

Translating Design Requirements into a Hybrid Prototype for Early Programming Education: The Iterative Development of IMPACT+

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Abstract: Teaching fundamental programming concepts to primary school children remains a challenge in computer science education. Early programming instruction must balance conceptual complexity with developmental appropriateness, as learners are expected to engage with ideas such as sequencing, loops, conditional logic, debugging and problem solving while still developing abstract reasoning strategies. This challenge is intensified by limited lesson time, diverse learner needs and the need for motivating approaches that are also pedagogically meaningful. Unplugged approaches can support collaboration, tangible manipulation and social interaction, but often require additional guidance and scaffolding. Digital tools, by contrast, can provide feedback, narrative framing and structured progression, yet may reduce hands-on engagement. The central design question is therefore not whether analogue or digital formats are superior, but which pedagogical function each format should fulfil. This paper presents the ongoing development of IMPACT+, a hybrid game-based learning project for 8- to 10-year-old children. The project introduces programming concepts through an unplugged board game extended by a digital prototype. Building on qualitative findings from an earlier classroom-based evaluation of the analogue version, the paper shows how identified design requirements were translated into concrete digital prototype features. The previous project phase highlighted the need for clearer scaffolding, stronger visual orientation, more structured progression and a motivating but carefully balanced narrative framework. Based on these findings, the digital prototype includes guided onboarding, level-based progression, visual orientation cues and narrative components that frame the programming task without replacing analogue planning. Methodologically, the study is positioned as a design-oriented follow-up within an Educational Design Research approach. The paper documents how empirical findings from the classroom evaluation of the analogue IMPACT game were translated into design requirements and prototype features. The results are relevant for researchers and practitioners designing accessible, motivating and pedagogically sound hybrid learning environments.

Keywords: Game-based learning, Hybrid learning, Early programming education, Educational design research, Computer science education

1. Introduction

Learning to program is cognitively demanding because novices must coordinate several interrelated activities, including understanding and structuring a problem, developing a solution approach, applying programming concepts, and testing and debugging their solutions (Du Boulay, 1986; Luxton-Reilly et al., 2018). When pupils first encounter programming in primary school, they may still be developing an understanding of concepts such as sequences, loops, and conditions (Mladenović & Žanko, 2025). At the same time, they need to coordinate problem-solving processes, programming concepts, and new forms of notation, which can place considerable demands on limited cognitive resources (Duran et al., 2022; Margulieux et al., 2020). Difficulties during this process may lead to frustration and reduce persistence in programming tasks (Tian et al., 2021).

In the Swiss canton of Zurich, the Curriculum 21 module for Media and Informatics schedules computer science instruction only in the second half of Cycle 2, i.e. from Grade 5 onwards, where it is taught as a dedicated weekly lesson; in Grades 3 and 4 it is integrated into the regular subjects (Curriculum 21, n.d.). Grades 3 and 4, typically attended by children aged 8 to 10, therefore represent a transition phase between early algorithmic experiences and formal programming instruction. In earlier grades, children already encounter precursor concepts by recognising and following formal instructions, such as recipes, game rules or craft instructions. From Grade 5 onwards, these ideas are developed more explicitly towards computational problem solving and programming, including sequences, loops, conditional statements and parameters. This creates a particular need for low-threshold approaches that build on children's existing understanding of structured instructions while preparing them for more formal programming concepts. Unplugged and board-game-based approaches can serve this function by foregrounding tangible manipulation, social interaction and playful problem solving (Huang & Looi, 2021; Brackmann et al., 2017; Kuo & Hsu, 2020; Machuqueiro & Piedade, 2022). Previous research has demonstrated the potential of unplugged, tangible and hybrid programming environments. However, less attention has been paid to the traceable process through which

classroom findings from an unplugged intervention are translated into decisions about which pedagogical functions should remain physical, and which should be supported digitally.

The present paper focuses on IMPACT+, a hybrid follow-up prototype that extends the analogue game through digital narrative and scaffolding elements and translates classroom findings into concrete prototype features. The guiding question is: How can empirical findings from an analogue programming game be translated into a hybrid game-based learning prototype for early programming education?

The contribution of this paper lies in making the design translation from empirical findings to a hybrid prototype transparent and traceable, rather than in evaluating the effectiveness of the resulting prototype.

