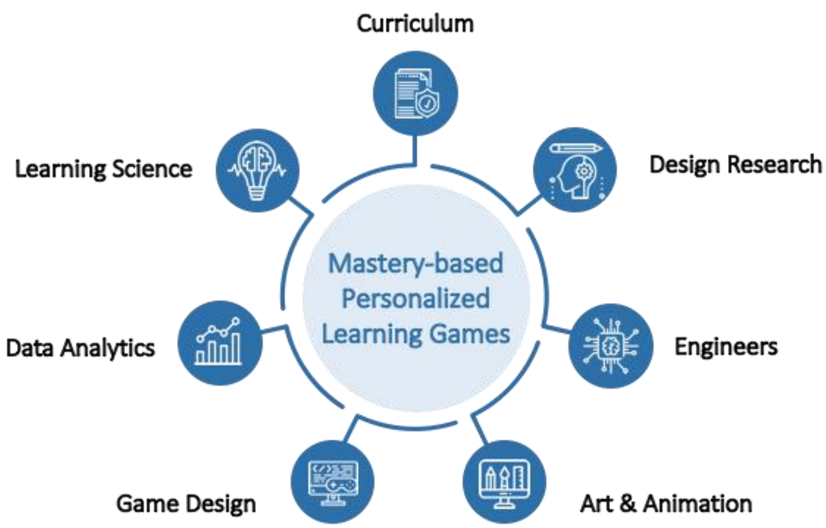
My Math Academy: A Research-Driven Design Approach to Personalized Learning for Young Children

Age of Learning developed My Math Academy—a game-based adaptive learning system—using a collaborative, child-centered process involving experts in learning sciences, curriculum research, user/design research, efficacy research, data science, assessment, and professional game design and development.



Age of Learning's experts from many disciplines collaborate to ensure an effective, engagement learning experience for children in My Math Academy

Our goal is to create a highly effective, engaging, and personalized learning experience to help all children build a strong foundation in early mathematics skills and develop a lifelong love of learning.

What is My Math Academy?

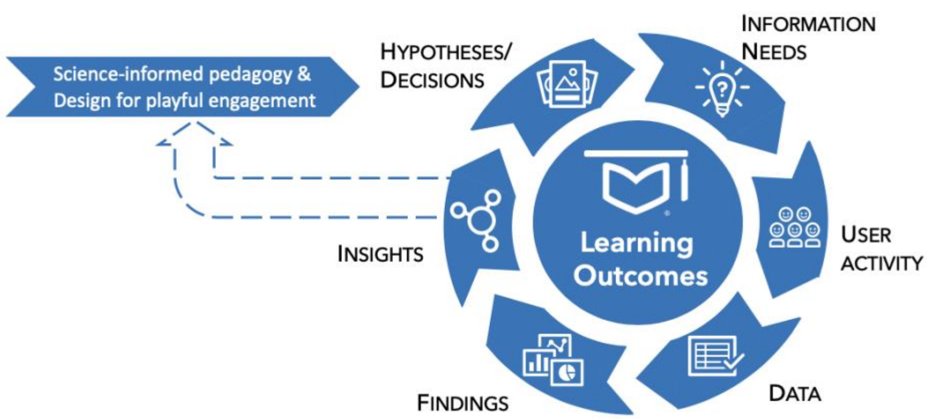
Our *My Math Academy* game-based adaptive learning system features 32 games with 300+ activities designed to help young learners build mastery of fundamental number sense and operations from pre-kindergarten to second grade. At the time of writing, a version of My Math Academy is available within ABCmouse *Early Learning Academy*. Each game has a clear learning objective, learning task, and evidence of learning, and each learning objective is supported by an interactive instruction level and several layers of scaffolding and feedback. The narrative, mechanics, and system design provide playful learning experiences tailored to students' ages. Based on each learner's performance, the adaptive system provides support and feedback and recommends games at the appropriate difficulty level using a predetermined map of learning objectives and their prerequisite relationships. My Math Academy also includes resources for parents and teachers who play key roles in creating an effective system for learning.

