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A learning experience design framework for multimodal learning in the early childhood

Valeria Aloizou¹ , Andri Ioannou^{2*} , Michael Boloudakis¹ and Symeon Retalis¹

*Correspondence:
andri.ioannou@cut.ac.cy

¹ Department of Digital Systems, University of Piraeus, 150 Androutsou Odyssea, 18532 Piraeus, Greece

² Department of Multimedia and Graphic Arts, Cyprus University of Technology, Limassol, Cyprus

Abstract

While the value of multimodal learning experiences is well articulated in the literature, rich examples of learning experience (LX) design aiming to guide research and practice in authentic school classrooms are currently lacking. This study's first objective was to provide a comprehensive account of the LX design process, aimed at enhancing multimodal learning in kindergarten education. With the aid of two kindergarten teachers, we followed a learning design approach that blended established instructional frameworks such as the learning via multiple representations, the learning stations, and the learning trajectories. This study's second objective was to conduct an evaluation study. The LX design was implemented with the two teachers and their 33 kindergarten students to assess its effectiveness. Both quantitative and qualitative data were employed for triangulation of the evidence. The study contributes to the literature by offering a replicable LX design framework that addresses calls for structured integration of multimodal digital resources in early childhood education. Furthermore, findings from the evaluation study shed light on teachers' positive perceptions of the multimodal learning experience based on observed students' behaviours and achievement. This work is a step forward in addressing a need for LX designs that can facilitate seamless multimodal learning in early childhood.

Keywords: Learning (experience) design, Early childhood education, Kindergarten, Multimodal learning, Station rotation model, Movement-based learning games, Kinems Learning Games Platform

Introduction

Multimodal learning experiences present significant opportunities in early childhood education, particularly through incorporating multiple representations of learning content—visual, auditory, and kinesthetic elements—which have been shown to enhance engagement and cognitive processing (Collins & Halverson, 2009; Yelland, 2015). The National Association for the Education of Young Children (NAEYC, 1996) acknowledges the value of technology in supporting young children's learning but emphasizes that digital tools should complement rather than replace traditional early childhood activities. This perspective underlines the need to thoughtfully integrate technology in ways that supplement, rather than replace, established early learning practices such as art, hands-on play, writing and exploration with tangible materials. Learning experience

(LX) design is a field contributing to the successful integration of technology and learning.

LX design is a process concerned with both the effectiveness of designed learning interventions and the interconnected and interdependent relationship between the learner-as-user, the designed learning experience, and the learning context (Schmidt & Huang, 2022). In LX design, effective technology integration in education relies not only on the tools but also on educators' pedagogical strategies (Aloizou et al., 2024; Cheng & Tsai, 2019; Dias & Atkinson, 2001; Southgate, 2020). Also, several studies have highlighted the significance of teacher guidance and instructional support for students in utilising digital tools to foster learning (Aloizou et al., 2024; Kennewell & Beauchamp, 2007). As Haleem et al. (2022) mention, the emphasis should be on considering the responsible and purposeful use of technology, ensuring that it aligns with the learning goals and instructional strategies, rather than being used merely for novelty or entertainment purposes. Further challenges in LX design include the alignment with state standards and resource creation (Hamand, 2019; Hicks, 2017). Finally, teachers may struggle with assessing the pedagogical value of digital resources, compounded by a lack of training (Abreu & Barbosa, 2022; Kayumova & Sadykova, 2019). Overall, LX design aims to provide workflows for addressing these challenges, which might feel daunting when multiple representations of learning content is perused in multimodal learning experiences.

Multiple representations of learning content are not new in Kindergarten classrooms. In fact, kindergarten classrooms provide an ideal context for implementing such approaches through structured learning stations. These stations foster engagement by allowing children to explore content through diverse modalities—visual, kinesthetic, tactile, and auditory representations. In this model, young learners benefit from hands-on activities, storytelling, and visual aids (Ainsworth, 2006; Martínez-Bello & Martínez-Bello, 2017). When digital tools like tablets, interactive boards, and other multimedia elements are integrated purposefully, they enhance these multimodal experiences (Moreno & Mayer, 2007; Novitasari et al., 2020; Park et al., 2011; Preston & Mowbray, 2008). For instance, tablet applications can foster spatial and motor skills through interactive games that blend digital and physical elements (Raths, 2015; Siregar et al., 2021). Yet, despite the recognized benefits of multimodal learning, creating and implementing such LX designs remains complex, with limited frameworks and resources that guide teachers in using multimodal digital resources effectively (Fowler, 2014). These might include guidelines to help teachers use technology to scaffold learning appropriately and integrate it seamlessly into various activities (Fowler, 2014). In sum, scholars like Kuhail et al. (2022) and MacDowell and Lock (2023) call for further research into frameworks that support multimodal learning environments in early childhood settings.

