategies and continuous technological advancement that stimulates frequent and premature demand for new devices. Thus, consumers often dispose of electronic equipment before it reaches its actual lifespan, directly contributing to the escalation of e-waste, currently one of the most significant environmental challenges worldwide.

In addition to the high generation of e-waste, raising awareness about the importance of recycling and the risks associated with improper disposal remains a challenge. E-waste contains several potentially hazardous substances (ALABI et al., 2021), including toxic heavy metals (e.g., lead, cadmium, mercury, and arsenic), persistent organic pollutants, plastics, and polybrominated diphenyl ethers. This mixture poses a threat to environmental and human health (GRANT et al., 2013; YANG et al., 2020).

In 2019, approximately 82.6% of global e-waste was not formally collected, resulting in improper management (FORTI et al., 2020). In the European Union, about 0.6 Mt of e-waste is improperly disposed of in regular trash, undermining its proper management, a similarly concerning situation (ROTTER et al., 2016).

In Brazil, Federal Law. nº 12.305, enacted on August 2, 2010, establishes the National Solid Waste Policy (PNRS), which classifies e-waste as a special category of solid waste, requiring mandatory collection. However, they are often improperly disposed of alongside general household waste (CARDOSO, 2016). Nearly half of Brazilian municipalities still rely on landfills as final disposal sites, and about 17.8 million citizens lack access to regular waste collection services. Consequently, only 4.0% of all disposed waste in the country is recycled (AGÊNCIA BRASIL, 2020). This scenario underscores the need to enhance public policies centered on environmental education and resource recovery.

Within this context, reverse logistics may mitigate the environmental impacts of e-waste. This strategy involves systematic collection, transportation, and appropriate disposal of e-waste, enabling the return of materials to manufacturers. Reverse logistics prevents the release of toxic substances into the environment and promotes their recycling (HALE; MCALLISTER, 2020). However, low awareness of the importance of recycling still hinders its effectiveness. Cultural obstacles are also common, such as concerns over data privacy or the perception that outdated electronic devices retain value and should be kept. Additionally, the complexity of e-waste composition demands appropriate infrastructure and technological capacity to ensure effective recycling (ABRELPE, 2020).

To reduce barriers and enhance participation in reverse logistics systems, investment in environmental education is essential. In Brazil, the National Education Guidelines and Framework Law,(Law nº 9.394/96) establishes that secondary education must provide to the students scientific knowledge and an understanding of socially relevant topics, encompassing the natural, social, political, technological, and economic spheres, including the development of skills, attitude, and values. Among the topics addressed is the management of solid waste, including e-waste.

Additionally, the National Environmental Education Policy (Law nº 9.795/1999) reinforces the importance of raising public awareness about the environmental and health risks associated with improper waste disposal. This law mandates the integration of environmental education into formal and informal educational processes. Therefore, environmental education must extend beyond technological knowledge to include ethical and social awareness, promoting meaningful behavioral change. In this context, this study assessed an exploratory snapshot of practices related to e-waste and its disposal among an academic community using an online questionnaire. Few published studies have focused on this purpose (ADEEL et al., 2022; ADEEL et al., 2023). Understanding the level of awareness and practices among this population is essential for identifying flaws in the educational process and implementing new strategies that foster a more engaged and environmentally responsible society, particularly in the context of reverse logistics.

Material and Methods

This study employed a descriptive design with a quantitative approach using a structured questionnaire to investigate perceptions, practices, and disposal practices related to e-waste among individuals in an academic community. The questionnaire was developed based on a literature review and adapted to the academic context. It included clear and objective questions addressing disposal practices, awareness about e-waste, environmental policies, waste toxicity, and availability of collection points, among other topics. Sociodemographic information was also collected, including gender, age, location, and institutional affiliation. The questionnaire consisted of 29 closed and open-ended questions, with a mean completion time of 15 minutes. Participation was voluntary and limited to individuals who signed an informed consent form. The questionnaire is available in the supplementary materials.