2. Related Work

2.1 Unplugged and Hybrid Programming Education

Unplugged approaches can introduce Computational Thinking (CT) and programming concepts through materials, bodily movement, cards or board games rather than digital interfaces. They typically address components such as decomposition, sequencing and logical reasoning while separating conceptual understanding from the technical demands of programming environments (Brackmann et al., 2017). Grover and Pea (2013) caution that introducing computing concepts without a computer may keep learners from the computational experiences that are central to CT practice; this is one motivation for combining unplugged planning with a digital execution layer. Existing research describes unplugged activities both as standalone learning environments and as preparatory experiences that can support the transition to later computer-based programming activities (Huang & Looi, 2021; Munasinghe et al., 2023).

Unplugged activities have been shown to improve CT dimensions such as algorithmic design, abstraction, evaluation, decomposition and generalisation in primary school (Dag, Sumuer and Durdu, 2023), while board-game-based approaches have been studied separately (Tsarava et al., 2018; Machuqueiro and Piedade, 2022). Studies further suggest that unplugged phases can facilitate later engagement with digital or block-based programming environments (del Olmo-Muñoz, Cózar-Gutiérrez & González-Calero, 2020).

In this way, hybrid learning designs can combine the collaborative and tangible qualities of material-based learning with digital guidance, representation and structured support (Horn, Crouser & Bers, 2012). For IMPACT+, this shifts the design question from choosing between analogue and digital formats to distributing pedagogical functions across both.

2.2 Game-based Learning, Narrative and Scaffolding

Game-based learning connects programming tasks with exploration, feedback, visible rules and meaningful action, thereby supporting CT practices such as strategy testing, iterative refinement and debugging. Board games are particularly relevant because they make rules and consequences visible through shared materials and social interaction (Kuo & Hsu, 2020).

Narrative can be a relevant design element in CS Unplugged and educational games, as storytelling may provide a meaningful and engaging context for learning activities (Naul & Liu, 2020). However, narrative should support the learning activity rather than function as an additional rule system. In inclusive game design, requirements studies have identified rich narratives, diverse characters and opportunities for character customisation as relevant design factors, although these findings were derived from a secondary-school context (Mozelius & Humble, 2023). Such design decisions should also consider how characters and visual representations may reproduce gender stereotypes (Spieler & Slany, 2018).

2.3 Related Games

Existing programming games were analysed to identify design patterns, spatial orientation and command-based movement. For example, Robot Turtles (ThinkFun), designed for children aged 4 and above, uses command cards to navigate turtles to matching jewels and introduces basic sequencing through a programmer-computer role structure, see Figure 1a and 1b. Another reference is Robo Rally (Asmodee/Renegade Game Studios), which is aimed at older players and uses programmed movement mechanics in which players plan physical command-card sequences to navigate robots through a grid-based environment, see Figure 1c. Crabs & Turtles illustrates how unplugged board games can operationalise programming concepts such as sequences, loops and conditionals through tangible command planning and embodied movement (Tsarava et al., 2018).



Figure 1a: Set-up of the game Robot Turtles. 1b: Solution for incorporation of rotation indicators within the game pieces as well as directional symbols on the cards. 1c: Basic game set-up of the game Robo Rally

3. From IMPACT to IMPACT+

IMPACT stands for “Informative Mini-Games for Programming Concepts and Computational Thinking” and was developed at Zurich University of Teacher Education (PHZH) and funded by Hasler Foundation (<https://haslerstiftung.ch/>). It is an unplugged board game for the purpose of introducing fundamental programming concepts to children in grade 3 and 4 (8-10 years old). The goal of the game is to execute sequences of actions using physical command cards. A round consists of a planning phase, in which pupils place commands on a planning board, followed by an execution phase, in which the planned actions are carried out on the game board. This separation mirrors programming practices such as sequencing, stepwise execution and debugging. The game, including all its components and rules, is documented at the following Notion link: [IMPACT Rules and Play](#).

Command cards represent algorithmic actions such as moving forward, rotating and later using loops and nested loops. A modular level structure allows teachers to select tasks according to prior knowledge, time and instructional goals. Figure 2 shows the analogue game setup.