A snapshot of selected games within the My Math Academy system

Our Learning Engineering Approach

We integrate research into every phase of developing My Math Academy. From product conception, through curriculum and product design, and into program implementation, research guides our decisions about what to create, iterate, and refine.[1]

We adopt a *learning engineering* approach to creating products that support learners and their development.[2] We apply the research on how children learn to inform our pedagogy, design for playful engagement, and use human-centered research and analytics to create and iteratively improve upon those learning experiences.[3]



Age of Learning's Learning Engineering Framework

[1] Bang, H.J. & Li, L. (2020). My Math Academy Significantly Accelerates Early Elementary Children's Math Skills and Fosters Greater Engagement in Math: A Replication of a Randomized Control Trial. Research Brief. Age of Learning, Inc. https://www.ageoflearning.com/My_Math_Academy_Research_Brief_2020.pdf; Thai, K.P., Li, L., Schachner, A. (2018). My Math Academy Significantly Accelerates Early Mathematics Learning. Research Brief. Age of Learning, Inc. https://www.ageoflearning.com/My_Math_Academy_Research_Brief_2018.pdf

[2] IEEE Industry Connection Industry Consortium on Learning Engineering (ICICLE). (2019, December). https://www.ieeeicicle.org

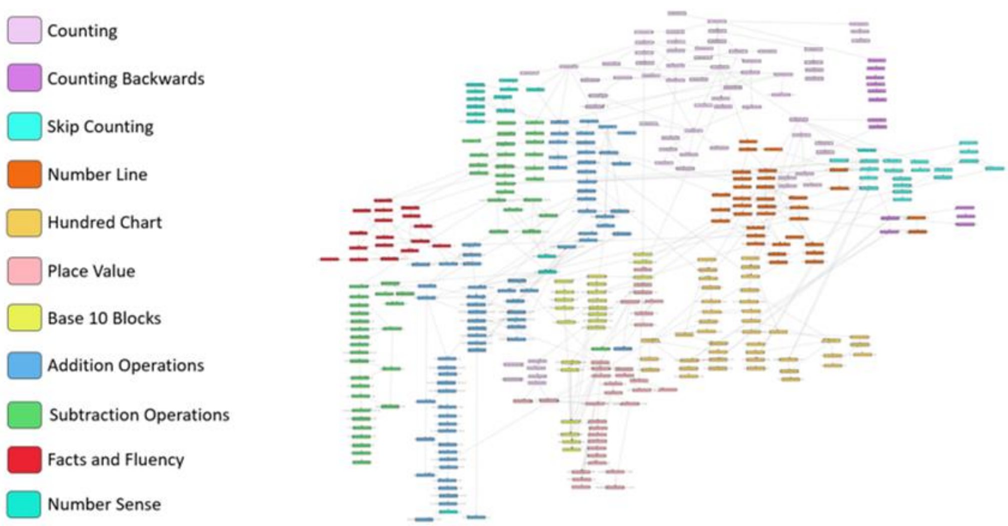
[3] Willcox, K. E., Sarma, S., & Lippel, P. H. (2016). Online education: A catalyst for higher education reforms. MIT Online Education Policy Initiative, 1–56.

Our process includes three phases: (1) Curriculum research, (2) Research-based design & iterations, and (3) Implementation research and analyses.

