Shifting the Time of Practice: A Digital Environment for Student-Athletes and Remediation

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Abstract: A student who trains and competes during school time misses mathematics lessons that are never given again. At the High School for Sports in Luxembourg, these absences are authorised, but authorisation does not return the missed lesson. Students must catch up, often when they are least available, and difficulties in doing so may have consequences for end-of-year promotion. The formal end-of-year remediation process arrives late: a summer assignment is issued in July, and the promotion decision is made in September. In 2023/24, 6.9 per cent of students in classical secondary education received a summer assignment, and 51.4 per cent of these students were not promoted after completing it (MENJE, 2025a). Autonomous study hours were introduced at the High School for Sports in 2025/26 across several subjects. Based on the school's implementation experience, the arrangement was judged not to have achieved its intended purpose and was redesigned for 2026/27. In mathematics, students in grades 7 and 8 move from four taught hours a week to three, the fourth becoming an autonomous study hour supported by the school's newly implemented learning management system. EMERALD (Enhancing Mathematics Engagement through Responsive and Autonomous Learning Design) is a curriculum-aligned digital practice environment for secondary mathematics, built and studied by the first author and integrated into the school's learning management system. Two studies follow. The first accompanies one cohort through the autonomous study hours for three school years. Its primary outcome is the temporal pattern of practice, tracking when students work, for how long, and how that reorganises around training and competition. The second study asks whether a digital environment can identify learning gaps early enough to support earlier remediation. This paper reports the design phase only and presents no empirical results.

Keywords: Autonomous Learning, Learning Time, Student-Athletes, Remediation, Design-Based Research

1. Introduction

Research on digital learning environments in mathematics has often focused on their effects on students' learning outcomes, attitudes, or engagement. Systematic reviews show that many studies use technology to enhance existing teaching rather than change the organisation of learning (Bray and Tangney, 2017; Darmanova, Abylkassymova and Nurmukhamedova, 2025). Less attention has been given to how digital environments may change the conditions under which learning takes place, particularly when, where and with what support students can practise.

This paper reports a doctoral project conducted at the High School for Sports in Luxembourg, a public secondary school for student-athletes where training and competition make attendance structurally irregular. The first author teaches the participating classes, supervises autonomous study hours, and is a member of the school development unit.

The paper reports the design phase of the project. It describes the setting, the theoretical framework, the environment, and the two study designs that have been submitted for ethical review. The central question is whether a digital environment can help student-athletes by allowing them to practise at times compatible with their training and competition schedules and giving them greater control over when and what they practise.

Research on distributed practice suggests that the temporal distribution of practice can affect later retention (Cepeda et al., 2006). This makes the timing of practice an important study dimension, rather than merely a consequence of students' schedules. In this project, however, students have autonomous study hours outside their taught hours and decide which topics to practise. The decision about when, where and what to practise therefore moves to the student.

2. Problem Setting: Missed Lessons and Delayed Remediation

Student-athletes train and compete during school time. Their absences are authorised, but authorisation does not replace the missed learning time. Students are expected to catch up afterwards, often in their own time, without guidance, and when they are least available.

Support is available at several points during the school year, but each comes with limitations. A teacher can differentiate, but the support is limited to the time available during class. Optional support courses run during the school year, but they are voluntary and therefore depend on students choosing to attend. A summer assignment follows the end-of-year results, and repeating the year comes last. Luxembourg also offers a national Summerschool programme during the summer holidays (MENJE, 2025b). These measures provide additional learning opportunities, but not continuous diagnosis of learning gaps.

The summer assignment follows a regulated national procedure (Règlement grand-ducal, 2005), while its specific content is determined locally within the school. The process leaves considerable room for differences in how teachers identify and address difficulties. Some teachers differentiate assignments according to specific learning gaps, whereas others provide a more general set of exercises. This variability was observed in two conference presentations on mathematics in Luxembourg (Klensch et al., 2025a; 2025b). At the national level, there is currently no digital environment that continuously estimates topic-level mastery to support curriculum-aligned remediation.

In classical secondary education, 6.9 per cent of students were given a summer assignment based on their end-of-year results in 2023/24, and 51.4 per cent of these students were not promoted after completing it. **Table 1** places the 2023/24 figures in a ten-year series (MENJE, 2020; 2025a). The share receiving summer assignments has ranged from 5.7 to 9.1 per cent, while non-promotion has generally remained close to one half.

Missed learning and delayed remediation therefore share the same timing problem: support arrives at a moment fixed by the school rather than when the learner needs it or is available. The project asks whether a digital environment can shift practice and diagnosis closer to when they are needed.