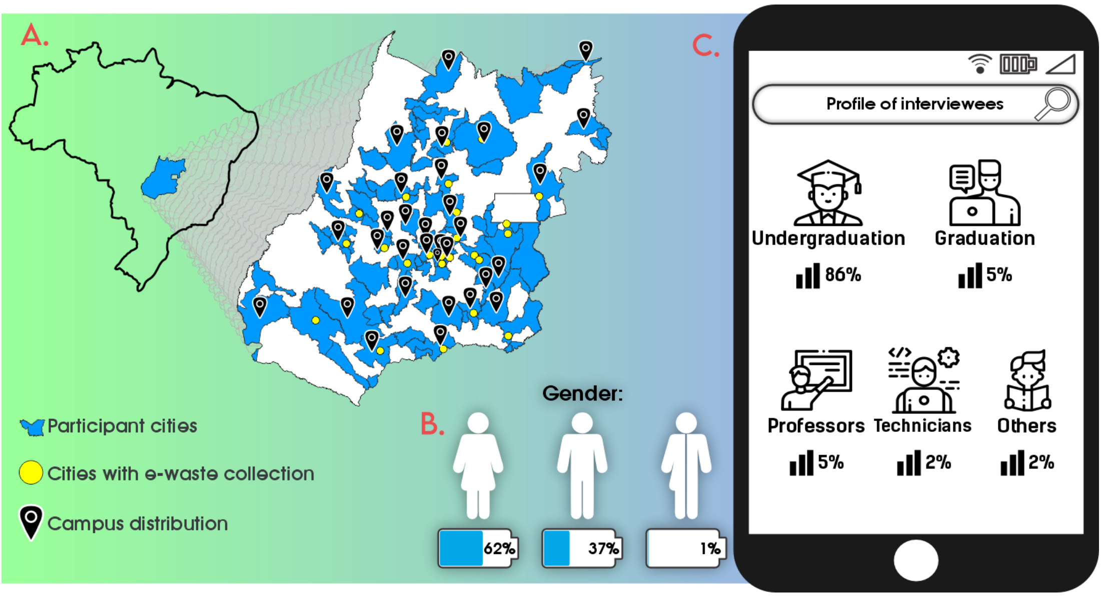
The study was approved by the research ethics committee (CAAE 49744221.6.0000.8113), and data were collected online between October 2021 and July 2022. A total of 648 individuals from a public university participated, including students, faculty, and administrative staff; most resided in municipalities in the state of Goiás, while some were from other regions. A convenience sample was used, including individuals with institutional ties regardless of age. While the results are not generalizable to the entire country, the diversity represented across 48 municipalities provides a relevant exploratory analysis. Data were analyzed using the R statistical software, employing descriptive statistics, correlation analyses, and the Chi-square test ($p < 0.05$). Data visualization of results was supported by Power BI, CorelDraw, Canva, Vecteezy, and Flaticon tools.

Results and Discussion

Characterization of the individuals

A total of 648 responses were obtained across different campuses in the state of Goiás (Figure 1A). Most individuals were women, with a mean age of 25 years (Figure 1B). Regarding academic roles, most individuals were students, which reflects the predominant composition of the academic community (Figure 1C). The total number of students, faculty members, and administrative staff across the studied campuses exceeds 20,000 individuals; therefore, the sample represents only a fraction of the overall population and was obtained through via online disclosure. Consequently, the findings provide an exploratory snapshot of the practices and perceptions of the academic community, without the intention of being generalizable to the entire campus population.

Figure 1. Profile of individuals: (A) map of municipalities and locations of e-waste collection points; (B) gender distribution, and (C) institutional affiliation.



