Energy transition in the context of family farming in Piaui: development of an educational application applied to energy transition

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Abstract

A just energy transition in rural Piauí is limited by a lack of accessible technical information on photovoltaic solar energy for family farmers. Connectivity and digital literacy barriers hinder access to knowledge, preventing the equitable distribution of the benefits of solar energy, abundant in the region. This article presents the development and pedagogical structure of the educational application Saber Solar, a tool designed to democratize access to this knowledge. The methodology integrated a literature review on educational obstacles in the field with technological development in Flutter for Android devices. The application was structured in thematic modules (Fundamentals of Solar Energy, Components, System Types), incorporating interactive resources (quiz) and, crucially, complete offline functionality. The main result is the functional version 1.0 of Saber Solar, a tangible product developed within the scope of PIBITI/UFPI. It is demonstrated that the application's architecture and functionalities directly address the connectivity and engagement gaps identified in the literature. It is concluded that Saber Solar represents a concrete contribution and a pedagogical infrastructure adapted to the rural reality, with the potential to strengthen the autonomy of producers and foster an inclusive energy transition. Field validation with the target audience constitutes the next planned stage of the project.

Keywords: Solar Photovoltaic Energy; Digital Education; Family Farming; Energy Transition; App Development; Piauí.

1. Introduction

The energy transition to renewable sources is a central contemporary challenge to mitigate climate change and reduce dependence on fossil fuels (Barbosa Lima; Hamzagic, 2022). In this scenario, photovoltaic solar energy stands out for its abundance, technical feasibility, and ability to decentralize generation. In Brazil, and especially in the state of Piauí, this source has high potential for exploitation, favored by the conditions of high insolation. Recent studies highlight solar energy as the "star" of Piauí's energy matrix, but its consolidation depends on regulatory frameworks and governance that ensure the equitable distribution of benefits. However, photovoltaic solar energy remains little explored in terms of direct benefits to family farmers (Moraes, 2013; Morais, 2024).

In the context of family farming, the adoption of renewable technologies faces challenges related to the lack of technical training and restricted access to low-cost technologies. These factors limit both the productive modernization and the efficient management of rural properties, creating barriers to a broader and more inclusive energy transition. Recent research points to the need for continuous public policies and training programs adapted to the specificities of the field (Santos, 2018; Silva, 2024). It is evident, therefore, that the strengthening of this segment depends not only on financial incentives, but on educational strategies that democratize knowledge and expand the autonomy of producers.

Digital education emerges, in this sense, as a vector of transformation capable of overcoming barriers to access to information. Digital tools, when guided by inclusive policies, can increase technological literacy and favor informed decision-making. Authors such as Demuner et al. (2024) highlight that the integration of emerging technologies (such as cloud computing, IoT, and big data) contributes to productive efficiency and the formation of socio-environmental awareness, expanding the conditions for the adoption of renewable energies. However, the same studies warn that, without infrastructure and equity, such benefits can widen social asymmetries.

Brazilian experiences demonstrate the potential of digital tools as instruments for training in renewable energy. The University of São Paulo (USP), for example, developed an application that helps in the sizing of photovoltaic systems

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(Jornal da USP, 2023), and the Federal University of Santa Maria (UFSM) invested in digital solutions aimed at supporting family farming (UFSM, 2021). Despite these initiatives, there is still a gap in accessible educational materials, specifically designed to disseminate the fundamentals of photovoltaic solar energy to family farmers with low connectivity or digital literacy, especially in the context of Piauí. In the absence of this targeted tool, the present work details the development of the educational application Saber Solar (Figure 1), aimed at Android devices.

Figure 1: Logo for the educational app 'Saber Solar'

The general objective of this project is to democratize access to technical knowledge about photovoltaic solar energy for family farmers and students in rural areas in Piauí, aiming to contribute to a fair, inclusive energy transition that promotes autonomy in the countryside. As specific objectives, the study aims to: (i) Develop an accessible didactic tool, focused on offline operation, which brings together fundamental content on solar energy; (ii) Structure the content in thematic modules, covering from the principles of solar energy to the components of a photovoltaic system and the typologies of installation in Brazil; (iii) Strengthen socioeconomic sustainability and the autonomy of rural producers in decision-making on the adoption of sustainable technologies**.**

2. Literature Review

The use of educational apps has been consolidated as an effective strategy for the dissemination of scientific knowledge in rural contexts, where geographical and social barriers often limit access to information (Silva et al., 2022; Saints; Santos, 2023). In Brazil, research shows that about 76% of teachers already seek to integrate digital resources into their pedagogical practices, evidencing the potential of these tools to expand the reach of teaching in regions with restricted infrastructure (CETIC.br, 2018). This scenario reinforces that education mediated by digital technologies can contribute to the democratization of knowledge, becoming a strategic ally in tackling inequalities and strengthening education in the countryside.

