TRANSVERSAL TECHNOLOGICAL SKILLS FOR THE ORNAMENTAL ROCK INDUSTRY FOCUSING ON THE APPLICABILITY OF BLOCKCHAIN IN A CIRCULAR ECONOMY 2023-1-DE02-KA220-ADU-000166863

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WP4-A2. Refined of e-learning tool.

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1. INTRODUCTION

This report summarises the final findings of WP4.A2: Refined version of the RockChain e-Learning Tool. In the overall framework of the RockChain project, this activity builds directly on the database and back-end architecture delivered in WP4.A1 and focuses on turning that technical core into a more robust and usable e-learning tool. By aligning the existing serious game with the project's functional and pedagogical requirements, the activity ensures that multiplayer sessions, market dynamics, and mining events effectively support learning about ornamental rock waste management and circular economy in real pilot settings.

The crucial task of WP4.A2 is to refine the initial RockChain prototype into a stable, learning-oriented application. Rather than introducing a new architecture, this activity consolidates and extends previous work by simultaneously addressing pedagogical needs, user experience, and technical stability. This effort involves integrating essential learning features, such as progress tracking and educational feedback, while streamlining the overall game flow, including login, waiting rooms, and round transitions, to facilitate navigation for adult learners with heterogeneous digital skills. Furthermore, the system's runtime behaviour has been hardened to ensure consistent operation under realistic conditions, specifically resolving challenges related to timer consistency, reconnection handling, and synchronisation between the authoritative server and Firestore.

In this context, the report deliberately does not repeat the full technical description of the data layer already documented in WP4.A1. Instead, it provides a focused account of how the existing backend components (Firestore database, Firebase Functions, and WebSocket server on Google Cloud Run) have been refined and extended to function as an integrated e-learning tool. The document details the iterative approach and feedback sources that guided these changes, the specific improvements implemented at pedagogical and technical levels, and the results of a short validation based on small-scale tests. In doing so, WP4.A2 bridges the gap between a production-ready backend and the interactive RockChain tool that will be specified, documented, and deployed in later WP4 activities and WP5 pilot actions.

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2. REFINEMENT APPROACH

WP4.A2 followed an iterative refinement approach rather than a complete redesign. Starting from the production-ready backend delivered in WP4.A1, the team ran a sequence of short cycles where small groups of users and technical reviewers interacted with the RockChain tool, while developers monitored behaviour through logs and metrics. Each cycle produced a limited set of concrete changes that were immediately validated in the next round, with the explicit constraint of preserving the core data model and architecture defined in WP4.A1.

2.1. Feedback sources

The refinements implemented in WP4.A2 were guided by four main feedback channels:

- Internal development and integration tests: The core development team carried out repeated end-to-end sessions (from login to end of game) on different devices and network conditions. These tests focused on identifying race conditions, timer inconsistencies, navigation glitches and desynchronisation between the WebSocket server and Firestore. The findings were complemented with targeted code reviews of the state management contexts and socket handling logic.
- External technical reviewers: In addition to the core team, the project involved a small group of peer developers with experience in real-time applications and mobile UX. These external reviewers examined the use of sockets, reconnection strategies, countdown synchronisation and the structure of the navigation stack, and suggested concrete improvements such as more robust socket lifecycle management, clearer separation between authoritative and local state, and simplifications in certain UI flows for non-expert users.
- Trainers and adult learners in early pilot-like sessions: Short, informal sessions were organised with trainers and small groups of adult learners similar to the target audience of RockChain. Participants were asked to complete simplified game rounds while trainers observed where users hesitated or became confused (e.g. during onboarding, joining a game, understanding the waiting room, interpreting timers or reading market/mining feedback). Their comments and observed behaviours provided direct input on usability, clarity of messages and cognitive load.
- Technical logs and runtime metrics: Both the client and the authoritative server were instrumented with lightweight logging. Metrics were collected around connection stability, reconnection events, timer drift, duplicated events and error conditions. These objective signals helped to confirm or nuance anecdotal feedback, and to prioritise issues that had the largest impact on stability (for

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example, occurrences of out-of-sync countdowns or repeated reward calculations).

