Sounds and Sippy Cups: New Approaches to Pre-Literacy in Adaptive Game-Based Learning for Young Children

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Abstract
Multiple professions and fields of study are dedicated to young learners and the key experiences they need to succeed. Academics across psychology, neuroscience, linguistics, and educational research seek answers to key questions about how children learn to read. Practitioners across public K-12 schools, preschools, private educational institutions, and community organizations seek paths to reading success with individual groups of children. Despite immense efforts, the disconnect between research and practice has greatly limited the tangible outcomes for learners. Measures of reading ability across the United Stated yield consistently disappointing. This paper discusses an iterative cycle of research-informed design – called learning engineering – used to create digital game-based learning experiences for young learners in *My Reading Academy*. *My Reading Academy* is an adaptive game-based learn-to-read program that is grounded in the science of reading and cognitive development research. A deep dive into phoneme awareness instruction will be used to demonstrate the processes by which instructional design can produce engaging experiences with meaningful learning outcomes. Successful mastery of phonemic awareness skills, a key predictor of future reading performance, can change the overall learning trajectory and academic success of young learners. Rooted in robust research (both academic literature and via direct interactions with learners, teachers, and families), the development of *My Reading Academy* is also refined with insights from learning analytics and user research. This powerful connection between science and practice has the potential to build a foundation for academic achievement and life-long learning.

Keywords: Phonological Awareness, Phonemic Awareness, Digital Learning, Digital Games, Research-informed Design, Adaptive Instructional Systems, Learning Engineering, Game-based Learning, Early Literacy, Reading Instruction, Early Childhood Education

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Introduction

Decades of research from interdisciplinary fields such as developmental psychology, developmental linguistics, cognitive psychology, neuroscience, and educational research have yielded tremendous insights into the process of learning to read (i.e., Gough & Tunmer, 1986; Scarborough, 2001; Ehri, 1996; Kilpatrick, 2015). The mechanisms of reading have been observed, tested, and documented, producing reliable models of reading acquisition and proven guidelines for effective instructional practices. Though scientific consensus exists on the causes of reading successes and failures, that has not translated into practices and interventions that have ensured success for all students. Only about one-third of fourth graders in the United States formally demonstrate the ability to read with accuracy, understanding, and fluency (de Brey et al, 2019). Performance is even more troubling when you consider that the average score for students from historically disadvantage ethnic backgrounds and those living with fewer economic resources are consistently lower than their White, middle- and upper-class peers. Seidenberg (2018) attributed lackluster literacy success to the disconnect between the science of reading and educational practice. He describes an educator culture that either resists new ideas and suggestions from academia or, to meet the constant high-pressure calls for educational innovation, accepts underdeveloped new theories too quickly (Seidenberg, 2013, 2018). Educators are often skeptical of conclusions developed by academics due to a belief that studies cannot account for the intangible dynamics of a specific classroom (Coles, 2000). Many educators trust their own observations despite the limitations that this approach entails.

Connecting scientific understanding of the reading process to the learning experiences of students is crucial. Reading success in the early years of formal schooling is a predictor of later academic achievement (Duncan et al., 2007), as well as a predictor of positive mental and physical health, financial, and social outcomes in adult life (Ritchie & Bates, 2013; Schweinhart et al., 2005). We cannot entrust the instruction of such high-stakes content to intuition, habit, or the status quo (Weinstein, Sumeracki, & Caviglioli, 2019). A partnership between science and practice is the path to greater reading outcomes for students.

Components of Early Reading Instruction

Reading instruction in the English language may be uniquely challenging (Spencer & Hanley, 2003). Linguistically, English has a “deep” or “opaque” orthography with layers of rules and conditions impacting the correspondence between sounds and letter (Miller, 2019). This creates a steep learning curve in the early reading phase as novice readers build a critical mass of sound-spelling correspondences. For example, in a comparison of five- and six-year-old schoolchildren learning to read Welsh, an orthographically “shallow” language, and others learning to read English, Spencer and Hanley (2003) found the children learning Welsh demonstrated significantly greater proficiency reading words and nonsense words. During their second year of formal schooling, the Welsh readers largely mastered the full system of Welsh sound-spelling correspondences while the English readers had additional correspondences and sight words to learn. In another study (Hanley, 2004) of Welsh and English students in their sixth year of formal instruction, the impact of the more challenging orthography in early learning showed itself most prominently in the performance of struggling English readers. While successful English readers had mastered word-reading, the lowest performing 25% of English readers had not yet acquired sufficient word reading skills. Despite these results, the steep learning curve in the early reading phases of English reading is not insurmountable. Singapore and Canada (with the exception of Quebec) conduct instruction in English yet maintain consistently high performance in international measures of reading (Schleicher, 2019).