Table 1: The summer assignment in classical secondary education over ten years (MENJE, 2020; 2025a).

School Year	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24
Passed in July (per cent of students)	87.3	88.4	89.0	89.2	88.6	92.3	87.7	88.4	90.3	89.9
Students assigned a summer assignment (per cent of students)	9.1	8.5	8.3	7.6	8.1	5.7	8.4	8.4	7.0	6.9
Not promoted after summer assignment (per cent of those assigned)	52.6	48.7	46.4	50.6	51.7	50.4	55.8	53.2	54.5	51.4

3. Theoretical Framework

The main theoretical framework is cognitive apprenticeship (Collins, Brown and Newman, 1989). It describes how learners develop expertise by making expert processes visible and gradually transferring responsibility to the learner. The framework is influenced by sociocultural perspectives associated with Vygotsky's (1978) zone of proximal development and situated learning (Lave and Wenger, 1991). The digital practice environment acts as a mediating artefact. The topic map, worked solutions and feedback carry part of the guidance otherwise provided by the teacher.

Collins, Brown and Newman (1989) organise cognitive apprenticeship around four dimensions: content, methods, sequencing, and sociology. EMERALD addresses the first three, while the sociology dimension is treated as a design boundary. The content dimension is addressed through domain knowledge, problem-solving strategies, and control strategies embedded in lessons and exercises. The sequencing dimension is addressed through increasing complexity and diversity. The six methods of cognitive apprenticeship, which are modelling, coaching, scaffolding, articulation, reflection, and exploration, provide the main link between the framework and the digital environment. **Figure 1** maps these methods onto the design of EMERALD.

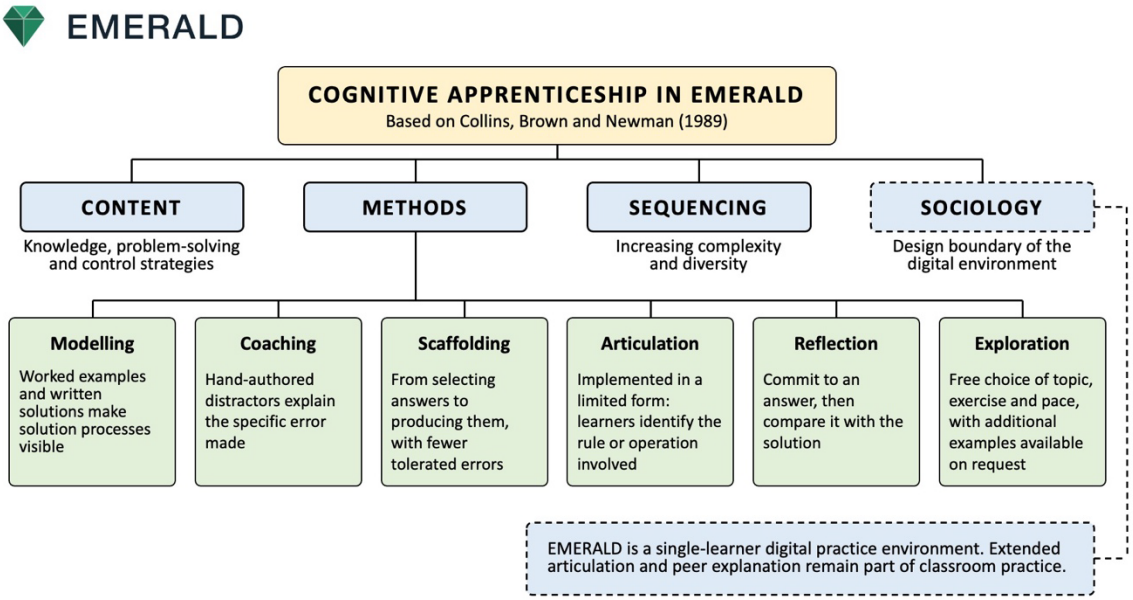


Figure 1: The mapping of the cognitive apprenticeship methods onto the design of EMERALD.