Photovoltaic solar energy, in particular, emerges as a promising technological alternative in regions with high solar irradiation, such as Piauí (Moura, 2024). The literature shows that its adoption in rural properties can positively impact both agricultural productivity and the quality of life of producers, by reducing electricity costs and dependence on fossil fuels (Barbosa Lima; Hamzagic, 2022). Despite its potential, the diffusion of this technology encounters obstacles related to the lack of technical knowledge and maintenance difficulties, which compromises the acceptance and sustainability of distributed generation projects in rural communities (Melendez, 2009).

Regional surveys reinforce that these obstacles are directly linked to the limited educational level of many family farmers. In a rural settlement in Piauí, it was found that low schooling significantly impacted income and the ability to absorb innovative practices (Barbosa et al., 2020). Similarly, a study conducted in Médio-Parnaíba revealed that 54.54% of farmers had low schooling, reflecting limitations in production management and the adoption of new technologies (Nunes; Silva, 2021). This panorama reveals the urgent need for accessible educational tools, which consider the specificities of the rural public and enable gradual training, creating real conditions for the adoption of renewable technologies such as photovoltaic solar energy in the rural areas of Piauí.

In this sense, educational initiatives aimed at teaching solar energy have explored digital methodologies. The Solar Quiz, for example, uses gamification to promote engagement and reinforce basic concepts (Fussuma et al., 2022). Studies validate this approach, pointing out that gamification enhances knowledge retention, especially through the use of challenges and rewards (Bittencourt et al., 2021; Becker; Karkov, 2020). At the regional level, the Solar

Schools project in Piauí demonstrated that the combination of teaching materials and educational practices can train students and teachers, strengthening the insertion of sustainability in the school environment (Costa; Sousa; Lima, 2020).

A textual synthesis of these initiatives reveals, however, limitations and a distinct public focus. The "Quiz Solar" (Fussuma et al., 2022) is a tool for validating general knowledge, and is not designed for the fundamental and practical training of rural producers. The "Escola Solares" project (Costa; Sousa; Lima, 2020), although located in Piauí, focuses its efforts on the formal school environment, targeting teachers and students in regular education. While the studies analyzed are mostly concentrated in school environments and urban audiences with greater digital literacy, there is a gap in the application of digital methodologies aimed at teaching solar energy in the context of family farming, a gap that Saber Solar seeks to fill.

To address this gap, the Saber Solar application was designed with the objective of combining accessible educational content with interactivity, focusing specifically on the needs of family farmers and students in rural areas of Piauí. The application is structured in thematic modules on the fundamentals of solar energy, components of the photovoltaic system and installation typologies. By including gamified resources (quizzes) and being designed for use with low or no connectivity, the application seeks to bring this audience closer to the universe of solar energy, offering a dynamic and contextualized learning experience. In this way, the tool contributes to the energy transition in Piauí, democratizing access to knowledge and encouraging sustainable practices in the field.

3. Methodology

The methodology adopted for the development of the Saber Solar application was organized in sequential stages that integrated technical and pedagogical aspects, in order to ensure both the feasibility of the software and its applicability in the context of rural education. The work was based on the use of the Flutter framework (Figure 2), selected for its flexibility and compatibility with Android devices, in addition to the possibility of offering high performance on multiple platforms, meeting different device profiles used by family farmers (Bueno, 2021). Flutter's widget-based architecture allowed the construction of responsive interfaces adapted to different screen resolutions (Devmedia, 2021), an essential aspect to ensure accessibility to the target audience, made up mostly of family farmers with various mobile devices. In addition, Android Studio was used, used as a testing environment and emulation of virtual devices (Google LLC, [n.d.]), which made it possible to simulate different conditions of use of the application, and Visual Studio Code (VS Code) as the main IDE, due to its lightness and wide integration with the Flutter ecosystem (Microsoft Corporation, [n.d.], favoring productivity in development. The choice of these tools dialogued directly with the proposal to create a lightweight, modern and easy-to-maintain application, while aligning with current trends in cross-platform development.