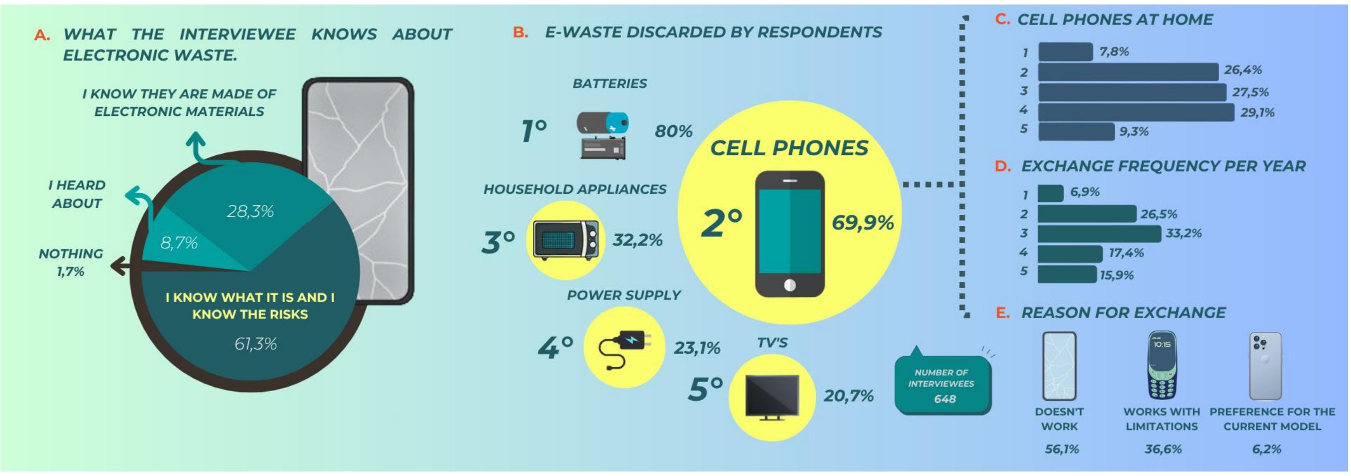
Characterization of e-waste generation and disposal

Individuals were asked about the main types of e-waste they generate. Most (89.7%) were familiar with the concept of e-waste (Figure 2A), and 61.3% indicated awareness of the environmental risks associated with it. Regarding the types of e-waste generated, the most frequently mentioned were batteries (80.0%), mobile phones (69.9%), household appliances (32.2%), power supply (23.1%), and televisions (20.8%) (Figure 2B). The question displayed in Figure 2B was deliberately designed to be open-ended, capturing the wide variety of electrical and e-waste, reflecting the spontaneous perception of what is considered e-waste.

Although frequently cited, batteries are not formally included within the 54 categories of e-waste defined by the Guidelines on E-waste Statistics: Classification, Reporting, and Indicators (FORTI, BALDÉ and KUEHR 2018), (UNU-KEYS). Nevertheless, batteries are integral components of electronic equipment and are often disposed of alongside other e-waste. The environmental hazard arises when these batteries become deformed through crushing or rupture during disposal, leading to the release of toxic liquids that pose serious risks to human health and the environment (CARVALHO, DIONÍZIO & DIONÍZIO, 2019).

Improper processing and disposal of used batteries can contaminate soil, waterways, groundwater, and air, posing a direct threat to ecosystems and human health (MROZIK et al., 2021). Estimates suggest that a single mobile phone battery containing cadmium can contaminate about 1,125,000 liters of water (YUXIN; JIANJUN, 2004). In Brazil, the final disposal of batteries is regulated by CONAMA Resolution (n° 401/2008), which mandates that batteries must be disposed of in appropriate destinations, under the responsibility of the manufacturer or importer (CONAMA, 2008).

Figure 2. Characterization of e-waste: (A) awareness of the individuals, (B) distribution of the most frequently disposed e-waste items, (C) mobile phones per household, (D) frequency of device replacement per year, and (E) reasons for device replacement.



The second most frequent type of e-waste was mobile phones (70.0%). They fall under the category of "small IT and telecommunications equipment" of UNU-KEYS, which also includes GPS, pocket calculators, routers, personal computers, printers, and landline phones. Most of the digital consumption in Brazil is concentrated on mobile phones (MEIRELLES, 2023). In 2021, an estimated 242 million smartphones were in use in Brazil (FGV, 2023). With 214 million inhabitants, Brazil has a significantly higher number of mobile phones, indicating continued growth in production. Mobile phones are the most sold electronic devices in Brazil, being three times more sold than televisions (FGV, 2023). In April 2021, the number of mobile phone users was estimated at 5.27 billion, evidencing that this elevated consumption is a global trend (PRABHU; MAJHI, 2023).