It is important to note, however, that word reading is only one element of the full cognitive task of reading. Consider the simple view of reading (Gough & Tunmer, 1986) which identifies two processes involved in reading: word recognition and language comprehension. While this model is simple, it encompasses the nuanced blending of several distinct components. Word recognition requires increasingly automatic blending of several elements--phonological awareness and phonological skills, letter-sound knowledge, orthographic knowledge, and sight word memory (Kilpatrick, 2015). Once mastered, the automaticity of word reading can mask its complexity. The language comprehension elements including background knowledge, text knowledge, attention and comprehension monitoring, vocabulary knowledge, and language skills (Kilpatrick, 2015) combine to form the second process. Automaticity is *not* the goal for language comprehension elements. Instead, readers become increasingly strategic and sophisticated in their use of language comprehension elements.

Phonological Awareness and Phonemic Awareness

This paper focuses on one key strand within the complex task of reading: the essential, foundational skills of phonological awareness. Phonological awareness describes the awareness of sounds and sound structures in spoken language (Bradley & Bryant, 1983; Kenner, et.al, 2017). Two factors impact the complexity of phonological awareness tasks—the size of the sound units and the type of manipulation of the sounds (Yopp & Yopp, 2009). Traditionally, phonological awareness tasks are organized by complexity, and progress from large units to individual sounds (i.e., words to syllables to onset-rime units to individual sounds). Tasks also move from recognition of sound units to increasingly sophisticated manipulation of sound units (i.e., identify, blend, segment, delete, substitute) (see Figure 1). Phonemic awareness describes the set of phonological awareness skills that involve recognition and manipulation of individual sounds called phonemes.

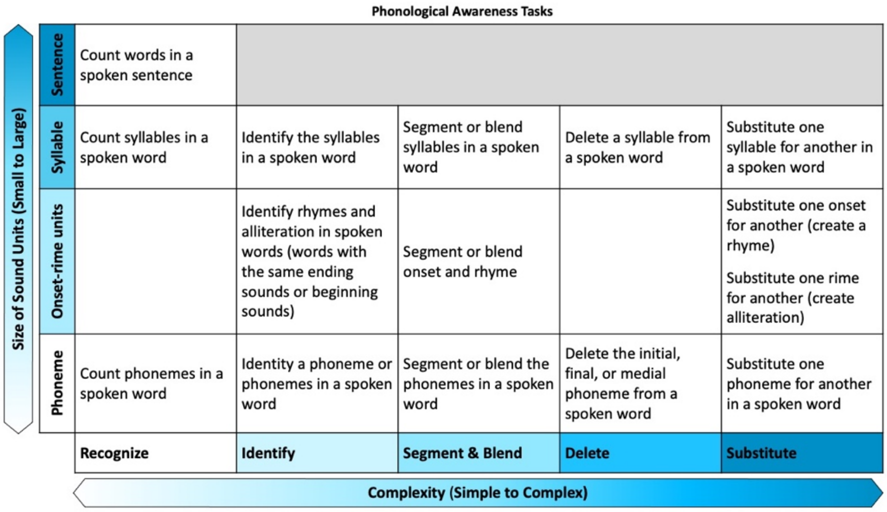

Figure 1: Phonological Awareness Tasks Organized by Complexity

For context, it is important to know that phonemic awareness is part of the suite of early reading skills. The National Reading Panel identified phonemic awareness as one of "The Big 5," the essential components of reading and reading instruction (Figure 2).

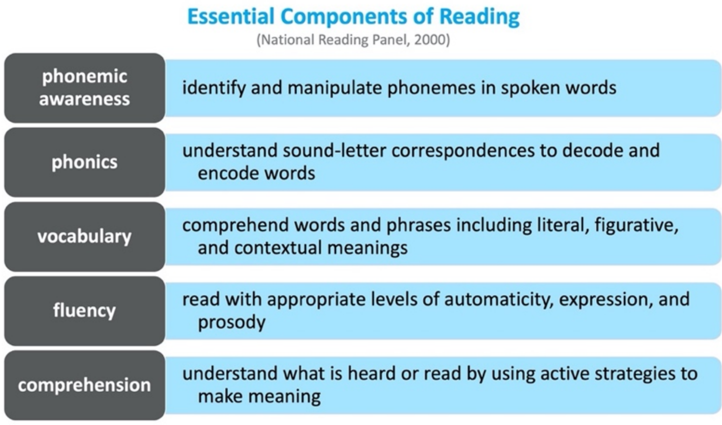

Figure 2: Essential Components of Reading (National Reading Panel, 2000)

Phonics instruction and practice is what many learners and families think of as the first step in early reading (Anderson, 2007). Hearing a young learner recognize letter names and sounds is visible, traditional, and satisfying. Decades of research has established phonemic awareness as a necessary predecessor to phonics success (Juel, C., 1988; Moats, 2014; National Reading Panel, 2000). Before young learners can accurately connect sounds to letters, they must engage deeply with sounds. Grounding pedagogy in evidence-based research protects instructional design from common misconceptions like this one (Hindman, 2020; Moats, 1999 and 2014; Seidenberg, 2013).

