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Telegram Bots in Science Education: Applications in the Context of Astrophysics

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Abstract

Digital tools have transformed how we create and share educational content, particularly in science. This change has opened up exciting opportunities for both educators and learners, making complex concepts more accessible and engaging than ever before. Among these tools, Telegram bots stand out for their versatility, accessibility, and ability to foster interactive user engagement [1]. This contribution focuses on the innovative use of Telegram bots in developing scientific education resources, highlighting some case studies in Astrophysics, such as the Astrophysical Cody Maze and the Astrophysical Code Hunting Game [2]. The Astrophysical Cody Maze is a virtual labyrinth that presents coding challenges and quizzes related to astrophysics and space exploration. It helps participants develop computational thinking and problem-solving skills while promoting scientific dissemination. The International Code Hunting Game is a virtual treasure hunt that guides participants through a map of the world, discovering astronomical observatories, from the largest and most famous to smaller, lesser-known ones, including currently operating and heritage facilities, alongside iconic locations and notable figures in the history of astrophysics.
Furthermore, this contribution demonstrates how a bot can be created and programmed using Python and how some functionalities can be incorporated into educational resources. As such, it highlights the value of Telegram bots in science education, encouraging educators and developers to explore similar approaches in every field of study. The adaptability of this platform offers endless possibilities for creating engaging, scalable, and impactful educational resources, as well as allowing the collection of valuable data for evaluation purposes.

Keywords: *Telegram bots, gamification, astrophysics, coding, STEM*

1. Introduction

As part of its "third mission," the National Institute for Astrophysics (INAF) is actively committed to spreading scientific culture and sharing the results of astronomical research with society. The COVID-19 pandemic has significantly impacted education and outreach activities in recent years, prompting a radical rethinking that shifted many projects towards online platforms. To address this challenge, in 2020, INAF developed a new, multilingual platform dedicated to innovative teaching – play.inaf.it – which hosts numerous resources for families, teachers, and students, and that is still available and actively updated to this day, even though the pandemic emergency has ended. In particular, INAF promotes digital literacy by developing astronomy education resources for schools of all levels that leverage coding to enhance computational thinking and digital skills. One of the most significant initiatives in this context was the Astrophysical Online Code Hunting Game, created in collaboration with the University of Urbino [3]. This project allowed thousands of people to virtually explore astronomical observation sites worldwide when they couldn't even leave their homes. As COVID restrictions eased, INAF began designing outdoor activities: among these, the Astrophysical CodyMaze, which premiered at the Genoa Science Festival in 2021. This initiative remains actively

used in schools and public squares across Italy during various events, such as the European Researcher's Night. New initiatives were developed by returning to in-person activities, including escape rooms and workshops focused on making and educational robotics. The most recent addition was the Astro-Tamagotchi, which premiered in 2024 at the Genoa Science Festival and described in detail in [4]. These three resources – the Astrophysical Code Hunting Game, the Astrophysical CodyMaze, and the Astro-Tamagotchi – share a key innovative feature: they are all managed through a Telegram bot, making the experience engaging and accessible to an ever-growing audience. Without going into too much detail on the three activities, this paper aims to demonstrate the potential of Telegram bots in developing educational applications for STEM subjects, such as astrophysics, which can be tailored for both schools and the general public. By leveraging the versatility and interactivity of bots, it is possible to create engaging and innovative tools that foster learning, stimulate curiosity, and enhance digital and scientific literacy in diverse audiences.

2. Telegram Bots

Since 2014, many online messaging platforms – including Telegram – have opened up to third-party developers, providing tools for building bots: advanced conversational agents that can interact with users within the messaging app. A comprehensive review of conversational interfaces, patterns, and paradigms can be found in [1]. The Application Programming Interfaces (APIs) provide tools that allow bots to interact with users and the messaging system they are integrated into [5]. They provide user interface elements like buttons, maps for sharing locations, and images. Thanks to these features, developers can create innovative services that operate through a conversational interface, meaning they function within a chat, making interactions more natural and accessible for users. In short, APIs enable bots to offer advanced and interactive services without requiring developers to build everything from scratch. Notably, Telegram released its bot-supported API in July 2015, followed by the introduction of version 2.0 in April 2016. Given their long-standing presence, Telegram's APIs are well-established and widely adopted, providing a robust and reliable framework for bot development.
Bots reside in a highly familiar environment: within a conversation thread alongside private chats with friends and family, which is increasingly the most frequently used feature on users' smartphones [6]. Most people use messaging apps multiple times daily and are well-versed in their interface and functionality. Rather than trying to draw users towards new applications, bots offer a highly convenient way for services and developers to engage with users where they are, leveraging the existing conversational paradigm. As such, bots are the perfect gateway for transforming instant messaging systems into powerful content delivery platforms.