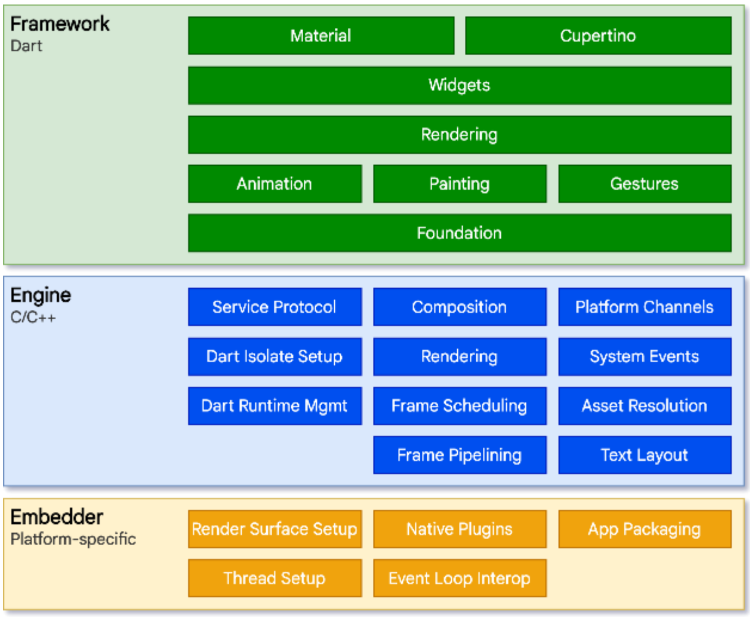

Figure 2: Flutter framework architecture

The first methodological stage consisted of a comprehensive bibliographic review, carried out in scientific articles, technical reports and institutional documents on solar energy, energy transition and teaching methodologies mediated by digital technology. This phase sought to theoretically support the project and allowed us to understand the potential and challenges of the insertion of solar energy in the rural context, especially in Piauí. In addition to identifying gaps related to access to technical information by family farmers, the review also subsidized the construction of an accessible language for the app's contents, reconciling scientific rigor and didactic clarity. This movement ensured that the educational materials developed were not only technically correct, but also adequate to the conditions of understanding and practical application of the public served.

Then, the educational modules that would structure the application were defined, in order to organize the content into progressive learning units. Five main modules were established: Fundamentals of Solar Energy, Photovoltaic Modules, Components of the Photovoltaic System and Types of Systems Installed in Brazil (Figure 3). The modular division logic was inspired by block teaching methodologies, allowing users to follow a gradual learning path, starting with basic concepts and moving on to technical and contextual applications. This organization also favored the personalization of the use of the application, since the farmer or student could directly access the topics of greatest interest, without losing the global coherence of the pedagogical proposal.