Together, these sources provided a balanced view that combined user-level experience (trainers and learners), technical soundness (internal and external developers) and runtime evidence (logs and metrics).
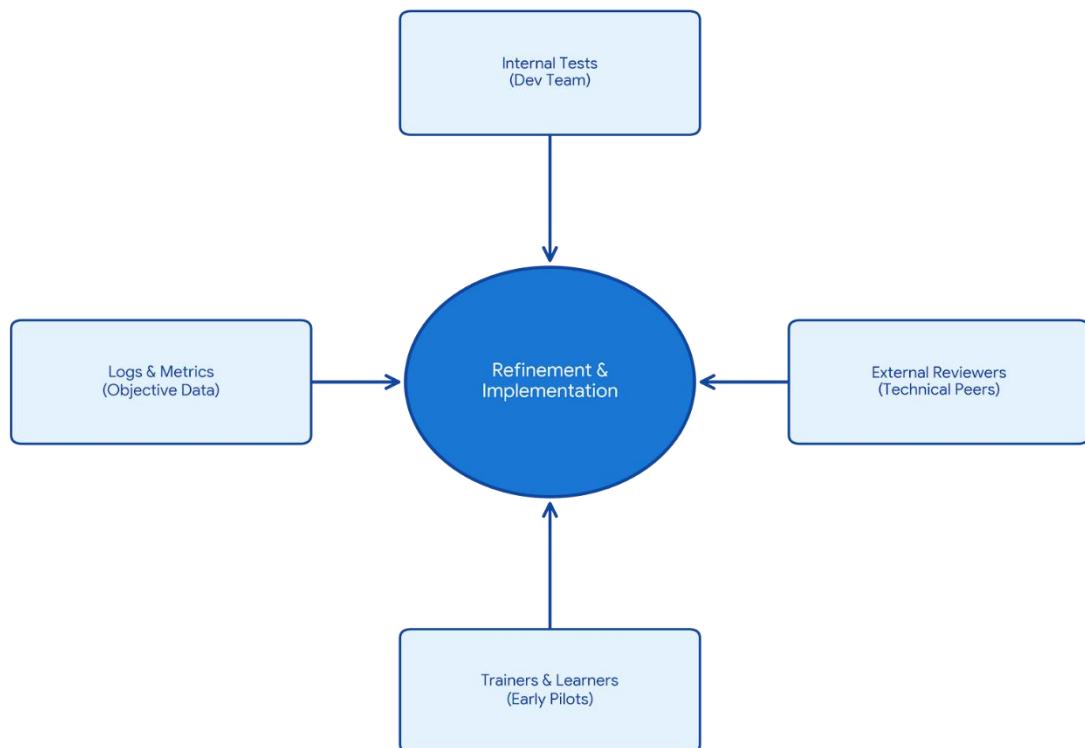

Figure 1: Feedback sources

2.2. Criteria used to prioritise improvements

Because the time and resources available for WP4.A2 were limited, not all findings could be addressed immediately. The team therefore applied a simple set of criteria to prioritise which refinements to implement in this activity:

- Impact on learning and facilitation: Changes that directly affected the ability of trainers to run a session or of learners to understand what to do were treated as high priority. This includes clearer round transitions, more explicit feedback messages, smoother onboarding and a more predictable waiting room experience.

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- Stability and risk for pilot sessions: Issues that could break a game session or severely disrupt synchronisation (e.g. timer inconsistencies, unreliable socket reconnection, duplicated rewards) were addressed before cosmetic or purely aesthetic improvements. The aim was to ensure that upcoming pilots would not be undermined by technical instability.

- Implementation cost versus benefit: Refinements that offered a clear benefit with relatively low implementation effort were prioritised ahead of more intrusive changes that would require large code rewrites or modifications to the Firestore schema. Wherever possible, improvements were designed to reuse the data structures and architecture established in WP4.A1.

- Alignment with upcoming WP4 and WP5 activities: Preference was given to enhancements that would also support later work: definition of functional specifications and guidelines, integration of learning analytics, and WP5 pilot deployment. For example, adding or consolidating learning-progress collections and events was prioritised over purely visual changes because it strengthens both pedagogical evaluation and future reporting.

Applying these criteria ensured that WP4.A2 produced a focused set of refinements with tangible impact on learning usability and technical robustness, while keeping the tool compatible with the backend and database design already established in the previous activity.