- Modelling is provided through worked examples and written solutions, allowing learners to observe complete solution processes. This also draws on research showing that worked examples can support the learning of problem-solving procedures in algebra (Sweller and Cooper, 1985).
- Coaching is provided through immediate and diagnostic feedback. Where possible, distractors are linked to specific misconceptions and trigger an explanation of the corresponding error. This is consistent with the formative-assessment view that feedback should provide information that supports learning (Black and Wiliam, 1998). EMERALD combines the two granularities distinguished by VanLehn (2011): single-step items are marked on the final answer, while multi-line calculations are marked line by line, without the expected value being revealed.
- Scaffolding is implemented mainly through the response format. As learners progress, they move from selecting answers to producing them. The number of tolerated errors also decreases as difficulty increases. Structurally, this exercise flow resembles programmed instruction: small steps, active responding, immediate feedback and self-pacing (Skinner, 1958). The wider design differs, however: the learner model is open and transparent, feedback is explanatory rather than only corrective, and learners choose their topics and their stopping points.
- Articulation is implemented in a limited form. Learners are asked to make part of their reasoning explicit by identifying an operation or rule, completing a structured representation, or naming the property involved.
- Reflection is implemented through comparison between the learner's response and the worked solution in the upper-year version of the environment. Learners first commit to an answer and then compare it with the solution.
- Exploration is supported through learner choice. Students can choose topics, start and stop sessions freely, and, in some workshops, request additional examples. Some workshops also allow learners to enter their own values and observe how the system responds.

The sociology dimension is treated as a design boundary. EMERALD does not implement peer comparison, ranking, or a community of practice, and learner-produced work is not shared between learners. It nevertheless supports classroom use through projection and teacher-controlled presentation features. Extended articulation and peer explanation remain part of classroom practice.

Cognitive apprenticeship provides the main pedagogical framework, while self-regulated learning and self-determination theory provide complementary perspectives on learner autonomy and engagement. The autonomous study hours give students greater control over their practice, but this freedom also creates demands for planning, monitoring, and adjustment. These processes are central to self-regulated learning (Zimmerman, 2002). Self-regulation may influence how much students benefit from the environment and is also

a condition for using autonomous study hours effectively. Self-determination theory provides a second perspective on autonomy and competence (Ryan and Deci, 2000). EMERALD gives learners choices about what to practise while providing information about their progress and estimated mastery level. The design therefore aims to support autonomy and competence.

Gamification provides a further, more limited design perspective. Meta-analytic evidence suggests positive average effects of gamification on cognitive, motivational, and behavioural outcomes (Sailer and Homner, 2020). However, rewards can have different effects depending on whether they are experienced as informational or controlling (Deci, Koestner and Ryan, 1999). EMERALD therefore uses playful workshops, feedback and progress information, and it deliberately excludes streaks, daily-login rewards, leagues and public rankings. The design aims to make rewards informational rather than controlling. The two lower medals are awarded when the estimate crosses its threshold; the two highest are not, because an online estimate can cross a threshold by chance, and they are confirmed by a short block of previously unseen items at the highest difficulty level. These choices aim to support learning rather than prolonged use and follow European guidance on engagement-oriented mechanisms for minors (European Commission, 2025). Whether students experience medals in this way is examined rather than assumed in Study 1.

4. Digital Practice Environment EMERALD

The present project does not seek to replace national digital mathematics practice environments such as MathemaTIC, launched in 2016 (MENJE, 2016). EMERALD is a digital practice environment developed and maintained by the first author for a more specific purpose: to align digital practice with teaching sequences, provide an open learner model, retain control over the practice environment, and integrate practice directly into the school's learning management system.

Its design draws on the concept of open learner models (Bull and Kay, 2010): learners can see the system's estimates and use them to guide their practice. They see a map of topics, each with an estimated mastery level, and can choose which topics to practise. Each topic has a pool of at least 1000 distinct items for each difficulty level. This reduces repetition for learners who practise a topic extensively and supports the study of practice over time. Each estimate is accompanied by a stability indicator based on the number, consistency and recency of the underlying responses. The indicator shows how stable the estimate currently is.

After each answer, the learner's rating is updated using an Elo-type rule (Elo, 1978), an approach used in adaptive educational systems (Pelánek, 2016) and in school mathematics (Klinkenberg, Straatemeier and van der Maas, 2011). Item selection then adapts to the learner's current rating. The design targets a modelled success probability of around 85 per cent on produced answers, and higher on selected-response items because of guessing. This target is a design decision, not a mastery criterion. Wilson et al. (2019) reported an accuracy associated with fastest learning in a class of algorithms, not a mastery threshold for human learners. Difficulty levels are therefore mixed during practice, most items falling close to the current estimate, rather than changing abruptly. Within a topic, successive items are also drawn from several distinct question forms rather than one repeated form, which is consistent with research showing that mixing problem types improves later performance in mathematics (Rohrer and Taylor, 2007). The current rating is displayed alongside the highest medal earned, providing both a current estimate and a record of achievement. Medals remain visible once earned, even if the learner's rating later falls, distinguishing current performance from accumulated achievement.