Across multiple studies in different contexts, phonemic awareness has emerged as the strongest predictor of later reading success in children both with (Mather, 2012; Clayton, et.al, 2020; Scarborough, 1989) and without (e.g., Anthony & Lonigan, 2004; Clayton, et.al, 2020; Stanovich, 1986) learning disabilities. Direct instruction of phonemic manipulation tasks has been shown to improve students' ability to perform the tasks accurately and automatically, but also prepares them for phonics and orthographic tasks (Kilpatrick, 2015; National Reading Panel, 2000). It is wise, therefore, to invest in research to confirm and refine our understanding of children's capabilities and development in this area and to use that research to design instructional experiences that meet the needs of all learners.

Another common misconception is that early reading skills are easy, and comprehension is hard (Seidenberg, 2013). Because word reading skills become increasingly automatic, they can become hard to observe. Accomplished readers tend to consciously attend to language comprehension skills and strategies. We look to a robust collection of literature to learn that early reading skills, such as phonemic awareness, require systematic and explicit instruction (Moats, 1999, 2014; Yopp & Yopp, 2009). Phonemic manipulation stands out as the most effective way to teach foundational phonological awareness skills (Kilpatrick, 2015; Moats, 2014). Well-crafted phonemic awareness experiences provide learners with practice recognizing and manipulating phonemes in spoken words through identifying rhymes and alliteration, isolating single phonemes, blending phonemes, segmenting phonemes, deleting a phoneme to form a new spoken word, and substituting one phoneme for another.

Tasks should generally be organized from large to small, in terms of sound units, and from simple to complex in terms of manipulation tasks (see Figure 1) and in accordance with the physical and cognitive development of learners. Long-standing theories surrounding phonological awareness development have posited that of all the phonological components, phonemic awareness develops last in the sequence (Anthony, Lonigan, Driscoll, Phillips, and Burgess, 2003; Goswami, 1990). This places phonemic awareness relatively late in the sequence of early childhood instruction, specifically during formal preschool years. Traditionally, learners engage in formal phonemic awareness activities starting in kindergarten or prekindergarten only after receiving instruction in the other phonological awareness tasks. Although there is a large body of empirical evidence to-date regarding the late development of phonemic awareness (e.g., Carroll, et.al, 2003; Liberman, et.al, 1974; Lonigan et al., 1998; Wackerle-Hollman et. al., 2015), recent work by Kenner and colleagues (2017) asserts an alternative theory. It may be that, because traditional phonemic awareness tasks are productive, and not receptive, we may be overlooking the actual phonemic awareness capabilities of very young children. In an innovative study with 2 and 3-year-old children, Kenner and colleagues (2017) found evidence for receptive blending phonemic awareness abilities in children as young as 2.5-years-old with final-phoneme discrimination trials. This alternative theory suggests there are opportunities for meaningful phonemic awareness experiences during the toddler years, prior to preschool instruction.

Playfulness is another key element of phonemic awareness instruction (Griffith & Olson, 1992). Play is central to children's development and learning (Dietze & Kashin, 2011; Hirsh-Pasek, Golinkoff, & Eyer, 2004). Both the nature of the content and the developmental stages of the typical learners shape best play-based practices. Phonemic awareness, and more broadly phonological awareness, requires learners to attend to small changes in sound. Rhythm, movement, song, and repetition can help sounds and changes in sounds stand out (Optiz, 2000; Yopp & Yopp, 2000, 2009). Effective phonemic awareness experiences include singing, chanting, "hunting" for sounds, and manipulating phonemes to create nonsense words. Learners can enjoy the silliness of mixing up a phoneme in their name or satisfaction of predicting the last word of rhyming verse. Such playful experiences provide the mechanisms through which game-based learning occurs (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). Designers of game-based learning have a unique opportunity to leverage play in their designs by fostering meaningful and engaging interactions for children (Hirsh-Pasek et al., 2015; Plass, Homer, & Kinzer, 2015; Rothschild, 2015). This is the core of well-designed environments for teaching and learning (NAEYC, 2012; Kervin, 2016; Lieberman et al., 2009).