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3. MAIN REFINEMENTS IMPLEMENTED

The refinement work in WP4.A2 did not change RockChain's core concept or backend architecture as defined in WP4.A1. Instead, it focused on how the game behaves, how it feels to use, and how clearly it supports the intended learning outcomes in realistic training conditions. The main changes can be grouped into three areas.
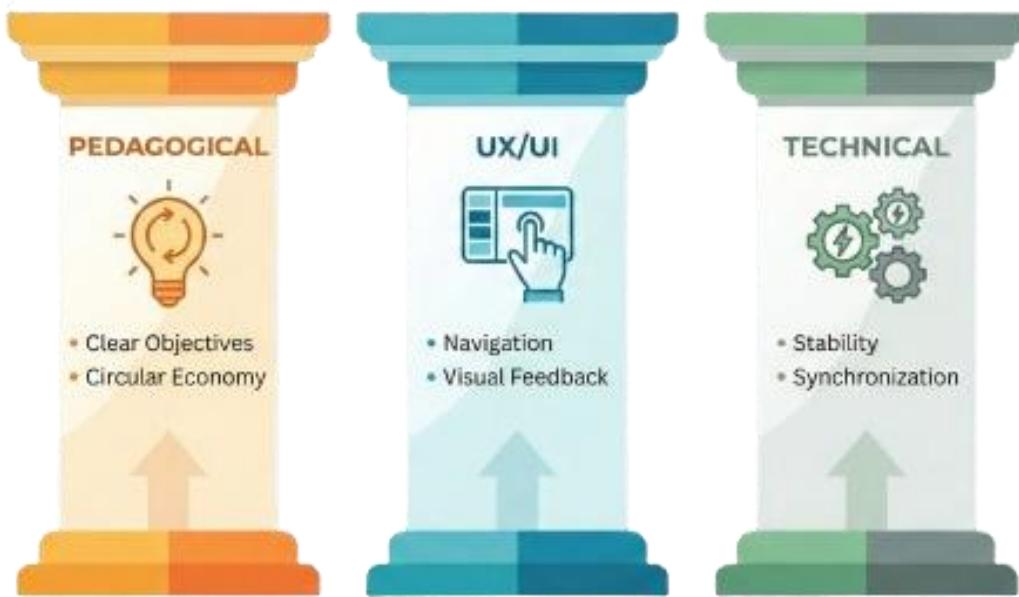
Figure 2: Three Pillars of Refinement

3.1. Pedagogical and game design adjustments

From a learning perspective, the goal was to make the intent behind each game element easier to understand and to reinforce the link between actions in the game and circular-economy concepts. Several changes contribute to this:

- Clearer objectives and round framing. Information shown at the start of the game and at each round has been refined so that learners know what they are expected to do (use resources efficiently, reduce waste, pay attention to specific industries) and how the round structure supports these goals.
- Adjusted pace for adults with diverse digital skills. Round timers, mining challenges and market events were reviewed to reduce unnecessary stress while keeping a sense of competition. Durations and event frequency were tuned to give enough time to read, think and act.
- Stronger link to circular economy. Short explanations and in-game messages now emphasise why certain actions are rewarded (recycling, transforming materials, choosing particular industries), making the connection to real-world waste management and resource efficiency more explicit.

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- More transparent rewards and end-of-round logic. The way winning industries and bonuses are calculated and presented has been clarified, so results feel less random and learners can better understand the consequences of their decisions.

Together, these adjustments sharpen RockChain as a structured learning activity, not only as a competitive game.

3.2. UX/UI and user journey improvements

The second group of refinements targets the user journey across screens and phases, with the aim of lowering friction and reducing the need for constant facilitator intervention, especially for first-time adult users.

Key improvements include:

- Consistent header and status information. A shared header now presents essential elements (time remaining, key resources, core indicators) in a stable format across the main game screens, reducing cognitive overload during fast rounds.
- Clearer navigation between phases. Transitions between the waiting room, market, mining and end-of-round views have been made more explicit through adjusted buttons, labels and intermediate messages, so learners understand when a phase ends and what will happen next.
- Better feedback in loading and waiting states. Visual indicators and short explanatory messages now mark synchronisation points and processing steps, reducing the perception that the system has "frozen" and helping groups to stay coordinated.
- Simplified texts and layout. Wording, prominence of key actions and error messages were revised to be more accessible for users with varying levels of digital familiarity.

As a result, RockChain is easier to onboard, smoother to run in short training sessions and more self-explanatory from the learner's point of view.

3.3. Technical stability and performance fixes

Finally, WP4.A2 introduced targeted technical refinements to strengthen stability and performance under realistic classroom conditions, without altering the underlying Firestore + Functions + WebSocket architecture described in WP4.A1.