The advantages of bots are varied, benefiting both users and developers. Here are just a few key points. For a more comprehensive list, see [1]:

- **No installation required**: Bots must not be downloaded or installed. Once a conversation is started in the messaging app, they are immediately operational. There is no need for device storage, installation, or complex configuration steps, making bots fast and lightweight compared to traditional mobile apps.
- **Platform-independent**: Bots live within instant messaging applications, meaning they are not dependent on the host operating system. As a result, bots are available on all platforms supported by the messaging app without any changes to their graphical or functional features.
- **No user authentication required**: Bots do not require separate user authentication. The messaging platform provides a reliable identity system, automatically identifying users without creating new accounts or passwords. Furthermore, users are already accustomed to sharing and storing contact information within messaging apps, so when a bot conversation begins, it automatically receives basic personal details from the user.
- **Asynchronous communication**: Instant messaging is an asynchronous process, and conversation threads retain context, allowing users to leave and return to conversations anytime and pick up where they left off.
- **Effortless deployment**: Since a bot's logic is implemented server-side and no code needs to be deployed to user devices, deployment is virtually effortless. Updates automatically propagate to all users, ensuring no one is left with an outdated bot version.
- **Reduced interface design effort**: Bots typically rely heavily on the instant messaging app's user interface, with limited options for graphical customization. This simplifies the design process, focusing on a rich user experience with a few key elements rather than complex interface design.

One potential limitation of bots is that they require an active internet connection. This can cause interruptions in service availability and may negatively impact the bot's perceived reliability, particularly in areas with poor network coverage or for users with limited data plans – issues that can be particularly noticeable during public events.

3. Coding Games

In this section, we provide a brief overview of the three activities, focusing on the specific tasks performed by their respective bots. We emphasize that these activities can be carried out both individually or in groups, either collaboratively or competitively. They are designed for use in schools and other organizations to promote astronomy outreach, computational thinking, problem-solving skills, and digital abilities. All resources are freely available on the Play INAF website.

Fig 1. *Participants at the European Researchers' Night event playing the online Code Hunting Game (top left) and the Astrophysical Cody Maze (top right). Below, a class of students engages in the Astro-Tamagotchi challenges during the Festival della Scienza in Genova in 2024.*

3.1 Code Hunting Games

Based on the Treasure Hunt Bot, the Code Hunting Game is a multiplayer game designed to foster digital skills and computational thinking [7]. In its online version, the game adopts the structure of a traditional treasure hunt, challenging players to solve tasks using coding logic to navigate a map of a specific geographical area. In 2020, we customized this format for an astronomical context, first focusing on Italy and later expanding it into a global game that explores over 300 locations worldwide related to astronomy. This became the first international Astrophysical Code Hunting Game [3]. This ambitious project involved more than 70 astronomers, science communicators, and astronomy enthusiasts from over 30 countries. The game map includes over 300 “pins” across 60+ countries and all continents, including Antarctica. These pins highlight a wide range of locations: iconic observatories, archaeological sites, and influential researchers who shaped the history of astronomy. The map also uncovers hidden treasures, such as lesser-known observatories, public sundials, astronomically significant monuments, and local stories about little-known figures in the field.
This treasure hunt is available free of charge at this URL:
https://play.inaf.it/en/international-code-hunting-game/

A Telegram bot manages the game, and a complete gameplay session follows these steps:

1. **Welcome and rules**: Players receive a welcome message on Telegram and a brief overview of the game’s rules. With a first simple challenge, the bot checks whether the basic rules have been understood.
2. **Registration**: Teams register by providing their name, the number of players, and, optionally, a team selfie.
3. **Coding challenge**: Teams solve a random coding puzzle to receive a clue for a specific location randomly assigned by the bot.
4. **Finding the location**: Teams navigate the world map to identify the area hinted at by the bot. Each location is marked with a pin on the map. Clicking a pin opens a window with a description, an image, and a QR code with a deep link.
5. **QR code verification**: Teams scan the QR code to check if they’ve found the correct location. If correct, and fewer than eight locations have been successfully reached, they return to step 3.
6. **Final coding challenge**: After completing eight locations, teams face one final, more complex challenge that requires them to retrace their steps and decipher clues left by the bot.
7. **Final destination**: Using the final clue from step 6, the team identifies the last location via geocaching. The need to resort to geocaching is not immediately obvious. For this reason, there is an option to request a hint.
8. **Victory**: The team's success is confirmed upon scanning the correct final QR code. They receive a certificate with their team name, selfie, and the total time spent on the treasure hunt.

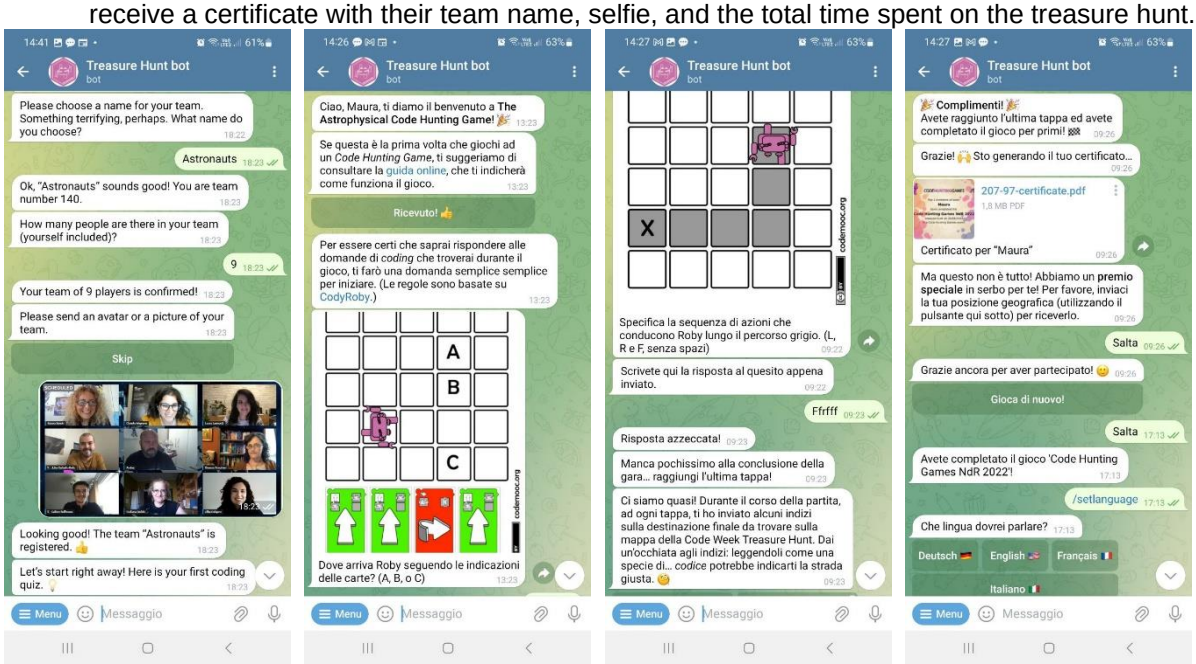

Fig. 2 *Some screenshots captured during different phases of the online Code Hunting Game, available in both Italian and English.*

3.2 Astrophysical Cody Maze

The CodyMaze is a mixed-reality, grid-based coding challenge that combines a simple, replicable physical chessboard with an online component managed by a Telegram bot [8]. The bot engages players with coding riddles that involve dynamically generated grid movement instructions. By scanning QR codes assigned to each cell of the physical chessboard, the bot tracks the player's movements and verifies the correct execution of the proposed tasks. The Astrophysical CodyMaze builds on this format by integrating quizzes about astronomy, astrophysics, and space exploration. It is a powerful educational tool combining coding skills with astronomy outreach, creating a unique and engaging learning experience.
The CodyMaze consists of 13 challenges. To complete each challenge, the player must reach the correct destination cell on the physical chessboard. Once all 13 challenges are completed, the player wins the game and receives a certificate. The chessboard used in CodyMaze is a 5×5 square grid, where each movement is described using coordinates that include the column letter, row number, and orientation (north, east, south, or west, depending on the player's facing direction). Each cell is marked with a unique QR code, enabling the Telegram bot to identify the player's position on the board during gameplay. Additionally, the bot leverages Telegram's "deep linking" feature, which allows QR codes to seamlessly connect players from scanning to bot interaction and game progression.
A detailed description of the coding challenges is available in [8], and the QR codes can be downloaded from this URL: https://play.inaf.it/en/astrophysical-cody-maze/