The widespread use of smartphones is closely linked to their multifunctionality and their central role in everyday life, enabling communication, internet access, banking transactions, geolocation, photography, and entertainment. However, the fast technological advancement, marked by the continuous release of new models and features, has contributed to increasingly shorter replacement cycles. According to Cordella et al. (2021), the perceived lifespan of smartphones is limited by technical factors, such as failures in key components like batteries and screens, and socioeconomic factors, including the desire for more advanced models. As a result, the average usage of smartphones has fallen below two years, which has exacerbated the generation of e-waste and has placed additional pressure on environmental sustainability. Within a short period, all these devices will become e-waste; thus, the population must be aware of proper disposal practices to mitigate their environmental impact.

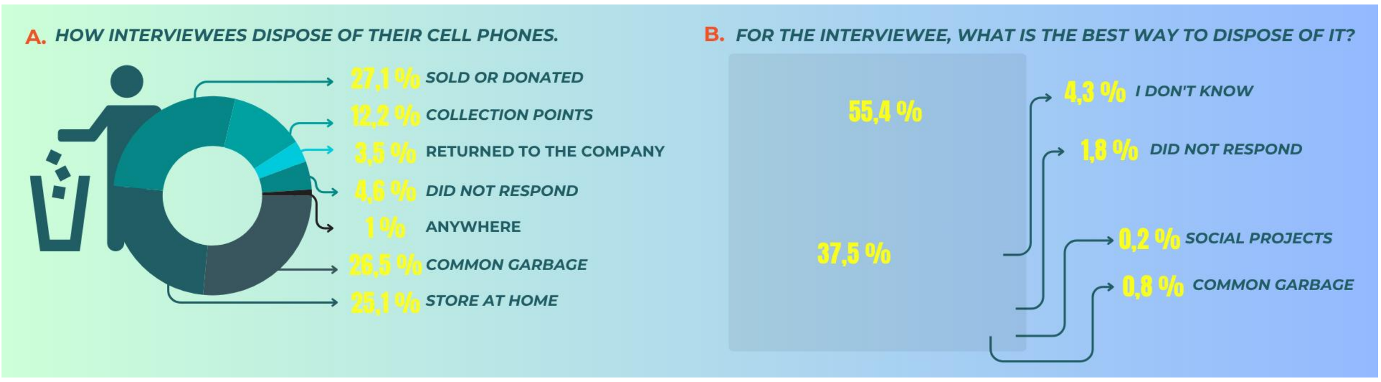
Regarding mobile phones, the questionnaire inquired about the number of devices per household, replacement frequency, and the reasons for replacement. Most (82.9%) had between two and four mobile phones at home (Figure 2C), and the average time of use was about two to four years (77.2%) (Figure 2D). The main reason for replacement was device malfunction (56.1%) (Figure 2E). However, 44.0% of individuals replace them while they are still functional. Within this group, 6.2% reported doing so solely due to a preference for newer models.

Our findings are consistent with those from another Brazilian study, conducted with an academic community at various universities, which also revealed a high number of mobile phones per individual and similar usage durations. Moretti et al. (2011) reported that most individuals had more than one mobile phone, with 26.1% having acquired three and 25.0% owning more than four. Regarding replacement intervals, 65.0% of them had replaced their mobile phones within two years. Although many electronic products, including mobile phones, are technically designed to last for several years, their actual lifespan is significantly shorter. According to the European Environment Agency (EEA, 2023), this discrepancy is influenced by several factors, including rapid technological changes, market pressures, incompatible software updates, and consumer preferences for newer models. In the case of mobile phones, while the technical lifespan may reach up to seven years, replacement often occurs within two to three years after purchase. This shortening of the effective lifespan directly contributes to increased e-waste generation and resource waste, while undermining the principles of a circular economy and global sustainability efforts.