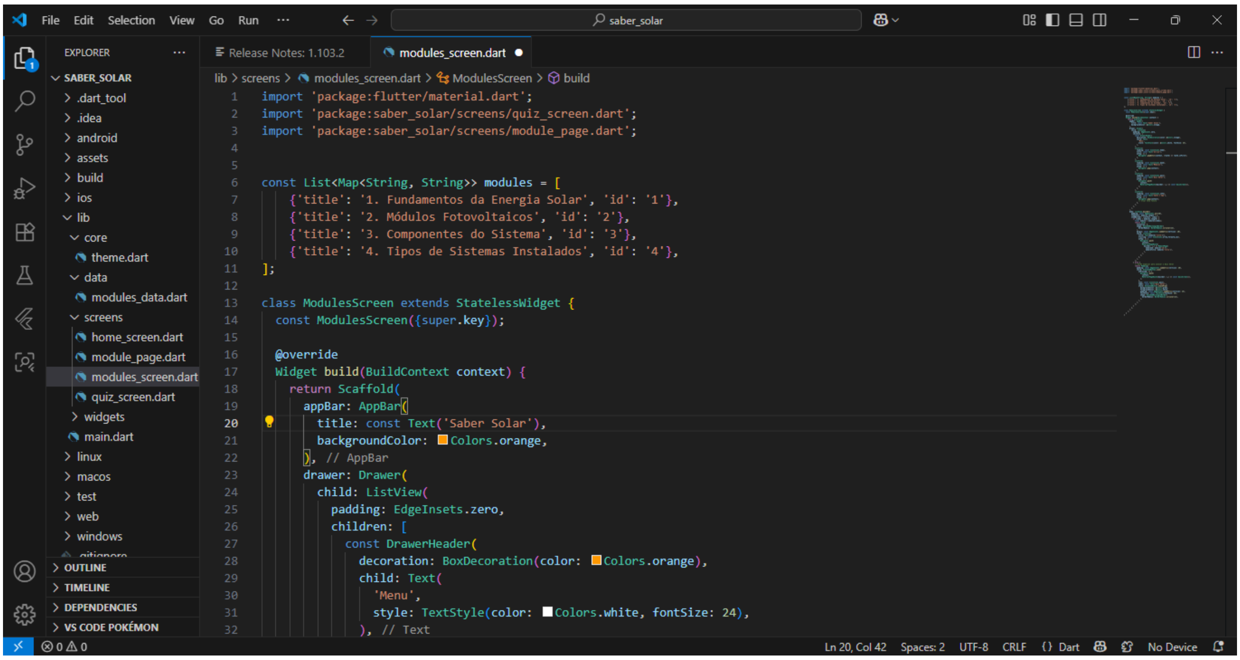

Figure 3: Development of the Saber Solar application module screen

The prototyping and interface design stage was conducted based on user-centered design principles and usability criteria. Digital prototyping tools were used to simulate the navigation experience, which made it possible to predict necessary adjustments before effective implementation. The interface sought to combine simplicity and attractiveness, incorporating visual elements related to the solar theme: such as solar panel icons, vibrant colors associated with clean energy, and contrasts suitable for reading in low-light environments. This aesthetic and functional concern aimed to promote greater user engagement, while considering the reality of farmers who, in some cases, are less familiar with digital technologies. In addition, accessibility was treated as a priority, with buttons of adequate dimensions and clear navigation flows, in order to ensure that the application could be used in different age groups and levels of digital literacy.

The next phase involved the development and implementation of the application, using the Dart language in conjunction with the resources offered by Flutter. In this stage, the startup screens (Figure 4), the navigation between modules (Figure 5) and the structuring of the educational content (Figure 6) were created, in line with the previously defined design. In addition, an interactive quiz resource was incorporated, available both at the end of each module and in a general review section, with the aim of reinforcing learning through self-assessment (Figure 7). From an educational point of view, this functionality dialogued with gamification and active learning approaches, which defend the participation of the student as a protagonist in the process of knowledge construction. Thus, the quiz was not restricted to an evaluative activity, but was thought of as a resource to stimulate engagement and consolidation of the contents covered.

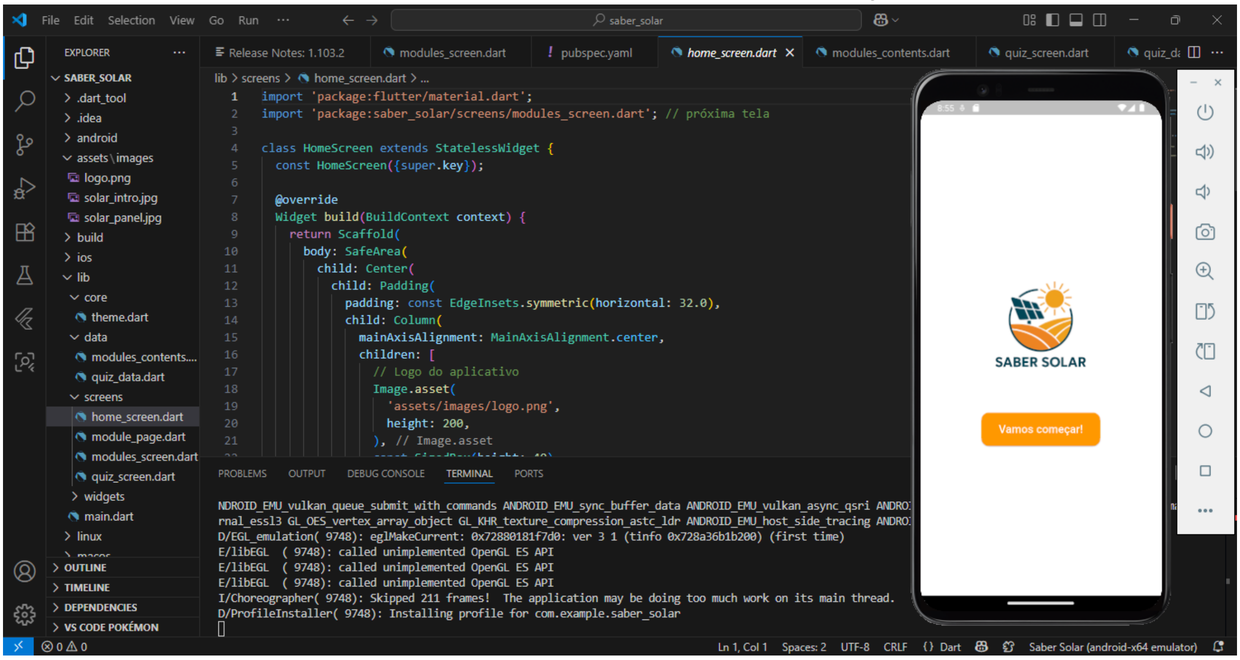

Figure 4: Development and simulation of the Saber Solar application launch screen