Figure 2: The IMPACT board game setup

The project follows an Educational Design Research approach (Plomp, 2013). Phase 1 focused on the design and classroom evaluation of the analogue prototype, including expert reviews and qualitative and quantitative data from pupils and teachers (Meyer-Baron et al., 2025).

Phase 2 introduces the “+” in IMPACT+ by translating selected findings from the analogue study into a hybrid extension called **Orbit Cleaner**. During the second phase, the project was joined by Inlusio (<https://www.inlusio.com/>), an external development partner specialising in interactive storytelling and digital learning experiences. Inlusio was responsible for translating the design requirements derived from Phase 1 into the digital prototype Orbit Cleaner. Design alternatives were discussed in iterative meetings and reviewed against the learning objectives, the analogue game logic and technical constraints. Final decisions concerning pedagogical functionality were made jointly, with the research team retaining responsibility for alignment with the educational objectives.

The prototype transfers the board game's programming logic into a space-themed mission setting in which pupils guide gender-neutral robots through Earth orbit to collect space debris. It preserves the didactic distinction between planning and execution: pupils compose command sequences and observe how the robot executes them on a 12 × 12 grid. Orbit Cleaner adds guided onboarding, mission-control narrative, visual feedback, orientation cues and level-based progression across ten levels. It supports both standalone digital use and a hybrid mode in which pupils plan with physical command cards and execute the mission digitally. Figure 3 shows the mission-control framing and gameplay interface. The topic also connects to classroom teaching, particularly the Swiss interdisciplinary subject area Nature, Humans and Society, where space, orbits and celestial bodies are addressed, as well as to sustainability, recycling and selected Sustainable Development Goals (SDGs).



Figure 3a&b: Orbit Cleaner mission-control framing (in German). 3b: Orbit Cleaner gameplay interface with grid, command cards and execution controls

4. Methods

The paper draws on the Phase 1 classroom evaluation of the analogue IMPACT game (Spieler et al., 2026), including play sessions with 161 pupils, focus groups with 21 pupils, semi-structured interviews with eight teachers, informal observations and additional stakeholder play sessions. The data addressed gameplay experiences, challenges, perceived learning effects, classroom feasibility and suggestions for improvement.

Focus groups and interviews were transcribed and analysed using qualitative content analysis following Mayring (2022), supported by MAXQDA. For this paper, recurring findings were reinterpreted as design requirements for IMPACT+ and translated into prototype features for the hybrid version. The methodological focus of this paper is the structured translation of previously analysed classroom findings into design requirements and prototype decisions.

Potential findings were selected from the existing Phase 1 coding system provided they met at least one of the following criteria: they appeared repeatedly in the data; they were mentioned by both students and teachers; they addressed a key challenge related to learning or usability; or they had a direct impact on implementation in the classroom. Each selected finding was reformulated as a solution-neutral design requirement. Alternative design approaches were then discussed with the development partner and evaluated in terms of pedagogical relevance, technical feasibility, accessibility, and compatibility with the logic of the analogue game.

5. Results

This section shows how findings from the analogue IMPACT game were translated into design requirements and prototype decisions for the digital layer, which was intended to support rather than replace the analogue game. Table 1 summarises this design translation.

Table 1: Translation from Phase 1 findings to Orbit Cleaner prototype decisions

Phase 1 finding	Design requirement	Orbit Cleaner implementation
Children proposed vivid story worlds, but teachers mentioned that story should not distract from learning.	Use narrative as motivational framing, not as an additional rule system. see Section 5.1	Mission-control setting with L.E.O. (low earth orbit) as guiding character, four Orbit Cleaner robots and short, skippable narrative prompts.
Children wanted clearer rules and	Provide guided onboarding and visible	Digital intro, level instructions, help

Phase 1 finding	Design requirement	Orbit Cleaner implementation
forgot card meanings during play.	task structure. see Section 5.2, 5.3	button and explicit mission briefings. Phase 3: allow commands to be entered as code
Children struggled with left-right orientation from the figure's perspective.	Provide visual orientation support. see Section 5.4	Direction symbols on cards and movement feedback. Phase 3: Optional symbol-based orientation support in the digital version.
Children enjoyed rewards and visible feedback.	Use feedback and reward elements. See Section 5.5	Space-debris collection, success and error feedback, and simple energy bar logic without overloading the first prototype.
Children valued tangible planning and social play.	Preserve analogue collaboration while adding digital execution. see Section 5.6	Hybrid mode in which children plan with physical cards, enter the card code digitally and observe the robot executing the plan. Orbit Cleaner is played collaboratively by four children.
Teachers valued level progression as motivating and useful for differentiation.	Introduce concepts gradually through structured levels. see Section 5.7	Ten levels with increasing complexity, starting with "Boost" and later introducing turns, energy bars and loops.
Teachers emphasised low preparation effort and classroom feasibility.	Keep the setup lightweight and reusable. see Section 5.8	Clear UI, standalone mode and hybrid mode as distinct entry points. A lightweight material that is easy to print and cut.