This study's first objective was to provide a comprehensive account of the LX design process, aimed at enhancing multimodal learning in kindergarten education. The study reports on the LX design process which involved two kindergarten teachers and two researchers designing and implementing a multimodal, station-based learning experience in early childhood education. This study's second objective was to present evaluation data. The LX design was implemented with the two teachers and their 33

kindergarten students to assess its effectiveness. In sum, the dual research goal of the study was:

- (i) To provide a comprehensive account of the LX design process, aimed at enhancing multimodal learning in kindergarten education.
- (ii) To report preliminary evaluation findings on the effectiveness of the LX design, based on implementation in the kindergarten classroom.

Background work

Learning stations

A learning station typically operates as a temporary arrangement in the classroom where students rotate through various activities designed to address specific educational objectives (Cople & Bredekamp, 2009). Engaging children in learning stations throughout the school day provides them with valuable hands-on learning experiences, as Reyes (2010) points out. Activities in learning stations, such as writing, art, and math, promotes children's literacy, cognitive, problem-solving and emotional development (Hamand, 2019). Learning stations provide different materials, strategies, and experiences that can be tailored to individual students, allowing them to work at their own level and be appropriately challenged (Gullo & Hughes, 2011). Meanwhile, learning stations can promote peer support, collaboration, and teamwork among students, providing an ideal environment for cooperative learning, interpersonal relationships, psychological well-being, and social competence (Harris & Meltzer, 2015). Numerous studies worldwide have examined the organisation of learning stations and their impact on various domains, showing that working in learning stations can increase student motivation, sense of responsibility, achievement, interest, and independent performance (Hicks, 2017).

Multimodal learning in learning stations

The integration of technology has enabled and introduced multimodality to kindergarten learning stations. This includes the enactment of multiple sensory modalities such as visual, auditory, and kinesthetic to promote active and engaging experiences for students (Bouchey et al., 2021; Dabbagh & Kitsantas, 2012; Massaro, 2012). Empirical studies have shown the effective use of digital resources by teachers, emphasising the multimodal presentation of content and the integration of interactive activities in a whole-class format to create an engaging learning environment (Ioannou & Ioannou, 2020; Kayumova & Sadykova, 2019; Reeves, et al., 2017). Multimodality can also be enriched via movement-based learning, engaging learners in multimodal learning experiences through physical interaction. Numerous studies have examined the effects of movement-based digital games in both general and special education contexts, exploring their potential to improve cognitive skills and academic performance in subjects such as maths and language (Kourakli et al., 2017; Kosmas et al., 2019; Kosmas & Zaphiris, 2023), promote motor performance (Kosmas et al., 2018) and other health benefits (Lieberman, 2012), as well as enhance learner self-efficacy, satisfaction and motivation (Staiano & Calvert, 2011). The design of learning experiences that emphasise multimodal learning

using digital technologies has the potential to advance student learning and to empower teachers in designing engaging learning experiences.

Methodology

Design of the learning experience (LX design)

The learning design team was composed of two kindergarten teachers and two researchers (educational technologists). The teachers lead the curriculum-related decisions of the LX design; one of the kindergarten teachers had 10 years of experience and the other one had 2 years of experience. Two educational technologists (20 and 5 years of experience respectively) lead the multimodal design decisions of the LX design. Overall, they worked together to consider pedagogical perspectives such as multimodal learning and well-established early education practices such as the station rotation model.

The learning design team drew on the affordances of an existing learning games platform (Kinems) to design an innovative learning experience for kindergarten children. Kinems is a platform of digital and movement-based learning games. To ensure the effective integration of Kinems into teachers' pedagogy and practice, the learning design team collaborated closely with teachers to align the use of the movement-based learning games with the developmental needs of five-year-old students. That is, the movement-based interaction was tailored to align with students' motor skills and attention spans, combining physical movements with educational tasks. The students were guided through the initial use of these tools, offering hands-on support and gradually encouraging independent exploration. Other platform features such as visual prompts and hints during play were used to support students' understanding and sustain their interest.