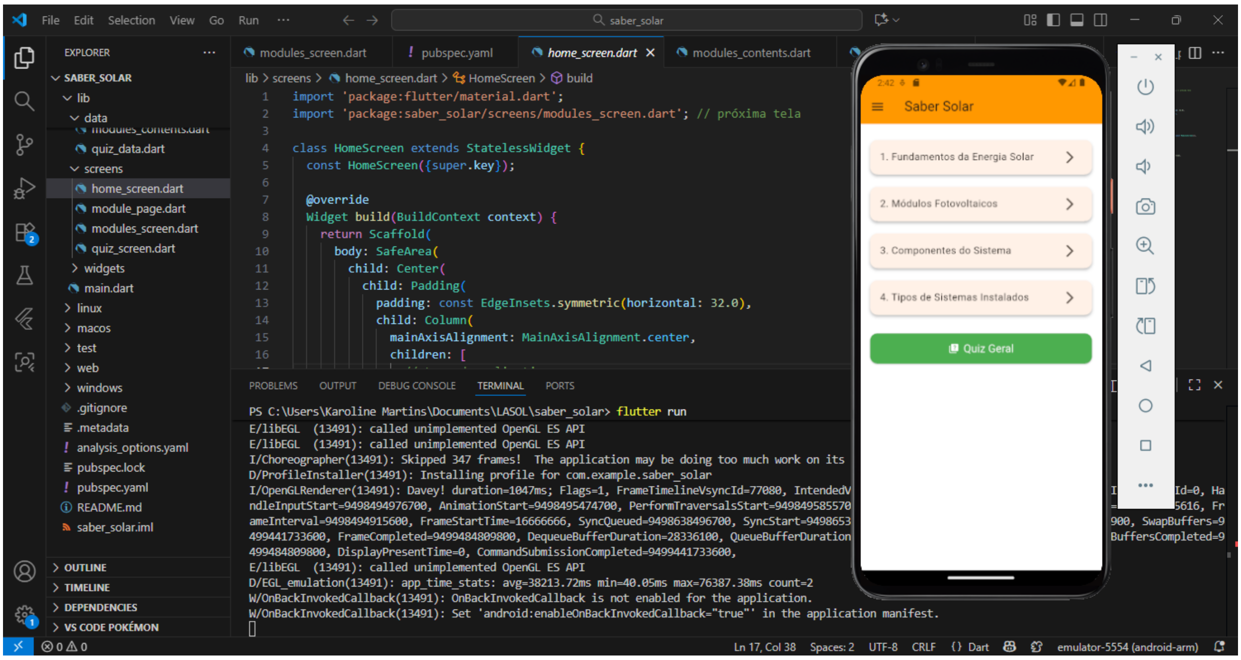

Figure 5: Development and simulation of the navigation screen between modules of the Saber Solar application