Practice time and pace are also visible to learners. A timer records elapsed practice time without imposing a time limit, while the system displays the learner's rate of practice in seconds per question. These indicators are presented as descriptive information and allow learners to monitor and reflect on their practice, consistent with the monitoring component of self-regulated learning (Zimmerman, 2002).

EMERALD is delivered as self-contained modules that run in the browser. The environment is therefore reached where students already go for their other subjects, and a teacher sees a learner's progress in the same place as the rest of the course material. The school's learning management system and EMERALD together report progress, timing, duration, pace, topic selection and item-level activity of each practice session. These traces allow Study 1 to examine when, for how long, and at what pace students practise, and how practice changes with training and competition. For the analysis, a practice session is a run of item-level events separated by no more than fifteen minutes, and its duration sums the intervals between consecutive events rather than the time the module remained open in the browser.

5. Research Questions

Three questions organise the design phase. Together, they shift the focus from attainment alone to the timing, organisation and conditions of mathematics practice.

> RQ1: When and for how long do students practise mathematics when practice is no longer tied to taught lessons, and how does practice reorganise around training and competition?
>
> RQ2: How do students differ in their use of the allocated autonomous study hours, and how is this use related to prior attainment, training and competition load, and self-regulation?
>
> RQ3: Can continuous diagnosis identify learning gaps early enough to allow targeted remediation before the end-of-year remediation process?

6. Two Studies

The project consists of two connected studies. Study 1 examines how students use the digital environment when mathematics practice is no longer tied entirely to taught lessons. Study 2 examines whether the same environment can support earlier and more targeted remediation.

6.1 Study 1: Three Years of Flexible Mathematics Practice

Study 1 follows eight lower-cycle classes, with EMERALD used during the autonomous study hours in grades 7 and 8 and follow-up data collected in grade 9. Two upper-cycle classes without autonomous study hours also participate, with the teacher allocating approximately one weekly hour per class to the digital environment. Across these ten classes, the number of students potentially accessible to the study ranges from approximately 40 to 220 per year. The primary longitudinal analysis focuses on the grade-7 cohort, while the other classes provide additional information on patterns of use across grades.

Within mathematics, the autonomous study hours are designed to allow selected topics to be practised independently of the taught lesson. A working group of three mathematics teachers, including the first author, selects suitable topics. Topics are particularly suitable when their content is later revisited or required as a foundation for subsequent teaching. Gaps identified during autonomous study hours can therefore be revisited through ordinary classroom teaching.

Each study wave combines two short questionnaires, an adapted Intrinsic Motivation Inventory and the Abbreviated Math Anxiety Scale (Hopko et al., 2003), a curriculum-aligned pre-test, a teaching sequence using the environment, a post-test, and a delayed test. Self-regulation is not measured by a questionnaire scale: it is approached through the practice traces, the confidence rating students give before each test, and the end-of-session reflections. Pre-test and post-test are parallel forms, and no test item is drawn from the practice pool of the environment. Sporting load is obtained from the school's records of training and competition, which are already held for attendance purposes. End-of-sequence questionnaires and voluntary student interviews provide additional information about students' experience of the environment. Each year, interviews are also conducted with three to six collaborating teachers to examine implementation and perceived changes in practice.

Analysis follows the primary outcome. The traces characterise each student's temporal pattern of practice: the number and length of sessions, the time of day, the spacing between sessions, and how these patterns change in weeks containing training camps or competitions, with each student serving as their own comparison. Differences between students are then described in relation to the three variables named in RQ2. Attainment is examined from pre-test to post-test and delayed test, descriptively, since Study 1 has no randomised comparison group. Questionnaire subscales are summarised by wave, while the self-regulation indicators are derived from traces and the reflections. Interviews are analysed thematically. The design assumption is supported if practice shifts to periods compatible with training and competition, and questioned if greater flexibility reduces overall practice.

The primary focus of Study 1 is therefore not whether the environment replaces classroom teaching, but how it changes when, for how long, and under what conditions students practise mathematics.

6.2 Study 2: Remediation and the Moment of Diagnosis

Study 2 follows approximately 10 to 25 students per year across three existing forms of support: mandatory or voluntary remediation with the first author, optional support courses during the school year, and the national summer programme in which the first author teaches. The study is primarily concerned with the feasibility and timing of diagnosis rather than with estimating a causal effect of one remediation format over another.

The two studies are connected through diagnosis. In the current system, formal remediation decisions are based on end-of-year results. Although semester grades are available, they do not trigger mandatory support, and a failed first semester cannot be retaken. A learning gap that emerges during the year may therefore remain unaddressed until the end-of-year process.