Disposal practices

Regarding disposal practices for mobile phones, 26.5% of individuals disposed of them with regular household waste, 25.0% kept them at home, 1.0% disposed of them in unspecified locations, and 8.1% did not answer. Additionally, 27.0% donated or sold their mobile phones to others, and only 15.7% reported disposing properly at designated recycling points or returning them to the store of purchase. These findings indicate that 57.3% of individuals did not dispose of their devices properly (Figure 3A).

Figure 3. Disposal practices: (A) disposal practices of the individuals and (B) perceptions regarding appropriate e-waste disposal.



Comparing the data from this study with a previous investigation conducted at the same university, the overall disposal practices remained unchanged after eight years. In the earlier study by Lacerda et al. (2016), 21.0% of individuals disposed of e-waste at collection points, 21.0% stored the devices at home, and 58.0% disposed of them with regular household waste. These findings reinforce that a significant challenge remains in raising awareness among students and developing effective skills for proper e-waste disposal.

Similarly, a study conducted with an academic community in São Paulo revealed that most individuals stored their phones at home (50.6%) or gave them to children (10.3%) (MORETTI et al., 2011). Only 19.6% of respondents properly disposed of their mobile phones, revealing a clear asymmetry between the effort invested in consumption and the limited effort devoted to environmental preservation (MORETTI et al., 2011). A comparable pattern was observed in a study conducted with an academic community in the United Kingdom, in which nearly 60.0% stored their mobile phones mostly as backup phones, and only 19.1% reported proper disposal.

The tendency to accumulate old mobile phones at home is not restricted to the academic community. Studies in several countries reported similar behaviors. In the United Kingdom, 86.0% of individuals kept their outdated devices stored (SPEAKE; YANGKE, 2015). In Australia, young adults (18 to 29 years old) also showed a preference for storing old mobile phones rather than taking them to designated collection points (ISLAM et al., 2020). In China, only 20.0% of these materials were disposed of in formal recycling streams, while about half remained at home (TAN et al., 2018). In Poland, individuals reported retaining devices for potential future reuse (NOWAKOWSKI, 2019).

Among the main factors explaining this behavior are concerns over data privacy and the perceived residual economic value of unused devices (CAI et al., 2023). These factors were also observed in this study, indicating that household accumulation is a global and multifactorial phenomenon, reflecting gaps regarding environmental education. The accumulation of e-waste at home often results from a combination of negligence, lack of continuous educational campaigns, and failures in collection points. While many individuals acknowledge that e-waste should be disposed of at designated collection points, their actions reveal a disconnection between knowledge and environmental behavior. This finding indicates that mere access to information is insufficient; thus, engagement strategies, emotionally resonant educational initiatives, and accessible logistical solutions are needed. Research indicates that engagement in environmental practices is influenced by knowledge disclosure, as well as the development of critical thinking, alignment of personal values with environmental issues, and adequate structural conditions (LIMA e PATO, 2021).

The accumulation of old devices at home represents not only economic waste but also environmental damage, as mobile phones contain valuable minerals that could be recovered, reused, or recycled. Currently, China has the highest volume of mobile phone waste, with an estimated 850 million old devices (ZHANG et al., 2022). This stockpile weighs about 135 million kilograms and contains more than 75, 20, and 9,000 tons of gold, silver, and copper, respectively (GUO; YAN, 2017). Consequently, mobile phone waste is considered a valuable secondary source of raw materials, offering environmental and economic benefits.

Figure 3B illustrates the awareness of individuals regarding the appropriate disposal points of their mobile phones. Most (92.9%) indicated that proper disposal involves returning devices to specialized collection points or certified companies. However, only 15.7% followed proper disposal practices. This gap can be explained by the Theory of Planned Behavior (AJZEN, 1991), which posits that human behavior is influenced not only by knowledge but also by attitudes, perceived norms, and perceived behavioral control. In other words, even when individuals know what is environmentally correct, they may fail to act accordingly due to a lack of motivation, limited access to infrastructure, or low self-efficacy. From the perspective of Critical Environmental Education (SAUVÉ, 2005), changing behavior requires more than just information; it demands continuous educational processes that involve critical reflection, value formation, and social empowerment. Therefore, public policies that inform, engage, educate, and facilitate the proper disposal of e-waste are needed, overcoming the barriers that prevent environmentally responsible practices.