The most relevant fixes are:

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- More robust timer and synchronisation logic. The handling of round timers and synchronised events was revised to reduce discrepancies between devices and to avoid situations where players remain stuck in waiting states or see inconsistent countdowns.
- Cleaner data handling and real-time propagation. Interactions between the React Native client, Firestore and the real-time server were adjusted to reduce redundant operations, avoid race conditions and ensure that updates (transactions, mining responses, round transitions) reach all players consistently.
- Improved error handling and recovery. Error messages are now more informative, and fallback behaviours have been added where possible, making it easier for trainers to interpret issues during pilots and for developers to debug unexpected network or state problems.
- Performance tuning for typical group sizes. Tests with realistic numbers of concurrent players and standard classroom networks led to small adjustments aimed at reducing delays, timeouts and unnecessary data transfer.

These technical refinements provide a more solid baseline for WP4 and WP5, ensuring that the refined version of RockChain can be used as a stable reference implementation for specifications, trainer guidelines and pilot deployment.
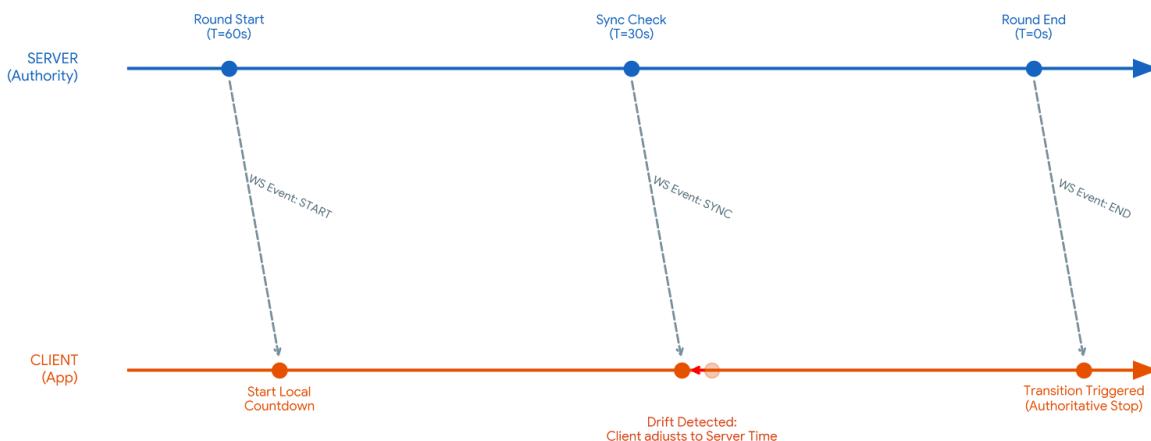

Figure 3: Countdown line diagram

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4. SHORT VALIDATION OF THE REFINED VERSION

WP4.A2 included a light but targeted validation phase to confirm that the refinements described above made RockChain more usable and reliable in realistic training scenarios, without introducing regressions in the core architecture delivered by WP4.A1. Rather than a large pilot, this validation took the form of small-scale end-to-end sessions and technical runs designed to test the refined tool under conditions similar to those expected in WP5.

4.1. Summary of small-scale tests and user reactions

Validation activities combined three complementary perspectives:

- End-to-end technical runs by the development team: The team conducted repeated full sessions (login → game creation/joining → waiting room → several rounds → end-of-game) on different devices and networks. These runs were used to verify that:

    o Games could be created and joined consistently.

    o Countdowns and round transitions behaved as expected.

    o Reconnections and delayed clients did not leave players permanently stuck.

    o Data written to Firestore (games, users, mining blocks, learning progress) matched the expected outcomes of each round.

- Focused trials with trainers and small groups of adult learners: Short exercises were organised where trainers and a limited number of adult participants, similar to the project's target group, used RockChain in a controlled environment. They were asked to:

    o Log in, join a shared game and complete simplified rounds.

    o Interact with the market, mining and recycling features.

    o Interpret end-of-round summaries and basic feedback.

  Observations from these trials indicate that:

    o Onboarding and joining a game became more straightforward, with fewer questions about "what to press next".

    o The waiting room and round transitions were easier to follow, thanks to clearer messages and more predictable timing.

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- o Participants better understood why they were rewarded for certain actions (e.g. reducing waste, choosing specific industries), and trainers could use these results as a starting point for discussion.