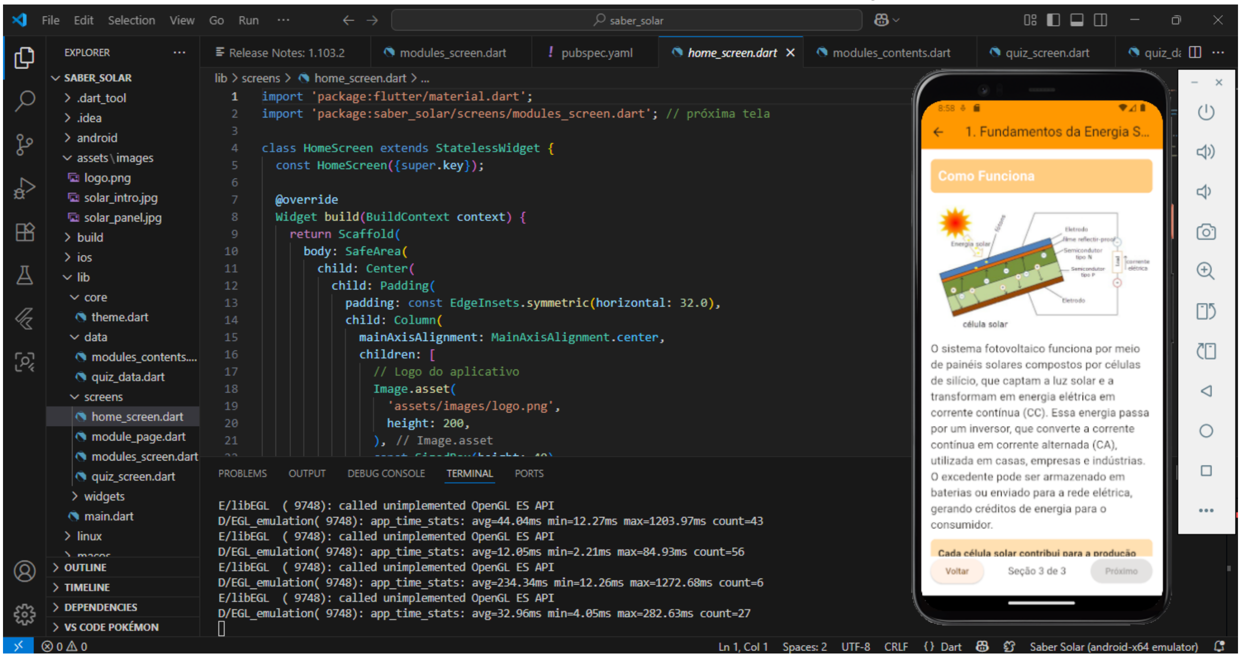

Figure 6: Development and simulation of the structuring screen of the educational content of the Saber Solar application

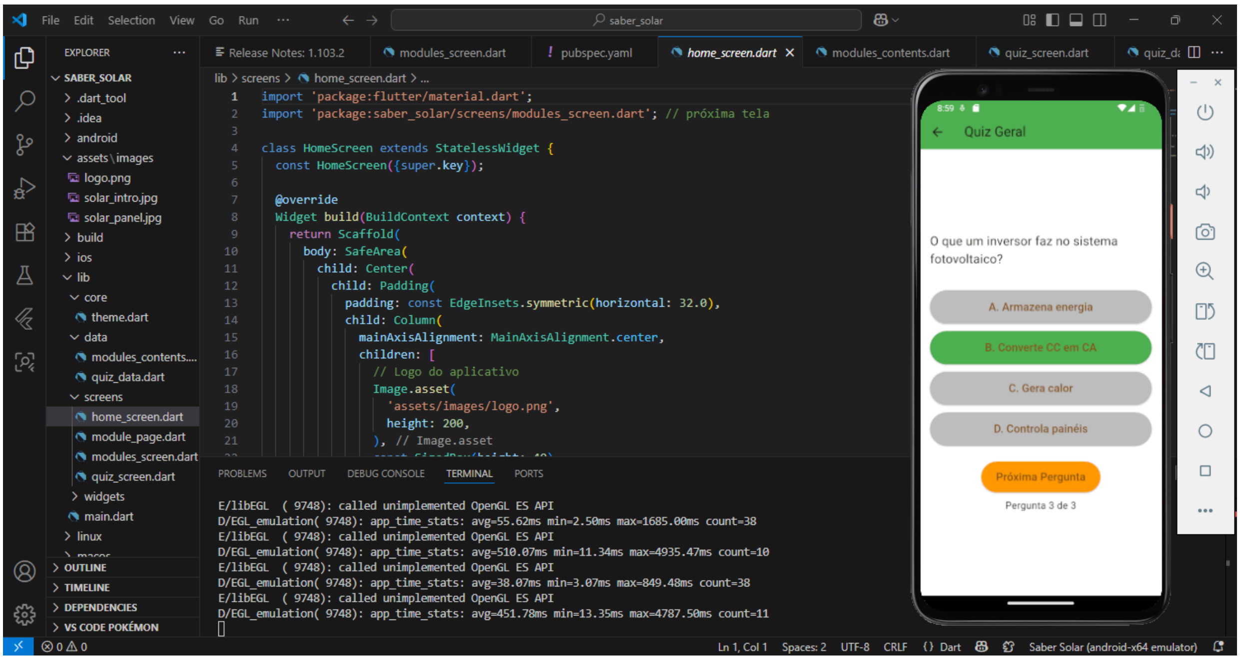

Figure 7: Development and simulation of the interactive quiz screen

Finally, the methodological validation stage, although not yet implemented at the time of submission of this article, is structured and will be conducted with the target audience [students from the Technical College of Teresina (CTT/UFPI) and family farmers in the region]. The evaluation will be divided into two main fronts: (1) Usability Evaluation and (2) Pedagogical Evaluation. For the Usability Assessment, a quantitative questionnaire based on the System Usability Scale (SUS) model, a standardized and widely accepted tool to measure perceived ease of use (Vlachogianni, 2021), will be applied. For the Pedagogical Evaluation, qualitative questionnaires and semi-structured interviews will be used after the free use of the application, focusing on the user's perception of learning. The success criteria for this validation include: (a) high usability (expected SUS score above 70); (b) clarity of the adapted technical content; (c) understanding of fundamental concepts (measured by engagement and quiz success rate); and (d) perceived educational relevance. The collection of this feedback will be essential to guide future adjustments and ensure that Saber Solar works as an effective pedagogical tool for the democratization of knowledge about solar energy.