EMERALD provides a different possibility. Because it maintains an evolving map of topics and learner estimates during ordinary practice, learning gaps can become visible during the school year rather than only at its end. Study 1 therefore provides the continuous diagnostic information, while Study 2 examines how that information can be used to provide earlier and more targeted support.

Across these routes, the study documents the use of two remediation formats: digital remediation sequences tailored to identified gaps, with immediate feedback, and traditional paper-based assignments. Generative AI makes completion of a paper assignment a less reliable indicator of independent practice, an issue raised nationally in a parliamentary question and the ministerial response to it (Chambre des Députés, 2026).

The formal remediation decision remains tied to end-of-year results and cannot be changed by the first author. Study 2 therefore does not attempt to change the institutional decision process. Instead, it examines whether earlier diagnosis and targeted support are feasible and sufficiently promising to address gaps before the end-of-year process begins and therefore justify considering earlier remediation at the institutional level.

7. Discussion

In a setting where attendance is structurally irregular, the contribution of a digital environment is not necessarily that it teaches mathematics better, but that it can decouple practice from the timetable. This decoupling is only useful if students receive enough support to use the additional autonomy effectively. In EMERALD, this support includes a map of topics and prerequisites, targeted practice sequences, and immediate feedback. Taught mathematics lessons remain the safety net alongside the autonomous study hours.

The decision to introduce autonomous study hours was made by the school development unit and applies to all students in grades 7 and 8. The project therefore studies an institutional change in which the first author is directly involved. The autonomous study hours themselves are a second attempt: they ran in 2025/26 without a digital practice environment and, on the school's own assessment, did not achieve their intended purpose. The 2026/27 redesign links them to the school's learning management system and to EMERALD.

The design also recognises that greater autonomy may not benefit all students equally. Students who have difficulty regulating their own learning may make less effective use of the autonomous study hours and, like all students in these year groups, have one fewer taught mathematics lesson each week. Ineffective use of the autonomous study hours is therefore not neutral.

8. Limitations

This paper reports the framework, study designs, and design decisions underlying the project. It reports no empirical results. The most important limitation concerns attribution. Study 1 has no randomised comparison group, so changes in attainment or motivation cannot be attributed causally to the environment. The primary outcome is therefore the within-student pattern of practice. Study 2 compares routes that students enter through existing institutional mechanisms, so differences between routes may reflect the students who enter them.

The participants are student-athletes in a single school. The setting makes the study particularly relevant to schools where attendance is affected by training and competition. However, this limits the generalisability of the findings. This mismatch is not confined to sport: illness, caring responsibilities and family mobility can produce the same mismatch between when a lesson is given and when a student is available. The first author is also the designer of the environment and the teacher of the participating classes, so the account of the design decisions documents the reasoning behind them rather than verifying it independently.

This dual role supports access and iterative design but may influence implementation and interpretation.

9. Next Steps

The ethics application covering both studies was submitted in August 2026 and is under review for the panel's September meeting. The national procedure governing research in Luxembourg schools also applies. Data collection will begin after the required authorisations have been obtained and will provide the first empirical test of the design assumptions presented in this paper. The successive waves follow the iterative logic of design-based research, in which design, implementation, analysis and refinement alternate in authentic educational settings (Brown, 1992; Anderson and Shattuck, 2012).

10. In Conclusion

This paper asks what educational technology can contribute when irregular attendance is a structural constraint rather than a reflection of mathematical ability. The proposed contribution is to shift not only where mathematics practice takes place, but when it takes place. EMERALD moves practice into autonomous study hours in which students have greater control over what and when they practise.

The two studies examine what happens after this shift. Study 1 follows when, for how long, and how students practise. Study 2 examines whether the same environment can make learning gaps visible early enough for remediation to begin before the end of the school year.

The contribution of the project is therefore not a claim that digital learning improves attainment. It is a design proposal and an empirical programme for studying when mathematics is practised, how students use autonomous study hours, and whether earlier diagnosis can shift when targeted support becomes possible.

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Ethics Declaration

This paper reports no empirical data from human participants. It presents the theoretical framework, study protocols, and design decisions developed before data collection begins.

AI Declaration

AI tools were used to help structure material from the first author's existing French-language documents and design register, to discuss and refine the presentation of design choices, to translate, edit, and refine passages into English, and to check reference formatting. The research questions, theoretical framework, study designs, design decisions, and underlying reasoning reported in this paper were developed by the first author. The author reviewed and revised all text and takes full responsibility for its content.

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