The LX design process was organised in two phases: the "Design Form" and "Enactment Form" as follows.

LX design- design form

The "Design-Form" phase was about defining learning goals from the national curriculum and planning the mastery of these learning goals through a series of tasks from simpler to more complex ones. We followed the principles of backward design, as outlined by Wiggins and McTighe (2006). That is, we reviewed the kindergarten mathematics curricula to identify learning outcomes, from which we considered both long-term and short-term goals in collaboration with teachers. Subsequently, we mapped the progression of short-term goals, sequencing them from simpler to more complex tasks, a process which was based on the principles of learning trajectories (Clements & Samara, 2009, 2014, 2017, 2020). For instance, for the kindergarten maths unit "Geometry", our long-term goal was that *"By the end of the school year, students should be able to recognize and name basic 2D and 3D shapes, understand shape properties, and effectively combine them to compose shapes"*. The developmental progression starts with short-term goals such as *"Recognize and name basic 2D shapes (circle, square)"* and advances to more advanced goals such as *"Identify shapes and their attributes in the environment"*.

LX design -enactment form

The “Enactment-Form” was about mapping those tasks into learning activities within multimodal learning stations, integrating also resources and tools from the Kinems professional learning games platform. When designing the learning experiences for the learning stations, we prioritised two key characteristics. Firstly, stations were designed so that, together, they enabled both individual as well as collaborative activities, fostering both independent learning and peer interaction. Secondly, the stations aimed to promote multiple ways of representation and interaction. For example, one station emphasised movement-based interaction or tablet/laptop-based work with touch or mouse. Manipulatives were utilised in another station, board games in another, while traditional pencil and paper activities were provided in a fourth station. Table 1 illustrates the example of a short-term goal “*Sort objects and shapes based on multiple attributes*” and how the learning activities in stations were designed.

Technology—the Kinems learning games platform

To support the implementation of the LX design we selected the Kinems Learning Games platform. This platform has been used in several contexts (Tsiakalou, 2016; Kourakli et al., 2017; Kosmas et al., 2019; Kosmas et al., 2018; Lee-Cultura et al., 2020). The platform provides a curriculum planner from which teachers can select preferred activities that are aligned to learning goals. Then, for each learning activity, the platform provides teachers with options of multimodal resources (digital games, board games, worksheets) to organise the classroom experience e.g. in learning stations.

The platform’s 37 customizable learning games support over 450 learning activities for Mathematics and Language, and its learning and kinetic progress monitoring mechanism is designed specifically for PreK-5 children assessment. The activities are generally offered in four different modalities, per the example of Table 2. In digital

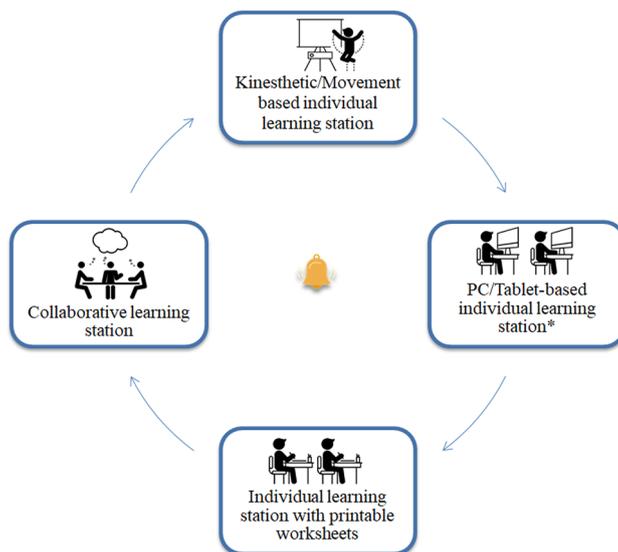
Table 1 Learning stations addressing the goal “*Sort objects and shapes based on multiple attribute*”