5.1 Narrative Framing

Children showed a strong interest in story worlds. During the focus group discussions, pupils proposed a wide range of imagined settings, including forests, islands, underground worlds, fantasy landscapes and highly stylised environments. These ideas showed that pupils tried to embed the activity in a meaningful and imaginative context. At the same time, several ideas reproduced highly stereotyped or strongly gender-coded aesthetics, while others referred directly to familiar commercial game worlds.

"So, there is a candyfloss field with lots of candyfloss ground, candyfloss houses, everything candyfloss, except for the field and the people." (Interview 2_students, pos. 151–153)

"Well, my fantasy world would be underground. And it would have 3D blocks. A bit like Minecraft." (Interview 2_students, pos. 161)

As a result, the prototype needed a narrative that was imaginative and motivating but not overly attached to stereotypical aesthetics or specific commercial game references. Teachers emphasised that narrative elements should not distract from the core learning objectives. For Orbit Cleaner, this led to the decision to use narrative as contextual framing rather than as a complex branching story system. Although a space-themed setting was not explicitly suggested in the data, it was selected because, as described in Section 3, it offers multiple connections to other curricular topics. The prototype introduces children as members of an Orbit Cleaner team whose mission is to collect space debris in Earth orbit and recycle valuable components. In addition, this setting was chosen because it provides a meaningful and gender-neutral "good cause" for programming activity: children are not simply moving a figure to collect abstract points but planning missions to clean up the orbit. The narrative also supports the pedagogical logic of the game. Since the robots operate in space and receive instructions from mission control, the separation between planning and execution becomes part of the story. The digital texts developed for Orbit Cleaner reflect this narrative function. L.E.O. (Low Earth Orbit), a robot from mission control, welcomes the children, explains that the orbit contains satellites and space debris, and introduces the Orbit Cleaner team: The four robots, Kio, Grabby, Luna and R81, are presented as friendly team members waiting for instructions. All four robots are designed as part of the same team and follow the same basic visual logic. They are intended to be round, friendly, readable on a small scale and equal in value. Their differences are visual and expressive, not functional or hierarchical. Small differences support

recognition and personal attachment without suggesting that one robot is stronger, better or more appropriate for a specific gender. Thus, the four robots in Orbit Cleaner are designed as an equal team rather than as competitive or hierarchical figures, which also addresses a problem raised by teachers in the interviews:

“At the beginning, they were quite focused on themselves, and everyone looked out for themselves and made sure they had their things or simply moved forward with their game piece without considering the others.” (Interview 1_teacher, pos. 8)

The story supports motivation, task orientation and role-taking, while the programming activity remains focused on planning commands and observing their execution.

5.2 Rule Clarity and Onboarding

A recurring Phase 1 finding concerned children’s difficulties with rule transparency and procedural clarity. Pupils reported that they forgot rules during play and wanted written support explaining the meaning of cards and procedures. Teachers also emphasised that introductory levels should not overload children with too many mechanics at once. This finding led to a clear design requirement: the hybrid prototype should provide guided onboarding and reduce the need for repeated verbal explanation by the teacher. In Orbit Cleaner, onboarding is implemented through a short digital introduction, mission briefings and level-based guidance. The intro is deliberately skippable, because teachers need flexibility in classroom settings and because repeated play should not require children to watch the same narrative sequence every time.

The onboarding also introduces the core didactic structure of the game: first understand the mission, then plan commands, then press play and observe execution. This structure is central because the distinction between planning and execution is one of the key programming concepts addressed by the prototype.