Phase 1 – Curriculum Research

Each child is different, with different strengths, skills, and background knowledge. Therefore, each learner has her own individual "trajectory" or pathway through the content. This idea of individual learning trajectories has roots in the constructivist work of such educational theorists as Lev Vygotsky, as well as more current research on hypothetical learning trajectories conducted by Martin Simon, and the learning trajectories approach for early mathematics by Douglas Clements and Julie Sarama.[4]

Since all learners are different, instruction is best individualized, which requires clear definitions of granular learning objectives. However, there is no national pre-k math curriculum, and kindergarten math curricula are too coarse to effectively tailor instruction. Thus, our curriculum experts spent two years analyzing and synthesizing state and national standards frameworks (e.g., Common Core State Standards, NCTM's Standards, and Principles for School Mathematics) and the literature on mathematics interventions, including the internationally recognized Math Recovery program and the highly researched Building Blocks early math curriculum.[5] This research helped us map what children need to know, how they build on what they know, the most problematic and challenging areas of early math, and the hidden concepts, principles, and skills that often cause children's misunderstandings. Based on our findings, we developed a knowledge map of fine-grained, measurable learning objectives and pathways toward early number sense development (below). It served as the foundation for the next development phases.



My Math Academy knowledge map overview of pre-k-2 number sense and operations. Each node represents a learning objective.

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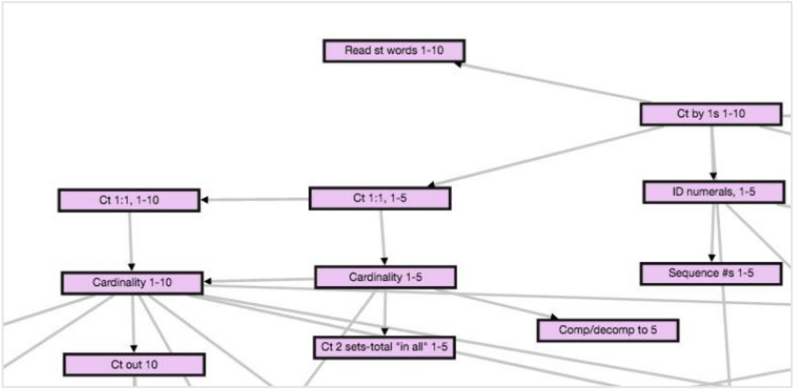
[4] Vygotsky, L. S. (1978). Mind in Society: the Development of Higher Psychological Processes. Cambridge, MA: Harvard University Press; Simon, M. (1995). Reconstructing Mathematics Pedagogy from a Constructivist Perspective. Journal for Research in Mathematics Education, 26(2), 114-145

[5] https://www.mathrecovery.org/; Clements, D. H., & Sarama, J. (2004). Learning Trajectories in Mathematics Education. *Mathematical Thinking and Learning*, 6(2), 81-89. https://doi:10.1207/s15327833mtl0602_1; Clements, D. H., & Sarama, J. (2014). *Learning and teaching early math: The learning trajectories approach.* Routledge.



Knowledge involved in counting 1-10

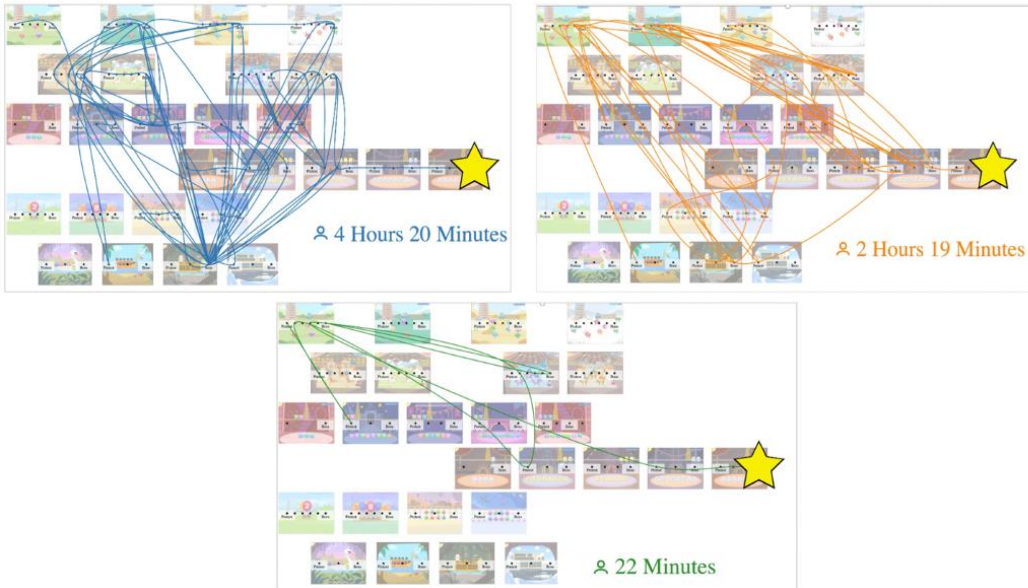
Phase 2 – Research-Based Design & Iterations