Learning station 1: “Attribute sort race”	Students engage in a movement-based race to sort objects and shapes based on specific attributes
Learning station 2: “Sort the objects into the right colour”	This tablet activity involves a digital sorting game where students drag and drop objects into different coloured boxes
Learning station 3: “Shape safari adventure”	This collaborative board game activity involves finding different shapes and objects along the way. Each player takes turns rolling a dice and moving their game piece on the board. When landing on a space, they draw a card with an object or shape depicted on it. Together, they discuss and decide how to categorise the object based on its attributes, such as shape, colour, or size, advancing through the game by correctly sorting objects
Learning station 4: “Object Sorting Challenge”	Students are provided with a worksheet depicting a variety of objects alongside available shape categories. They are tasked with holding a colourful marker, drawing a line, and sorting the objects into the appropriate categories

Table 2 Kinems modalities of learning activities

Modality	Description	Picture
Kinesthetic/Movement based individual learning with digital resource	Students play a learning game using hands and bodily movement, for a movement-based learning experience	
PC/tablet-based individual learning with digital resource	Students play a learning game on a PC/ tablet	
Individual learning with printable worksheets	Students work individually in completing worksheets using "pencil & paper"	
Collaborative learning with board game activities	Students collaborate in groups or in pairs on crafting (cut-and-glue) and practicing with board game activities	

experiences (movement based or tablet), the teachers can modify game settings, such as duration and level of difficulty. Figure 1 illustrates an example of the classroom orchestration in multimodal learning stations.



*If PCs or tablets are not available, teachers can substitute with classroom manipulatives or other resources for this station activity.

Fig. 1 Classroom orchestrated in multimodal learning stations based on the station rotation model

Evaluation study

The evaluation study was guided by three (3) research questions:

- RQ1: What are the teachers' attitudes and perceptions of the learning experience and LX design?
- RQ2: How do students perform during the learning experience?
- RQ3: What are the students' attitudes and behaviours regarding the learning experience?

Participants

The evaluation study was conducted as an in-depth case study, aiming to capture detailed, nuanced perspectives. By working closely with two Kindergarten teachers, we were able to focus on capturing rich, context-specific data that offer a deep understanding of the implementation and perception of the learning experience. In line with case study methodology, the two teachers were carefully selected due to their readiness to integrate digital and movement-based learning tools into their pedagogy. Their prior experience enabled them to provide informed feedback on the LX design, which was crucial for assessing both its practicality and effectiveness. Moreover, the evaluation involved the teachers' students i.e., a total of 33 five-year-old students in two kindergarten classrooms ($n_1 = 16$, $n_2 = 17$). The complete student sample consisted of 15 girls and 18 boys. There were two children with learning disabilities (mild attention deficit and attention deficit and hyperactivity) in each classroom. The students worked in groups of 4–5 students whilst we ensured diverse group composition in terms of gender and ability. We sought to maintain ethical integrity throughout the study. Both teachers and parents provided informed consent, understanding the purpose and scope of the research, and were fully aware of the study's goals and the voluntary nature of their participation.

Procedures

The learning experience was implemented once a week over a six-week period. Each session lasted approximately 60 to 90 min, during which the kindergarten teachers implemented the multimodal stations in their classrooms and conducted data collection for evaluation purposes. First, the teacher introduced the learning stations and materials to the class, demonstrating the expected level of engagement and interaction for each activity. The instructions and materials provided were designed to enable students to work independently within their groups. Then, students in groups of 4–5 started the work in stations as in Fig. 1. Throughout the session, the teacher maintained an active presence, monitoring the students and offering prompt support as needed to ensure smooth progress and understanding. Upon hearing a bell, groups moved to the next station. In some learning stations, the students engaged in the activity individually; in other stations they worked collaboratively (see Table 2). At the movement-based station, turn-taking was necessary, and this was facilitated based on a name's checklist prepared by the teachers. The learning experience continued until all groups had the opportunity to rotate in all learning stations.

Data collection

Evaluation data were collected once a week over a six-week period. Both quantitative and qualitative data were collected, as follows.

(i) *Classroom Behavior scale*. The scale, adapted from Achenbach and Edelbrock (1991), rates student behavior across six key areas: active participation, group cooperation, following instructions, smooth transitions between stations, focus on cognitive tasks, and project completion. Each behavior is rated from 1 (very poor) to 5 (very good), with detailed indicators at each level. For example, a rating of 5 for active participation signifies that the student engages consistently and independently, while a 1 shows minimal engagement despite prompts. In group cooperation, a 5 indicates proactive teamwork and encouragement of peers, while a 1 reflects resistance or disruptions within the group. For following instructions, a 5 represents independent, accurate adherence to tasks, whereas a 1 suggests frequent need for redirection. Smooth station rotation at 5 means seamless transitions between tasks, while a 1 shows difficulty moving between stations without guidance. Focus on cognitive tasks rated as a 5 means the student remains fully engaged, requiring no redirection, while a 1 reflects frequent distraction. Finally, a 5 for project completion shows independent work and full understanding, contrasting with a 1, where the student makes little to no attempt. Observations and ratings were conducted by the teachers, ensuring consistency across sessions (i.e., 6 learning sessions addressing 6 maths learning goals). Initial support was provided to the teachers to ensure consistent and accurate completion of these scales.