4. Results and Discussion

The main result of this work, at the present stage, is the implementation of version 1.0 of the educational application Saber Solar , a functional tool developed in Flutter and fully operational on Android devices. Unlike the initial summary stage, the project has advanced to a tangible software product with a defined content scope, explicitly designed to overcome the barriers to information access identified in the literature. To ensure broad accessibility in rural areas, the compiled *.apk* file was optimized to approximately 20MB, facilitating distribution via local file sharing (e.g., Bluetooth or offline transfer) without consuming significant storage space. Furthermore, the application requires a minimum operating system of Android 5.0 (Lollipop), ensuring high compatibility with older mobile devices commonly found in rural communities.

To meet the objective of structuring the content progressively, the application's architecture was designed with a non-linear navigation system. Users are presented with four main thematic modules: Fundamentals of Solar Energy, Photovoltaic Modules, System Components, and Types of Systems Installed. The interface allows farmers or students to freely select and navigate through any module based on their immediate needs or interests, without forced sequential progression. Each module is further subdivided into brief, digestible sections (Figure 6), preventing cognitive overload and adapting to the user's learning pace. The core functional achievement of Saber Solar is its 100% offline operational capacity, directly addressing the severe connectivity and digital literacy barriers diagnosed in the Piauí context. To achieve this, no external databases or cloud API requests were utilized. All educational content, schematic images, and evaluation tools were hardcoded directly into the application's source code (managed within Dart files such as *modules_data.dart* and *quiz_data.dart*). This technical decision ensures that once installed, the user has uninterrupted access to all knowledge and interactive features, regardless of internet availability.

In terms of engagement, the interactive quiz feature (Figure 7) was implemented not merely as a validation tool, but as an active learning mechanism. When interacting with the general quiz or end-of-module questions, the user receives immediate visual feedback: selecting an option triggers a color change-green for correct answers and red for incorrect ones. At the end of the session, the application calculates and displays the final score (e.g., indicating the number of correct answers out of the total). This functional mechanic effectively applies gamification principles to enhance knowledge retention. The complete operational logic, including the independent access to the general quiz and the non-linear navigation through the educational modules, is illustrated in the user flow diagram (Figure 8).