a. Mastery-based Personalization

Children learn best when they receive individualized instruction with appropriate feedback that allows them to master each topic before moving on.[6] The Personalized Mastery Learning System™[7] in *My Math Academy* uses initial diagnostic assessments to place each child onto the knowledge map and provides different levels of scaffolding, feedback, and content based on the learner's performance. Each game starts with a teaching portion, a game overview, the problem-scenario, and instructions on the mathematics content to successfully complete the task. A child may pass, stay, or go back to an easier level in a game, and the various adaptivity and scaffolding mechanisms are tailored to her math level and learning pace, as shown in Figure 3, which illustrates the pathways of three different students through the same My Math Academy content. The lines represent each child's learning trajectories; time to completion shows the different lengths of times each child took to master the content (4 hours and 20 minutes; 2 hours and 19 minutes; 22 minutes). It would be challenging, if not impossible, for a teacher in a traditional classroom to personalize instruction in this way for 30 students, each with his or her own unique learning trajectory.

[6] Bloom, B. (1968). Learning for mastery. In J.H. Block (Ed.), *Mastery learning: Theory and practice* (pp.47-63. New York, NY: Holt, Rinehart, & Winston.

[7] Dohring, D., Hendry, D., Gunderia, S., Hughes, D., Owen, V. E., Jacobs, D.E., Betts, A., & Salak, W. (2019). U.S. Patent No. 20190236967 A1. Washington, DC: U.S. Patent and Trademark Office.



Examples of student learning trajectories in My Math Academy (from Betts, 2019)

b. Game-based Learning and Engagement

Play is essential to children's development and learning, and games can be great vehicles for learning.[8] My Math Academy sustains children's engagement and motivation via ongoing feedback, interactivity, and adaptive challenges that are personalized.[9] It also ensures that each child's in-game action is specifically designed to support learning objectives and provide evidence of growth over time (more below in *d.*). Additionally, storylines in game-based learning activities present authentic learning contexts for learners and help them make sense of math problems, facilitating their ability to transfer skills (or apply what they have learned).[10] Children help "Shapeys" (characters and manipulatives in the games) in various story contexts, using their developing math knowledge (e.g., helping Shapeys with a headcount so they can go on a boat ride). Additionally, formative assessment (i.e., assessment *for* learning rather than summative assessment, or assessment *of* learning) provides ongoing feedback to children.[11]

[8] Eyer, Hish-Pasek, & Golinkoff (2004); Fisher, Hirsh-Pasek, Golinkoff, Berk, & Singer, 2010

[9] Gee, J. P. (2003). *What Video Games Have to Teach Us About Learning and Literacy*. New York, NY: Palgrave Macmillan; Gee, J. P. (2005). Learning by design: Good video games as learning machines. *E-Learning and Digital Media*, *2*(1), 5–16; Rupp, A.A., Gushta, M., Mislevy, R.J., & Shaffer, D.W. (2010). Evidence-centered Design of Epistemic Games: Measurement Principles for Complex Learning Environments. Journal of Technology, Learning, and Assessment, 8(4). Retrieved [date] from http://www.jtla.org.