(ii) *Goal Attainment Scale (GAS)*. The scale, adapted from Kiresuk et al. (1994), is a tool used in this study to measure each student's progress toward predefined math learning goals. Teachers completed the GAS scale at the end of each of six sessions, each targeting a unique math objective. The scale offers a range from -2 to $+2$ to evaluate how well students met these goals:

- -2 (Much Less than expected): The student did not meet the goal and showed minimal progress; for instance, in a session on basic counting, a student might be unable to correctly count up to 10 without significant assistance.
- -1 (Less than Expected): The student showed some progress but fell short of the expected level; for example, the student could partially count but needed consistent support or made frequent mistakes.
- 0 (At Expected Level): The student achieved the goal as expected, demonstrating the desired level of understanding, such as correctly counting up to 10 with little to no assistance.
- $+1$ (Higher than Expected): The student exceeded expectations, showing a higher understanding or skill than the goal required; for instance, counting up to 10 or more with ease.
- $+2$ (Much Higher Than Expected/Overachieved): The student surpassed expectations significantly, demonstrating advanced understanding or skill, such as applying counting in new, unanticipated ways.

Using the GAS in this study provided a standardized way for teachers to assess students' individual progress and the effectiveness of each session in achieving its targeted

learning goal. Initial support was provided to teachers to ensure consistent and accurate completion of these scales. This scale offered a clear view of varying levels of goal attainment across different math skills and allowed for nuanced insights into each student's learning trajectory.

(iii) *Semi-structured interviews*. Qualitative data were gathered during a 30 min semi-structured interview with each of the teachers, conducted by one of the researchers, at the ending of the learning experience. The aim of the interview was to better understand the teachers' perceptions regarding the enactment of the LX design and their observed outcomes in terms of student achievement, attitudes and behaviours. The following questions guided the semi-structured interviews, while follow-up questions were asked as needed:

- How has the LX design simplified your process of using multiple representations in teaching?
- In what ways have digital and physical tools influenced your pedagogical strategies in the classroom?
- How has practicing math learning goals across different stations affected student mastery of these concepts?
- Can you describe how group work has contributed to your students' understanding and retention of math concepts?
- What observations do you have regarding overall student engagement in the movement-based learning station?
- Have the students exhibited any particular attitudes or behaviors during the learning experience.
- How has movement-based learning specifically benefited students with learning disabilities or attention challenges?
- What aspects of the LX design do you find most effective for enhancing your teaching practices?

(iv) *Learning analytics*: Learning analytics were collected when the students' completed the digital learning activities. Data collection was automated through the education platform, which gathered aggregated accuracy scores, based on the number of correct and incorrect answers, and the reaction time. This data was used to create mastery levels per goal per student. Additionally, the platform provided detailed reports for each activity, offering an in-depth view of individual student progress. For example, if a student answered 16 out of 20 math questions correctly with an average reaction time of 3.5 s per question, they would achieve an 80% accuracy score, placing them at a "Partially mastered" mastery level for counting skills.

Data analysis

To evaluate the effectiveness of the multimodal learning experience, the collected data (teachers' perceptions, student performance metrics, and semi-structured interviews, analytics) were analyzed together, aiming for triangulation of evidence. In particular, the teachers' perceptions were assessed through the GAS scale to determine whether the multimodal station sessions achieved the desired learning goals. The 5-point behavior

scale was used to evaluate the quality and effectiveness of classroom orchestration in each session. The learning analytics collected from the platform were analyzed by examining student performance metrics to assess the overall effectiveness of the experience. Finally, the data obtained from the semi-structured interviews were analyzed qualitatively. Two researchers coded the teachers' responses for ideas directly connected to the RQs of the evaluation study (teachers' attitudes and perceptions, students' achievement, students' attitudes and behaviors). Independent coding resulted in over 90% agreement between the researchers and any discrepancies were resolved to consensus. The researchers aimed for triangulation of the evidence drawing from all data analysis, both quantitative and qualitative.