The gameplay session, orchestrated by the Telegram bot, follows these steps:

1. **Enter the maze**: Players begin by scanning the QR code of a cell on the chessboard's border.
2. **Position check**: The bot confirms the player's initial position and orientation.
3. **Astronomy quiz**: The bot presents the player with an astronomy-related challenge.
4. **Coding challenge**: The bot assigns a coding exercise. Successfully solving it reveals the coordinates of the next destination cell.
5. **Move to the destination cell**: The player navigates the board, scanning the QR code of the target cell. The bot verifies the new position and requests the player's orientation (with respect to cardinal points).
6. **Repetition**: Steps 3, 4, and 5 are repeated for each challenge. Eventually, the bot announces the game's conclusion if all 13 challenges have been completed.
7. **Victory**: After completing all 13 challenges, the player successfully exits the maze and, before receiving their certificate, can answer a few questions for statistical purposes. Again, the bot asks the questions on telegram and stores the answers.

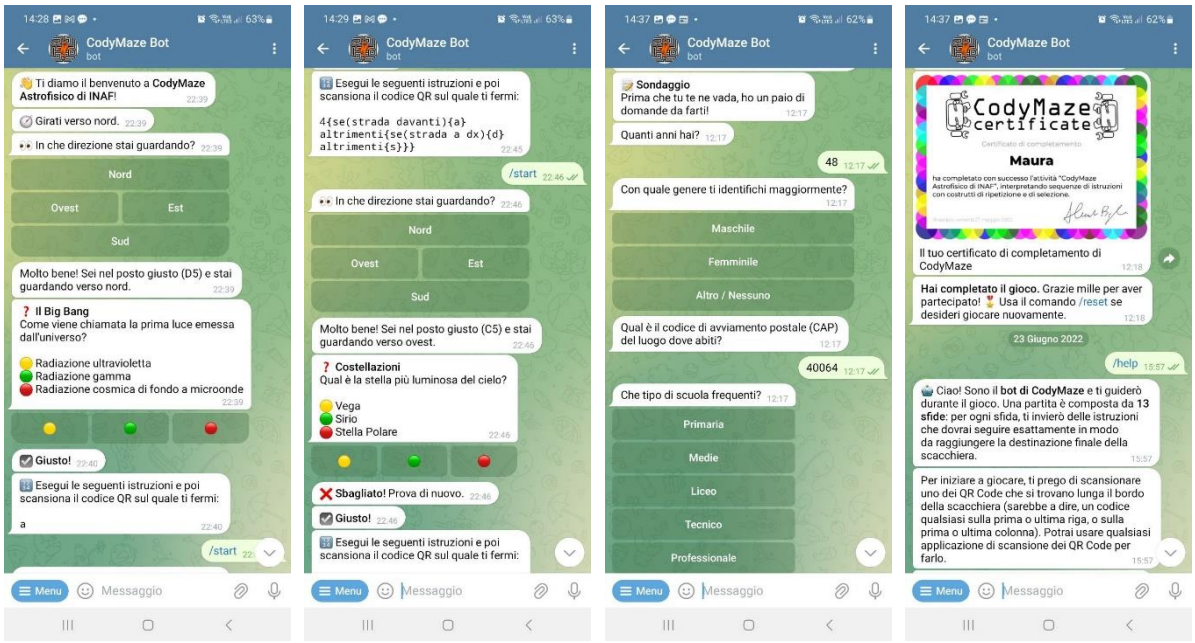

Fig. 3 *Some screenshots captured during different phases of the Astrophysical CodyMaze, available in both Italian and English.*