5.3 Command Cards Design

The Phase 1 evaluation showed that physical command cards were central to the learning experience. They allowed children to externalise command sequences, discuss solutions and debug errors visibly. At the same time, the analogue setup created organisational challenges, including confusion about card ownership, card meanings and the distinction between used and unused cards.

Orbit Cleaner translates this finding into two complementary input modes. In standalone mode, children can plan digitally, for example through drag and drop. In hybrid mode, children plan their mission with a limited number of physical cards. The digital robot executes the mission and provides immediate visual feedback. To further enhance the hybrid experience, the next iteration will allow the new analogue card set to be imported digitally via code, see Figure 4c. Figure 4a and 4b illustrate the analogue card layout.

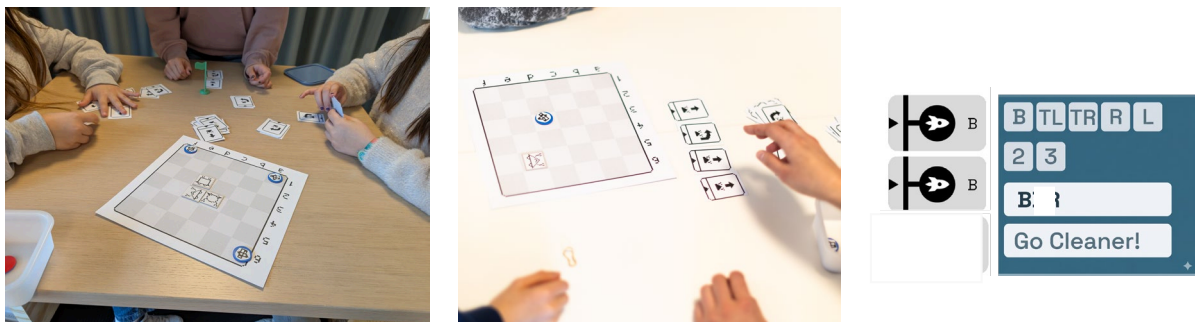


Figure 4a, b&c: 4a and 4b show how pupils first plan a level analogously by placing command cards and moving the cleaners on the physical layout. 4c left: new cards can have letters on them, e.g., B “boost” and 4c right: in the input box one enters this corresponding card codes, to navigate the cleaner online. This is useful when children play on one shared screen and call out the code

The first prototype focuses on a small command set. Boost moves the robot one field forward. Turn left and turn right rotate the robot by 90 degrees. Starting in level 6, loops and repetitions are introduced, see Figure 5. The product requirements emphasise that loops should be visually understandable rather than formally syntactic. Children should recognise which commands are repeated and where the repeated sequence begins

and ends. In a future update, the end of the loop could be added automatically, allowing users to insert cards in between without having to worry too much about syntax (closing parentheses).



Figure 5: Luna can now be controlled using commands within loops. In Levels 6 and 7, loops are initially introduced by allowing command sequences to be repeated twice

The prototype also includes limited card counts. This design decision responds to the pedagogical goal of encouraging planning rather than unrestricted trial and error. Children need to consider which cards are available and how to use them efficiently.

5.4 Spatial Orientation

One of the most important findings from Phase 1 concerned spatial orientation. Pupils struggled with left and right from the perspective of the player figure, especially when the figure was facing a different direction from their own bodily orientation. This difficulty was not only a usability issue. It was part of the programming-related learning challenge because children had to coordinate their own perspective, the robot's orientation and the planned command sequence.

"For me, it's when the character looks in a different direction than I do, and afterwards I don't know which is left and which is right." (Interview 7_students, pos. 17–18)

Orbit Cleaner responds to this challenge through stronger visual orientation support. Turning actions are supported through visible rotation animations. For the first prototype, both the paper-based robots and the command cards use matching colour codes to support orientation and card-to-robot mapping, as shown in Figure 6.

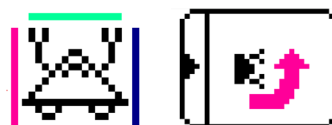


Figure 6: Colour-coded robot and command-card system used in the first Orbit Cleaner prototype

The analysis of related programming games in Section 2.3 further supported this design decision. Crabs & Turtles shows how young children can be supported through directional command cards and visual orientation cues on the game pieces. Together with the classroom findings, these examples frame spatial orientation as part of the programming challenge, not merely as a usability issue. For Orbit Cleaner, this informed the use of consistent direction symbols on the cards and in the digital interface, visible robot orientation and rotation feedback. In future iterations, these supports should be refined further: in the analogue version, symbol-based orientation markers, similar to the approach shown in Figure 1b, would be preferable to colour-only coding, as they better support black-and-white printing and children with colour vision deficiencies. In the digital version,

direction symbols should likewise be available as optional visual aids that can be shown or hidden depending on learners' needs.