Findings

Triangulated evidence from all data sources helped to address the RQs of the study, as follows.

Teacher attitudes and perceptions (RQ1)

Both teachers valued the importance of enabling various pedagogical strategies using digital and physical tools and thought that the LX design followed in this work simplified the process of designing and utilising multiple representations e.g.,

"It made designing and using multiple representations to teach in the learning stations a lot simpler for me. It also made it easier for me to understand what the kindergarten curriculum is all about and helped prepare my students for their readiness tests". (teacher 1)

"The LX design helped me mix up my teaching styles, making it easy to use both digital and hands-on tools to create fun and engaging learning experiences for my students". (teacher 2)

Specific teacher input suggests that maths learning, and mastery of the learning goals was reinforced thanks to the opportunity for the student to practise in different stations, via different tools, manipulative, and modalities, as well as the opportunity to work in groups e.g.,

"Students had the opportunity to practise the same learning goal using multiple modalities, tools, and manipulatives, all within a single session. This approach allowed the children to explore and become acquainted with a diverse range of materials, fostering the creation of new mental structures and enriching their learning experience". (teacher 1)

"The group work enabled by the setup also expanded the students' systems of communication and interaction, fostering learning. My kids remembered concepts better after the sessions because we used different ways to teach them" (teacher 2)

The movement-based station was reported to be the most intriguing one e.g., *"Students exhibited a high level of engagement and active participation in the movement-based station" (teacher 1)*. Moreover, the second teacher noted that the movement-based learning experience was particularly encouraging for her students with learning disabilities e.g.,

“The implementation resulted in greater motivation and engagement, particularly for my students who typically faced challenges in maintaining focus during other activities, due to difficulty in articulation, mild attention deficit and attention deficit and hyperactivity. The incorporation of movement-based learning experiences not only increased motivation but also extended the duration of engagement, allowing even students with concentration difficulties to achieve the desired learning outcomes.” (teacher 2)

Student achievement (RQ2)

Per findings in RQ1, specific teacher input suggests that maths learning, and mastery of the learning goals was reinforced thanks to the opportunity for the student to practise in different stations. Yet, student achievement is further supported by learning analytics gathered by the learning platform for the digital stations and aggregated at class-level gathered. These data showed that very few mistakes were made for these activities across the six maths goals. Namely the success score ranged between 78% (total of 29 correct out of 39 questions) to 100% (33/33 correct questions) with 90.7% mean success rate, which is suggesting high performance and mastery of the learning goals.

Moreover, the mean GAS score across learning sessions was slightly above the midpoint of the scale (mean score=0.12) suggesting the average achievement level was “at the expected level” with some exceptions in the positive direction of the scale. A closer look at teachers’ ratings of (observed) student achievement during the fifth session (S5), showed that 26 out of 33 students performed at designed/expected levels as perceived by the teacher (i.e., “0” per GAS scale), while the rest of them (7) performed at higher-than-expected levels (i.e., “+ 1” and “+ 2” per GAS scale). The students with learning disabilities (4) in both classrooms were amongst those who performed at higher-than-expected levels (Fig. 2).

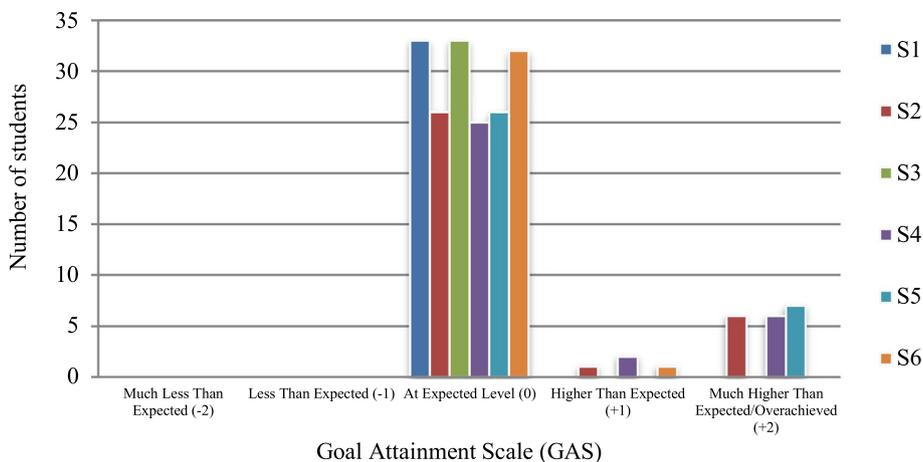


Fig. 2 Students’ academic performance based on GAS assessment

Student attitudes and behaviours (RQ3)