Collection points and barriers to recycling

One hypothesis to explain the improper disposal of e-waste promoted by our sample is the lack of formal collection points in municipalities. To evaluate this hypothesis, a Chi-square test was performed to assess the association between the presence or absence of e-waste collection points and the proper or improper disposal behavior. The municipalities with collection points are depicted in Figure 1A, and among the individuals, 194 disposed of their e-waste correctly, whereas 235 did not. In municipalities without such infrastructure, 96 individuals disposed of their waste correctly, while 102 did not. The Chi-square test result was not statistically significant ($\chi^2(1) = 0.46$, $p = 0.49$), indicating no association between these variables. This finding suggests that the mere availability of a collection point does not ensure effective access, knowledge of locations, or community engagement. Structural and behavioral factors, such as the visibility of collection points, public education campaigns, ease of access, and the perception of environmental responsibility, may be equally or more influential. Therefore, public policies must integrate educational, communicative, and participatory strategies to ensure that collection systems are effectively used and fulfill their intended environmental purpose.

The efficient recycling of e-waste faces multiple challenges, including insufficient infrastructure and the difficulty of recovering valuable materials (GIESE et al., 2021). A significant barrier is the general lack of public awareness; many individuals are unaware of the environmental hazards posed by e-waste and frequently dispose of it along with household waste or mix it with recyclables in curbside collection (OLIVEIRA et al., 2020). Another common behavior is storing old or damaged electronics at home, which hinders recycling and recovery efforts. To ensure the effectiveness of reverse logistics systems, public awareness campaigns must be implemented to promote proper sorting and disposal of e-waste.

A further challenge is the existence of

informal or illegal recycling markets. Due to its high market value, e-waste often attracts informal workers who dismantle devices under unsafe and environmentally harmful conditions (GHISOLFI et al., 2017; OLIVEIRA et al., 2020). Additional issues include inadequate transportation and storage; e-waste poses a high risk of combustion and contains toxic substances that can contaminate the environment (ALABI et al., 2021; GIESE et al., 2021).

Moreover, the recycling of e-waste is hampered by a shortage of specialized labor, which complicates the separation of components. Other significant obstacles are the complexity of extracting valuable materials from electronic devices, low processing efficiency, and material loss (GIESE et al., 2021). The intricate design and composition of specific devices make them unsuitable for reuse or recycling (TOFFEL; HORVATH, 2004; BERKHUNT; HERTIN, 2004). Thus, new technologies are still required to dismantle electronic devices effectively. However, developing efficient methods for recovering metals from e-waste remains challenging.

Traditional recycling techniques (e.g., pyrometallurgy and hydrometallurgy) are combined with emerging methods (use of microorganisms, ultrasonic processes, and eutectic solvents) and are currently being tested for their effectiveness. However, little information is available on scalable industrial applications, and few technologies have been deployed (ANDRADE et al., 2021). Overcoming these challenges and establishing efficient recycling strategies are essential to reduce the extraction of raw materials from nature, enhancing sustainability using environmentally appropriate waste disposal practices (ANDRADE et al., 2021). Nevertheless, no recycling process is free from environmental risks (ANDRADE et al., 2021). The most effective strategy remains reducing waste generation at the source, preserving primary and non-renewable natural resources (OTTONI et al., 2020).