5.5 Hybrid Mode

The Phase 1 findings showed that tangible planning and collaborative discussion were pedagogically valuable. Children could arrange cards, point to possible errors, negotiate solutions and observe consequences together. For this reason, the digital prototype was not designed to replace analogue play. Instead, Orbit Cleaner supports two modes: standalone mode and hybrid mode.

"It also works analogously, and the children were able to concentrate well and engage with it over a longer period, which speaks in favour of the game. It also shows children that you don't always need devices to learn digitally. You can also do it analogously." (Interview 6_teacher, pos. 32)

In standalone mode, the full mission can be planned digitally. This supports individual or small group use without physical materials. In hybrid mode, the children plan the mission with physical cards, move them digitally and then observe the robot executing the mission on the screen. This mode directly connects analogue planning with digital execution. It also makes the hybrid logic visible as a design principle: the analogue layer supports planning and collaboration, while the digital layer supports execution, feedback and narrative framing. This design assigns different pedagogical functions to the analogue and digital components.

5.6 Feedback, Error Handling and Motivation

Phase 1 showed that children experienced frustration when rules were unclear, when cards were missing or when planned actions did not produce the expected result. However, these moments also created opportunities for debugging and discussion. The design task was therefore not to remove errors from the game, but to make them visible, understandable and recoverable.

Orbit Cleaner addresses this through several feedback mechanisms. The robot visibly executes the planned commands on the grid. Success and failure are communicated through visual feedback, such as movement animations, collection effects and error messages. Undo and restart functions are part of the first prototype. This allows learners to revise their command sequence without navigating complex menus. Unlike in the first version of the game, where children only had 20 seconds (hourglass) to bring their programming cards together, the digital version of Orbit Cleaner does not include a timer. This was deliberate, as the first prototype focuses on understanding the mission, planning sequences, observing execution and revising errors without additional time pressure. However, the timer remains a possible feature for future levels. First classroom trials with Orbit Cleaner indicated that pupils often had enough time to complete all ten levels and then replay them. In this context, one teacher suggested introducing an additional challenge by asking which group could solve the missions in the shortest time. This indicates that time-based challenges may be valuable once pupils are familiar with the mechanics but should be introduced as an optional extension rather than as a default constraint in the early learning phase.

5.7 Level-Based Progression

Teachers in Phase 1 perceived levels as both motivating and pedagogically useful. Their motivation-related value was linked to pupils' familiarity with digital games, where progressing from one level to the next signals achievement and creates a sense of advancement. At the same time, levels were also seen as a didactic structuring device, as they allow difficulty to be adjusted, concepts to be introduced gradually and pupils to progress at different speeds. Teachers therefore stressed that new mechanics should be introduced step by step to avoid overload.

Orbit Cleaner implements this requirement through a ten-level structure. The first levels focus on simple movement and sequencing, while later levels introduce additional concepts such as turning, energy bars and loops. The level structure follows a principle of gradual progression: the entry should be easy, new concepts should be introduced incrementally, and each level should provide a clear success experience. Planning the steps in advance with physical command cards also lowers the barrier to getting started.

The level architecture is also designed to support future development. Each level can define the start position, start orientation, debris positions, available cards, mission goal, input method, energy state and whether loops are unlocked. This makes the prototype extensible while keeping the first version manageable.

5.8 Classroom Feasibility

Teachers in Phase 1 repeatedly emphasised classroom feasibility. They valued the modular structure of the analogue game, but also noted the importance of low preparation effort, clear setup, flexible timing and reusable materials. This is particularly relevant in Grades 3 and 4. In the Swiss context, for example in the Canton of Zurich, programming-related competences are addressed without dedicated computer science lessons at this stage, requiring their integration into broader classroom activities. Similar curricular arrangements can be found across Europe, where informatics in primary education is frequently integrated into other subjects or introduced as a separate subject only in later grades (Swiss Curriculum 21, n.d.; European Commission/EACEA/Eurydice, 2022). The relevance of this concern became even clearer in the subsequent analogue iteration, where the game mechanics had been further developed, but the material setup also became more demanding. Multiple components had to be printed, cut out and organised, and additional materials such as transparent folders for loop structures had to be procured. This created a barrier for scalable classroom implementation, particularly when several groups were expected to play in parallel.