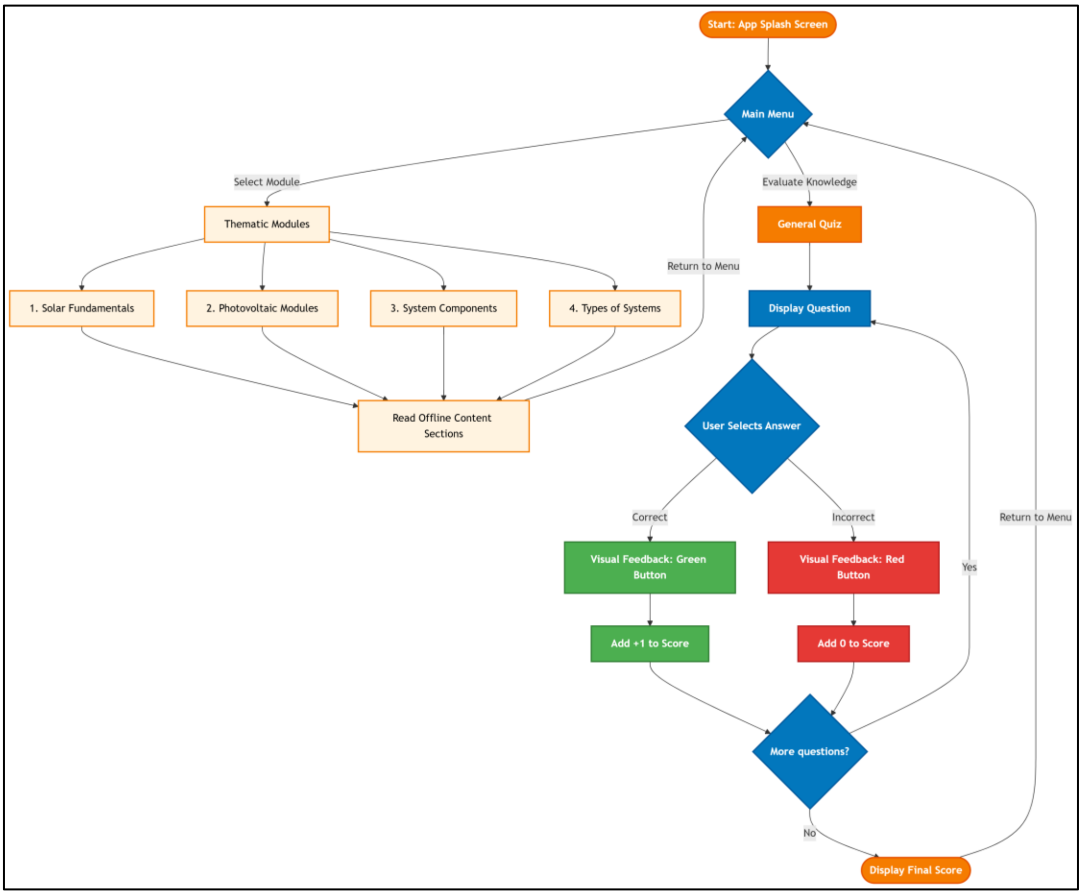

Figure 8: User flow and operational logic of the Saber Solar application, illustrating the non-linear navigation through educational modules and the gamified feedback mechanism.

Prior to the planned field validation, rigorous internal functional testing was conducted to guarantee software stability. The application was extensively tested in simulated environments using Android Studio (API 33 - Android 13) and deployed on physical devices (specifically, a Xiaomi Redmi Note 11). These tests confirmed that the widget-based architecture successfully rendered responsive interfaces across different screen resolutions, and that the offline data retrieval executed seamlessly without system crashes or latency. Table 1 summarizes how these implemented functionalities directly validate the project's specific objectives.

Table 1: Mapping of Project Objectives to Implemented Functionalities and Internal Validation

Specific Objective	Implemented Functionality	Internal Functional Validation
Develop an accessible tool focused on offline operation	Local data architecture (Hardcoded assets in Dart files).	App installed and operated seamlessly on physical devices with Wi-Fi and mobile data disabled.
Structure content in thematic modules	4 Unlocked Modules divided into internal sections.	Non-linear navigation confirmed, allowing users to freely access specific subjects.
Strengthen autonomy through engagement	Gamified Quiz with immediate visual feedback (Green/Red) and final scoring.	Interactive logic tested and validated, ensuring accurate score calculation and feedback display.

The architecture and functionalities of Saber Solar represent a synthesis of effective practices identified in the literature, while filling a specific regional gap. While initiatives like "Quiz Solar" focus strictly on gamified validation of general knowledge , and tools like the USP app assist in complex system sizing , Saber Solar uniquely merges fundamental theoretical training with offline accessibility. It acts as an intermediate, preparatory step tailored specifically for the reality of family farming in Piauí. The primary delimitation of this study at the current stage is the absence of field validation with the final target audience. While the internal technical tests confirm that the software meets its functional requirements, measuring the pedagogical effectiveness and perceived ease of use remains essential. This formal validation, utilizing the System Usability Scale (SUS) and qualitative pedagogical analysis with students from the Technical College of Teresina (CTT/UFPI) and regional family farmers , constitutes the next planned stage of the project.

5. Conclusion

The energy transition in the rural area of Piauí faces significant barriers, notably the gap in accessible technical knowledge on photovoltaic solar energy aimed at family farmers. This article responded to this challenge by detailing the development process, pedagogical structure, and functional validation of the educational application Saber Solar. The primary objective of creating a functional, accessible, and 100% offline teaching tool was successfully achieved, resulting in the lightweight (20MB) version 1.0 of the application.

By hardcoding content and structuring it into non-linear, progressive modules, the app’s architecture directly addresses the connectivity and digital literacy barriers pointed out by the literature. Furthermore, internal technical testing on emulators and physical Android devices confirmed the software's stability and the viability of its interactive gamified features, such as the quiz's immediate visual feedback and scoring mechanisms.

This development was carried out within the scope of a Voluntary Technological Initiation (ITV) work plan of the Institutional Program of Initiation Scholarships in Technological Development and Innovation (PIBITI) of the Federal University of Piauí (UFPI). The main delimitation of the study at the present time, the absence of field validation data with the target audience, is recognized. The project continues in 2026, focusing on the rigorous application of the validation methodology (based on the System Usability Scale and pedagogical analysis) with farmers and students from CTT/UFPI to measure the real impact of the tool.

It is concluded that Saber Solar is a tangible, technologically validated, and promising contribution to the democratization of technical knowledge. The tool positions itself not only as a repository of information but as a pedagogical infrastructure adapted to the rural reality of Piauí. The project demonstrates that technological innovation focused on the end-user's actual limitations (e.g., offline access and hardware compatibility) is an essential component to ensure the benefits of solar energy are distributed equitably, fostering a fairer and more inclusive energy transition.

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