3.3 Astro-Tamagotchi

The activity is inspired by the famous Tamagotchi, a popular electronic game from the 1990s and 2000s that allowed players to care for a virtual pet powered by a microchip. In the Astro-Tamagotchi, which is a mixed-reality educational activity provided to in-person participants, players can adopt a star after identifying it amidst the colorful clouds of a star-forming nebula (a stellar nursery). They must help the star ignite and continue its evolution by overcoming logic challenges, solving coding puzzles, and utilizing augmented reality. The goal is to entertain the audience while fostering an understanding of the complex dynamics that govern the formation and evolution of stars in the Universe. For a complete and detailed description of the Astro-Tamagotchi, see [4]. Also in this case, the game is managed through a Telegram bot, which is activated by scanning a “welcome” QR code: the latter guides participants through the various challenges, starting from a nebula of gas and dust within which stars form. The first challenge involves a deck of cards, each representing an essential element in the process of igniting a star: protons, electrons, positrons, deuterium, and helium atoms must be combined correctly to replicate the chain of nuclear reactions occurring within a star’s core [9]. Once this challenge is completed, players learn the mass of the star they have successfully ignited. They can observe it using an augmented reality application developed with CoSpaces Edu (an online application of which INAF is an *Impact Partner*) and Merge Cube. The augmented reality feature brings the stars to life in 3D, making their growth visible, enriching the gameplay space with interactions, and prompting participants to complete a quiz about stellar evolution. The bot checks if all quizzes have been solved and, in such a case, provides the code needed to tackle the final challenge, which focuses on coding and robotics.
The list of materials needed to reproduce this activity is available at this URL:
https://play.inaf.it/astro-tamagotchi/

The gameplay session, controlled by the Telegram bot, follows these steps:

1. **Welcome**. A QR code launches the game with a welcome message, in which the bot assigns one of the five nebulae to the player.
2. **Finding a protostar**. Players begin by scanning one of several QR codes scattered throughout the printed image of a nebula. The bot evaluates whether the selected gas and dust seed can form a protostar. If successful, the bot directs the player to the first challenge: igniting the star by simulating the proton-proton chain, a key sequence of nuclear reactions in stellar interiors.
3. **The proton-proton chain**. The game mat features a QR code that must be scanned once the game is completed. The bot verifies the outcome of this challenge through a multiple-choice quiz. A correct answer rewards the player with a code to unlock a cryptex (an encoded, locked device that can be opened using a sequence of letters). Inside the cryptex, the mass of the newly ignited star is revealed, along with instructions for progressing to the next challenge.
4. **Astronomical quizzes**. Upon solving the second challenge – four astronomical quizzes – the bot provides a sequence of letters that players must use to program Ozobot, a small educational robot that teaches children programming through colors and pathways, guiding the robot through a maze reproducing the final stages of the stellar life cycle.
5. **Getting out of the maze**. When Ozobot reaches its final destination, the bot checks the accuracy of the result by presenting another multiple-choice quiz, which is activated by a deep link embedded in the QR code printed on the maze. A correct response concludes the journey, and the bot rewards the player with a digital certificate or prize delivered via the chatbot.