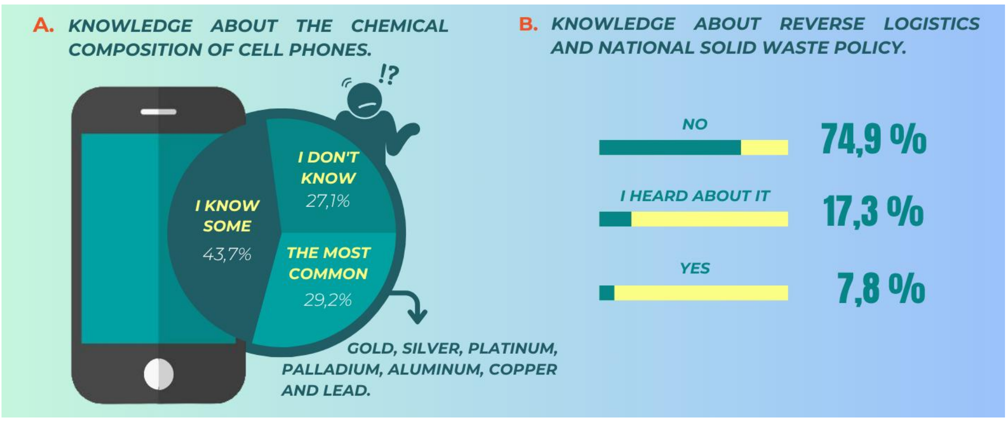
Issues related to the improper disposal of mobile phones

Mobile phones are composed of various complex components. Our study assessed the awareness of individuals regarding the internal composition of mobile phones, and most had some knowledge regarding the components (Figure 4A). A typical mobile phone consists of a printed circuit board, a liquid crystal display, a battery, electronic circuitry, a keypad, an antenna, and a plastic casing (MARAGKOS et al., 2013). The manufacturing of these materials requires resources, such as gold, copper, silver, silicon, nickel, praseodymium, neodymium, gadolinium, lithium, cobalt oxide, aluminum, terbium, lanthanum, and europium. A single mobile phone, weighing about 75 to 100 grams, may contain over 40 different chemical elements (MARAGKOS et al. 2013). When disposed of improperly, either in landfills or via informal channels, mobile phones may release toxic substances that leach into soil and water systems. Wu et al. (2008) evaluated two generations of mobile phones over a five-year period and identified about 12 highly and 12 moderately hazardous substances present in the metal recovery stream. Additionally, newer models of mobile phones were considered more environmentally friendly, as they contain fewer hazardous materials and a lower total mass of metallic components. Furthermore, toxic substances were also identified in the plastics used in phone casings (MOLTÓ et al., 2011).

The contamination by potentially toxic metals and plastics is largely the result of improper waste disposal. In Brazil, Federal Law nº 12.305/10 establishes the PNRS, which regulates the management of solid and toxic waste and defines the responsibilities of waste generators and public authorities. This legislation identifies reverse logistics as a key instrument to ensure the proper return of solid waste to the production chain for environmentally appropriate final disposal.

When individuals were asked about reverse logistics and the PNRS, 72.9% were unfamiliar with the topic (Figure 4B). This finding highlights gaps in the environmental education of individuals and their awareness of waste management. According to the PNRS, since August 2010, every individual has been responsible for the appropriate disposal of their waste and also for critically rethinking their role as consumers. Meanwhile, the private sector is responsible for the environmentally appropriate management of the solid waste it generates.

Figure 4. Issues related to improper disposal: (A) knowledge of mobile phone chemical composition and (B) awareness of reverse logistics and national solid waste policy.



Conclusions

This study, conducted within an academic community, revealed that mobile phones were the most frequently disposed of e-waste devices. Although 92.0% of individuals knew that they should dispose of their devices in collection points or specialized companies, 57.3% disposed of them improperly. Among these cases, 25.0% reported storing old mobile phones at home, which hinders the recycling and reuse of valuable materials. This situation highlights an environmental challenge that may worsen in the absence of a culture of appropriate disposal practices. Furthermore, 75.0% of individuals demonstrated a lack of awareness regarding reverse logistics and the National Policy on Solid Waste. Considering these findings, universities must promote isolated awareness-raising initiatives, incorporate proper disposal practices into their curricular activities, and establish partnerships with collection points. Integrating environmental education into academic training can change habits and strengthen public policies for the sustainable management of e-waste.

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