During the semi-structured interview, the teachers reported positive student attitudes observed in the form of enthusiasm, active engagement with the learning experience, and anticipation for the next learning session e.g.,

“The multimodal learning experience captured the students’ interest and enthusiasm, fostering a dynamic and interactive learning environment. I feel that students demonstrated exceptional levels of concentration” (teacher 1)

“The excitement and anticipation of the students were palpable, as they eagerly waited for the next session and the chance to engage with new games and in teamwork with new materials. The entire process held significant meaning for the children, motivating their active participation and overall engagement” (teacher 2)

This input corroborates with observed ratings of classroom behaviour including active class participation, cooperation in groups, sequence of instructions, smooth rotation between stations, focused attention on cognitive tasks, and completion of projects. Namely, we calculated the mean score of the teachers’ ratings on the 5-point Classroom Behavior scale ranging from very poor to very good, across all six learning sessions. The mean score approved the high end of the 5-point scale (mean-score=4.77), suggesting that the students exhibited very good behaviour. A minor correction was noted by one of the teachers, perhaps linked to the students’ enthusiasm around the movement-based station. In particular, the teacher found that,

“The completion of projects took longer than expected, activating a timer, especially for the movement-based learning activities through the platform’s settings could have been beneficial in terms of better time management”. (teacher 2)

Overall, positive findings from the evaluation based on teacher feedback and student outcomes suggest that the LX design framework can effectively support young learners. These findings will be discussed next.

Discussion and implications

Learning experience (LX) design is fundamentally about creating effective, contextually relevant learning interventions that prioritize the interconnected relationships between the learner, the designed experience, and the educational setting (Schmidt & Huang, 2022). Despite the documented benefits of multimodal learning in early childhood education, the literature lacks detailed examples of LX designs implemented in real classrooms. This study addresses this gap by reporting on the design, enactment, and evaluation of a multimodal LX design for kindergarten students using a station rotation model supported by a multimodal multisensory learning games platform that also supports movement-based learning.

This study’s first objective was to provide a comprehensive account of the LX design process. With the aid of two kindergarten teachers, we followed a learning design approach that blended established instructional frameworks like learning via multiple representations, the learning stations and the learning trajectories. The design process was organized into two phases: the “Design-Form,” focusing on defining and sequencing curriculum-aligned learning goals, and the “Enactment-Form,” which involved mapping

tasks to multimodal learning stations using both digital and physical resources. This step-by-step process contributes to the literature by offering a replicable LX design framework that addresses calls for structured integration of multimodal digital resources in early childhood education (Fowler, 2014).

For the second objective, we collected teacher feedback through an initial evaluation of the LX design in two kindergarten classrooms with 33 students. Teachers reported positive experiences, particularly appreciating the flexibility to employ various pedagogical strategies that combined digital and hands-on tools. They noted that the LX design simplified the process of integrating multiple representations of content, as well as of the effective use of classroom infrastructure, echoing concerns in the literature about the challenges of creating standards-aligned technology enhanced multimodal learning stations (Hamand, 2019; Hicks, 2017).

Observational data also indicated high student engagement, active participation, and cooperation across the learning stations. Teachers' assessments revealed that most students performed at or above expected levels, with notable engagement in both group and individual tasks. These observations suggest the potential of this LX design framework to support diverse learning needs, including those of students with learning disabilities, by allowing for practice across multiple sensory modalities.

Implications for research and practice

This study has implications for both educational practice and future research in early childhood LX design.