In response, the analogue version was simplified again during the development of Orbit Cleaner. The required material set was reduced to command cards, game pieces, space debris and the game board. This reduction aligns with the broader design principle of keeping both the analogue and digital components low-threshold, reusable and feasible under ordinary classroom conditions. In hybrid mode, physical cards remain central, but the board state, execution and feedback are represented digitally. This supports classroom orchestration because the teacher does not need to manage all movement, tokens and feedback manually. At the same time, the design remains compatible with analogue materials, since the code and card logic are intended to match across both formats. Thus, classroom feasibility is addressed by reducing preparation effort and distributing tasks between analogue planning and digital execution.

6. Discussion

The development of Orbit Cleaner shows how qualitative findings from a classroom-based evaluation of an analogue programming game can be translated into concrete design decisions for a hybrid prototype. The prototype uses the digital layer selectively, where it responds to specific needs identified in Phase 1: narrative framing, onboarding, orientation support, level progression, feedback and classroom feasibility.

This illustrates a central principle for hybrid game-based learning. The question is not whether analogue or digital formats are superior, but which pedagogical function each format should fulfil. In Orbit Cleaner, analogue planning remains valuable because it supports collaboration, discussion and the visible construction of command sequences. Digital execution adds value because it can provide immediate feedback, animation, orientation cues, progression and narrative context.

The Orbit Cleaner prototype also shows that narrative can be used as a pedagogical scaffold without becoming a separate gameplay burden. The mission-control setting gives purpose to the programming task, while the robot characters support identification and motivation. At the same time, the core gameplay remains focused on sequencing, turning, looping, planning and debugging. Another key insight concerns visual orientation. In the analogue version, left-right reasoning from the figure's perspective was a central challenge. Orbit Cleaner addresses this not by simplifying the task away, but by making the robot's orientation and movement more visible. This is a productive use of digital support: it scaffolds a difficult concept while preserving the need for spatial reasoning. Finally, the prototype responds to teachers' implementation concerns. Its level-based structure, hybrid mode and low-text interface are intended to reduce preparation effort and support differentiated use.

Limitations: This paper documents the development of the hybrid prototype but does not provide a systematic evaluation of its learning effects or motivational impact. The prototype features are grounded in findings from the analogue version, but it cannot yet be assumed that the digital responses adequately address the identified challenges. In Phase 3 of the project (starting in Autumn 2026), the distribution of functions across the analogue and digital components will be empirically examined in classroom use.

7. Conclusion and Outlook

This paper described the development of Orbit Cleaner as the hybrid prototype of the IMPACT+ project. Building on findings from the analogue IMPACT game, it showed how children's and teachers' experiences were translated into concrete design requirements and prototype features. The main design decisions concerned narrative framing, gender-neutral character design, guided onboarding, command input, spatial

orientation support, level-based progression, hybrid planning and execution, feedback and classroom feasibility.

The paper contributes to an evidence-informed design translation and an explicit allocation of pedagogical functions across analogue and digital components. Claims concerning learning effects and classroom feasibility require separate evaluation (see Phase 3 of the project). Orbit Cleaner demonstrates how a digital layer can support an unplugged programming game by providing narrative context, guidance, visual feedback and structured progression while preserving the tangible and collaborative qualities of analogue planning. Following prototype development, Orbit Cleaner was tested in four primary school classes in May and June 2026. The evaluation examined usability, design feedback and initial learning gains, particularly in sequencing and loops. The results will inform further refinement and future research on transitions from analogue planning to digital programming environments.

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Ethics Declaration. Participation was voluntary, with informed consent from legal guardians and age-appropriate assent from pupils. All data were anonymised, stored securely and used only for research purposes. No sensitive personal data were collected.

AI Declaration. AI tools were used to support language editing, academic phrasing, and structural refinement. The authors reviewed and approved the final text and remain fully responsible for its content.

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