- Runtime logs and metrics from the refined version: During both technical and user-focused sessions, the client and server logs were monitored for:

  - o Connection and reconnection events.

  - o Timer drift and countdown discrepancies.

  - o Duplicated or missing round events.

  - o Error conditions in Firestore writes and reward calculations.

Compared to earlier internal builds, the refined version showed fewer inconsistencies in timers and round states, more reliable reconnection to the real-time server, and a reduction in edge cases where players remained out of sync or did not receive final round results.

Taken together, these small-scale tests suggest that the refinements in WP4.A2 have improved both the user experience and the technical behaviour of RockChain, providing a more stable and understandable tool for upcoming pilots.

4.2. Remaining limitations and open points for pilots

At the same time, the validation remained intentionally limited in scope, and several open points are reserved for WP4.A6–A7 and WP5 pilot activities:

- Scale and diversity of users: The refined version has been tested with small groups and controlled settings, but not yet with larger, more heterogeneous cohorts across all partner countries. Behaviour under peak load, varied classroom infrastructures and different trainer styles still needs to be observed.

- Formal usability and accessibility evaluation: Feedback so far has been qualitative and observational. More systematic usability testing – for example, structured questionnaires or task-based assessments with adults over 45 and low digital skills – will be carried out in later activities to confirm and refine the current UX decisions.

- Learning analytics and trainer-facing tools: The data structures for recording learning progress and key in-game events are now in place, but trainer-facing dashboards and reporting tools are still at an early stage. Pilots will be used to identify which indicators are most useful and how they should be visualised for non-technical educators.

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- Residual edge cases and network constraints: While the main stability issues have been addressed, occasional edge cases may still appear under poor connectivity, rapid user actions or unexpected app closures. WP5 will provide a broader evidence base to decide whether further safeguards or fallbacks are needed.

- Content and localisation fine-tuning: The current version supports multiple languages and basic explanatory texts, but wording, examples and pacing may still require adjustments once RockChain is used in different national and sectoral contexts.

For these reasons, the refined version produced in WP4.A2 should be seen as a pilot-ready implementation: stable enough to be used in real courses, but intentionally open to further improvements based on structured feedback from WP5. The pilots will therefore play a dual role – both as educational activities and as an extended validation phase that will inform any final adjustments to the tool and its supporting materials.

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5. CONCLUSIONS AND NEXT STEPS

WP4.A2 has refined the initial RockChain prototype into a pilot-ready e-learning tool, building directly on the backend and data layer delivered in WP4.A1 without altering the core architectural choices (Firestore, Firebase Functions and the authoritative WebSocket server consumed by a React Native client). The focus of this activity has been to make the existing system behave more like a structured learning tool than a pure game: clarifying how actions relate to circular-economy concepts, reducing friction in the user journey for adults with heterogeneous digital skills, and addressing concrete issues of stability, synchronisation and error handling that emerged in early tests. As a result, RockChain is now more predictable to run in a classroom or workshop setting and easier for trainers and learners to understand, round by round.

The refinements implemented in WP4.A2 also provide a much clearer picture of what the tool actually needs to do in practice. By tuning the game flow, stabilising key data flows and consolidating learning-oriented features such as progress tracking and feedback messages, this version of RockChain effectively acts as a "working specification" from which more formal documentation can be derived. It will inform the functional specifications in WP4-A3, by indicating which behaviours and data structures are essential and which are optional, and it will guide the guideline notes in WP4-A4, by offering concrete examples of how to introduce RockChain, manage rounds and debrief results with adult learners in different training contexts. For WP4-A5, having a coherent and stable reference implementation significantly reduces technical risk and allows partners to concentrate on packaging, polishing and completing the interactive tool (assets, translations, configuration) rather than rethinking core mechanisms.

Looking ahead to WP5, the tool emerging from WP4.A2 is intended as the starting point for pilot deployment: technically robust enough to be used in real courses, yet deliberately open to further adjustment. The pilots will provide broader and more diverse evidence—across countries, institutions and learner profiles—about how RockChain behaves under real conditions and how it supports learning about ornamental rock waste management and circular strategies. In this sense, WP4.A2 marks a transition: from designing and stabilising the technical and pedagogical foundations of the tool to using RockChain in authentic educational settings, where the focus can increasingly shift from "making it work" to maximising its educational impact and extracting lessons for future use and possible extensions beyond the lifetime of the project.

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