For practitioners, the LX design framework developed here offers a structured way that combines digital and physical resources in a station-based format tailored for young learners. This approach provides a practical pathway for educators to integrate technology meaningfully, aligning with national curriculum standards while supporting multimodal engagement (Fowler, 2014; Yelland, 2015). The "Design-Form" and "Enactment-Form" phases outlined in this study give educators actionable steps to create LX designs that enhance student engagement and learning outcomes. Our preliminary evaluation findings suggest that using multimodal tools can help differentiate instruction to meet the diverse needs of the learners, including those with learning disabilities. Consequently, by integrating various modalities into their teaching practices, educators can create more inclusive and personalized learning experiences to address all students' needs. As another practical insight, time management during station rotations is a critical consideration. Movement-based activities, while highly engaging, may require timers or scheduling tools to ensure efficient transitions and prevent delays.

For researchers, this work contributes to the LX design literature by demonstrating a structured, replicable approach to integrating multimodal resources into kindergarten classrooms making use of learning trajectories. The work is a step forward addressing the limited frameworks and resources that guide teachers in using multimodal digital resources effectively. Positive teacher feedback and encouraging student outcomes suggest that the LX design can effectively support young learners, providing a basis on which other educators and researchers can build. Meanwhile, there is great value in developing and researching professional development programs for teachers designed to

enhance their ability to use the present (or similar) LX design frameworks for successful design and implementation of multimodal learning in real classroom settings.

Limitations & future work

The focused nature of this study enabled close collaboration with teachers, providing nuanced feedback on the integration of multimodal resources and the balance between digital and physical tools—key elements that enhance classroom LX design. It further enabled in-depth insights into the LX design, implementation, and teachers' experiences. Yet, being limited to the experience of two classrooms restricts the generalizability of the findings. While the study provides promising preliminary findings, there are several avenues for future research to explore:

Replication with larger samples: Working with only two teachers (and their students) is a major limitation of the study. A natural next step would be to replicate this study with a larger cohort of participants to validate and expand upon these findings. A more diverse sample across multiple educational settings would offer a broader perspective on the effectiveness and scalability of the LX design model. As of now, findings from this case study evaluation are only transferable to similar contexts and settings, with limited generalizability.

Systematic evaluation across a full school year: The short study duration (six weeks, once a week) is another limitation of the study. Future research could involve implementing the LX design over an entire school year to assess its long-term impact on academic achievement and student behavior. A study could provide insights into how the LX design supports long-term curriculum goals, fosters engagement, and achieves mastery across various subjects. In general, longitudinal studies examining the impact of LX designs on student engagement and academic growth, especially with larger samples, could provide valuable insights into the sustained effectiveness of multimodal LX design in early childhood education.

Teaching executive functions: Future research could explore the implementation of the LX design to teach other critical skills, such as executive functions, in early childhood or special education settings. This would involve adapting the multimodal approach to support the development of cognitive skills like working memory, impulse control, and task flexibility, assessing its effectiveness in enhancing these skills. In general, future research should examine conceptual frameworks that promote immersive and multimodal learning across diverse contexts (Kuhail et al., 2022; MacDowell & Lock, 2023).

Experimental designs addressing causal effects: Although the case study design, enabled in-depth examination of two teachers and their students, findings from this work are descriptive accounts of the experience. Documenting how the LX design framework can result to better learning and achievement, and better attitudes or behaviours, would require experimental designs with a control group. This would be an interesting direction for future research.

Conclusion

In conclusion, this study contributes to the LX literature by demonstrating a structured, replicable approach to integrating multimodal resources into kindergarten classrooms making use of learning trajectories. Positive teacher feedback and encouraging student outcomes suggest that the LX design can effectively support young learners, providing a framework that other educators and researchers can adapt and build upon. This work is a step forward in addressing a need for LX designs that can facilitate seamless multimodal learning in early childhood. Meanwhile, this work highlights the need to further explore LX design frameworks that support multimodal learning in early childhood settings.

Participants

All procedures performed in this study involving participants were in accordance with the Ethical Guidelines for Educational Research (BERA, 2018).

Authors' contribution

All authors contributed significantly to this piece of work. Valeria Aloizou led the conceptual framework, coordinated the research activities, and was responsible for drafting the manuscript. Andri Ioannou supervised the methodological design of this work and drafting of the manuscript. Michael Boloudakis critically reviewed the manuscript and provided feedback. Symeon Retalis contributed to the conception, design, and development of this work. All authors critically reviewed the manuscript, provided feedback, and approved the final version for submission.

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Availability of data and materials

The data that support the findings of this study are available from the corresponding author, Valeria Aloizou, upon request.

Declarations

Competing interests

No potential conflict of interest was reported by the author(s).

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