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[11] Shute, V. J., & Kim, Y. J. (2014). Formative and Stealth Assessment. In J. M. Spector, M. D. Merrill, J. Elen, & M. J. Bishop (Eds.), *Handbook of Research on Educational Communications and Technology* (pp. 311–321). https://doi.org/10.1007/978-1-4614-3185-5_25; Ke, F., Shute, V., Clark, K. M., & Erlebacher, G. (2019). Interdisciplinary design of game-based learning platforms.

Children practice counting out quantities by helping Shapeys doing a headcount for a boat ride

c. Consideration for Long-term Retention and Transfer

Desirable difficulties such as actively retrieving previously learned information (retrieval practice) and alternating one kind of task with another (interleaving) support long-term retention.[12] My Math Academy's algorithmic recommendation of activities employs these principles. It also helps children transfer through the games and at-home resources. With games, children explore each math concept in depth, practicing with many examples with the same concept at work. At-home offline learning activities offer opportunities for children to apply math concepts to different contexts (e.g., counting household objects). Furthermore, since children transfer better if they see opportunities to apply what they know, enrichment projects and math talks (conversation prompts for parents to use to talk about math) encourage children to think about math and practice seeing the relevance of math in their daily lives.[13]

d. Game-based Assessment and Structured Data for Evidence

As learners move through the system, game interactions translate into learning performance data. Our approach borrowed much from the research on Evidence-Centered Design, an assessment framework estimates learners' competency levels while generating the evidence to support claims about the targeted competency.[14] The system continually measures growth, adjusts to each child's needs in real time for a personalized, engaging learning experience, and generates game events that can be interpreted directly in terms of competency types and learning objectives, which allow us to readily translate our analyses results into feedback and iterative game design.[15]

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[15] Shute & Kim 2014

e. Design-Based Research

To effectively design for children, we employ child-centered design research practices to obtain a full understanding of our learners: how they learn, why they want to learn, and their learning contexts.[16] We conduct weekly research with children to evaluate our user interface, user experience, player motivations, and interactions. We apply this human-centered approach with parents/caretakers and teachers in creating parent- and teacher-facing dashboards and materials, as parents and teachers play a crucial role in supporting children learning.[17] Via dashboards, we offer child progress information to support real-time, interpersonal intervention, and model effective uses of technology to help parents and teachers foster a positive math learning environment at home and at school.[18]

Phase 3 – Implementation Research and Analyses

Multiple implementation and efficacy studies of My Math Academy have been conducted. A randomized control trial (RCT) conducted with pre-k and kindergarteners in 2017 showed that My Math Academy significantly accelerated their learning gains in comparison to the control group (N=453).[19] These results were replicated in another RCT in 2019 with kindergarteners, 1st and 2nd graders (N=958).[20] In both studies, those who mastered more skills in My Math Academy also demonstrated greater learning gains, and the greatest impacts were found on the most difficult skills. Additionally, teachers across both studies recognized My Math Academy as a valuable learning resource, especially given their students' greater engagement, motivation, and confidence in learning math.

In Closing

A cross-disciplinary team of curriculum experts, learning scientists, game developers, and researchers at Age of Learning collaborate to create products to help children build a strong foundation for academic success. My Math Academy is designed to equip all children with early math skills, which are the strongest predictor of later academic success and educational attainment.[21] To achieve this goal, we apply learning sciences research to inform our pedagogy and initial design, conduct user-centered research to make informed design decisions, and use evidence-centered design and learning analytics to drive learning outcomes. We have created and implemented a learner-centered development process that gives us a comprehensive view of the child and their environment, enabling us to build effective, engaging, personalized learning experiences for diverse learners. Please consult the references below for more information on the specific research that informed the creation of My Math Academy.

Questions can be directed to: learningengineering@aofl.com

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[19] Thai, Li, & Schachner, 2018

[20] Bang & Li, 2019

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