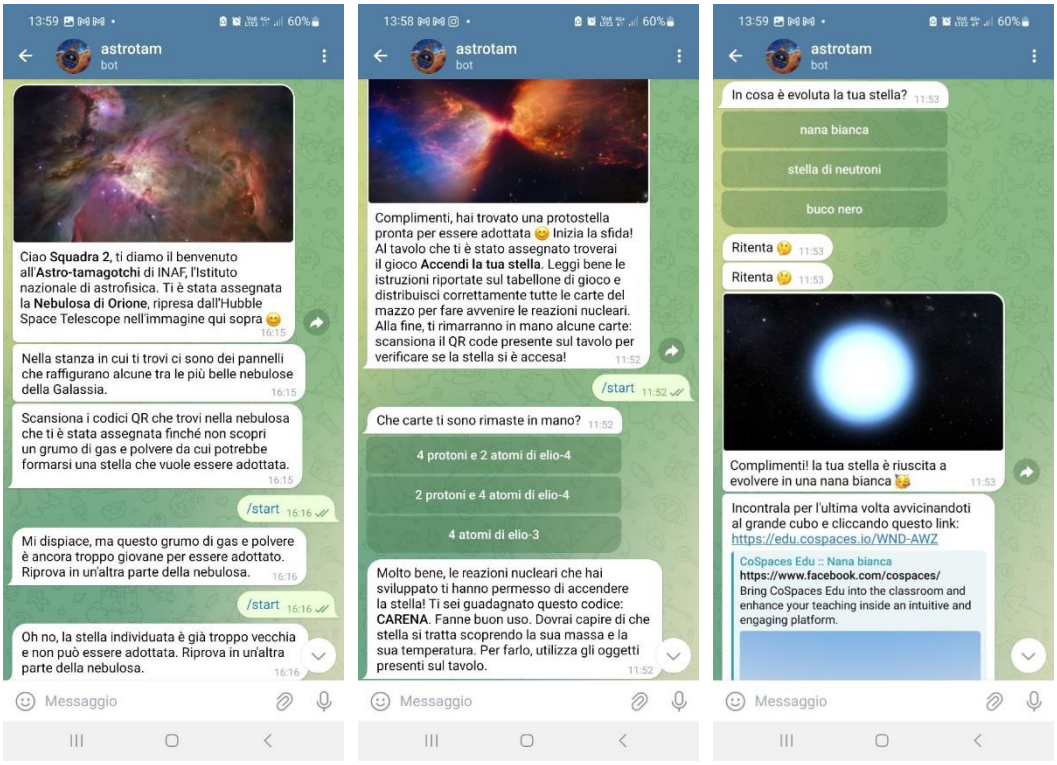

Fig. 4 *Some screenshots captured during different phases of the Astro-Tamagotchi.*

4. Bot Development

Creating a Telegram bot is straightforward, thanks to the tools and APIs provided by Telegram (and also to generative AI). The journey always begins by chatting with BotFather, Telegram's official bot-management bot. Developers can easily create and configure their bot by conversing with BotFather within the Telegram app. After sending the /start command, BotFather guides the user through the setup process, asking for a name (the bot's display name) and a unique username that must end with "bot". Once this step is completed, BotFather generates an API token, a key piece of information that enables the developer to connect the bot to their code. This token is essential and should be stored securely, as it provides full access to the bot's functionality. The next step is to write the bot's code. Telegram's Bot API is versatile, and libraries such as python-telegram-bot make it easy to interact with Telegram in Python, a programming language widely chosen for its simplicity and readability. After setting up a development environment and installing the necessary libraries, the bot can be programmed to handle commands, respond to messages, and perform various tasks. The Python script would establish a connection to Telegram using the provided API token, define the bot's behavior through handlers, and run a continuous loop to monitor and respond to user interactions.

Deep linking allows a bot to associate specific questions with specific moments in a live event or geographical location. In Telegram, a deep link is a URL that includes the bot's username and a unique question identifier. These links can be used directly or embedded in QR codes, making them easily accessible via screens, videos, or printed materials. When scanned, the link opens in a web browser with instructions or directly in the Telegram app, if installed, seamlessly starting a conversation with the bot.
The bot developed to manage the Astro-Tamagotchi is a representative example of the different functionalities that Telegram bots can offer. It seamlessly integrates multiple interactive features, such as sending images and links, which provide players with visual guidance and supplementary information during the game. Additionally, the bot manages multiple-choice quizzes to test players' knowledge, ensuring an engaging and educational experience. It can also verify manually entered text responses directly within the Telegram chat, allowing for a broader range of challenges that require more creative or precise input. This combination of dynamic content delivery, interactive quizzes, and real-time input validation showcases the bot's versatility and highlights how it leverages Telegram's robust API to deliver an immersive, multi-faceted user experience.

5. Conclusions

In this paper, we presented three applications of Telegram bots in science education, developed within the context of astronomy education and public outreach. These activities attracted substantial participation: hundreds of teams have signed up for the various versions of the online Code Hunting game since 2020; thousands of people have played the CodyMaze since 2021, and of these, around 1,400 completed the related questionnaire with additional information about their age, school level, and geographical distribution; and approximately 2,000 students participated in the Astro-Tamagotchi during the 2024 Genoa Science Festival. In our view, bots offer an engaging "software platform" for creating educational activities, representing a significant evolution in how digital information and functionalities are delivered. Moreover, they provide a direct means of collecting data on user engagement and enjoyment. Instant messaging – where bots are implemented – is a particularly effective technology due to its simplicity and widespread accessibility. Given current usage demographics [6], it can be considered one of the most engaging technologies.

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