Digital games can be used to bring dynamic and individualized phonemic awareness experiences to young learners. Games sustain engagement and motivation by providing interactivity, adaptive challenges, and ongoing feedback (Bransford, Brown, Cocking et al., 2000; Gee, 2003; Shute, 2008; Rupp, Gushta, Mislevy, & Shaffer, 2010). In games, learners are presented with a series of well-ordered problems and receive just-in-time feedback that correspond to each learner's level, effort, and demonstration to support growing mastery (Gee, 2007). Such integrated, formative assessment in games provides useful feedback *during* the learning process, in contrast to a summative assessment conducted at the end of an instruction sequence to evaluate cumulative learning (Shute & Kim, 2014). Formative assessment enables ongoing feedback cycles and customized learner difficulty levels, cultivating long-term engagement and appropriate challenge. Such game elements can further promote perseverance by encouraging children to embrace challenges and use mistakes to learn, making them a perfect mix of desirable difficulties that maximize long-term retention (Kornell & Bjork, 2008)

Additionally, digital games empower instructional designers to gather actionable data by monitoring and measuring learner actions (Lieberman, et al., 2009). Game interactions produce rich performance data, which can include time spent on specific tasks, types of errors made, and responses to in-game feedback and remediation. Frameworks based on evidence-centered design (Mislevy, Almond, & Lucas, 2003) can guide the work of generating evidence about learning from data in game-based learning contexts (Shute, 2011). This enables game events to be interpreted directly in terms of learning objectives and competency types (Shute & Kim, 2014). As children play, the data can be used to make real-time adjustments to the level of difficulty or the types of scaffolds offered the learner. Ongoing adjustments to the game experience and content work to keep learners in their zone of proximal development, the state just beyond their current abilities, and maximize efficiency of learning (Bodrova et al., 2013; Koster, 2014; Vysotsky, 1978). This is an instance in which practice can inform research. Traditional research often relies on averages and patterns across learner populations, while practice (and some forms of action research) focuses on the data of single individuals (Molenaar, 2013; Rose et al, 2013). Digital games and their data collection tools can be used to measure and address learner variability.

Phonemic Awareness Instruction through Digital Game Play

Three of the four authors on this paper are part of the learning design team at Age of Learning, Inc., a producer of digital learning content for young children. Committed to the partnership of science and practice to create digital programs that produce learning outcomes for young children at scale, the learning design teams at Age of Learning employ a cycle of research-informed design and development called "learning engineering." An interdisciplinary team of experts, including learning scientists, instructional designers, curriculum specialists, artists, engineers, and game designers, works together to design, build, test, and refine digital activities based on these research-informed hypotheses.

Learning engineering, originally introduced by Herbert Simon (1967), has recently been formalized as “a process and practice that applies the learning sciences using human-centered engineering design methodologies and data-informed decision making to support learners and their development” (ICICLE, 2019). Figure 3 illustrates Age of Learning’s learning engineering (LE) framework. The LE team applies learning sciences research to inform pedagogy and initial design, and uses design-based research methodologies (Wang & Hannafin, 2005; van den Akker, 1999), evidence-centered design (Mislevy, Almond, & Lucas, 2003), and learning analytics (Baker & Siemens, 2014) to drive learning outcomes.

This research-informed design process begins with defining the scope and hypothesized trajectories of learning objectives, in other words, a sequence made of granular learning goals (Baker & Smit, 2018; Simon, 1995) (see Figure 3). Based on a review of the literature and best practices in instruction, LE team members work in collaboration to develop interactive learning activities designed to help learners achieve the desired learning outcomes. These activities are then tested with children, data are gathered and analyzed, insights are developed, and the learning activity is redesigned, thus beginning the iterative design cycle anew. Research thus informs not only the pedagogy of the initial design (Design Based Research Collective, 2003; Laurel, 2003), but subsequent designs as well.

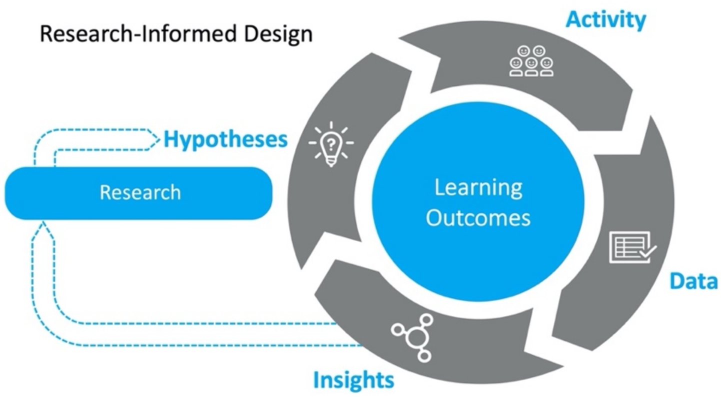

Figure 3: Age of Learning’s learning engineering process

The LE team at Age of Learning used this iterative cycle of research-informed design to create a mastery-based adaptive, digital, game-based reading program called *My Reading Academy*. Grounded in the science of reading and cognitive development research, this program delivers explicit and systematic phonemic awareness and phonics instruction, paired with rich reading and language experiences. *My Reading Academy* includes learning games, reading experiences, and instructional videos (Figure 4).

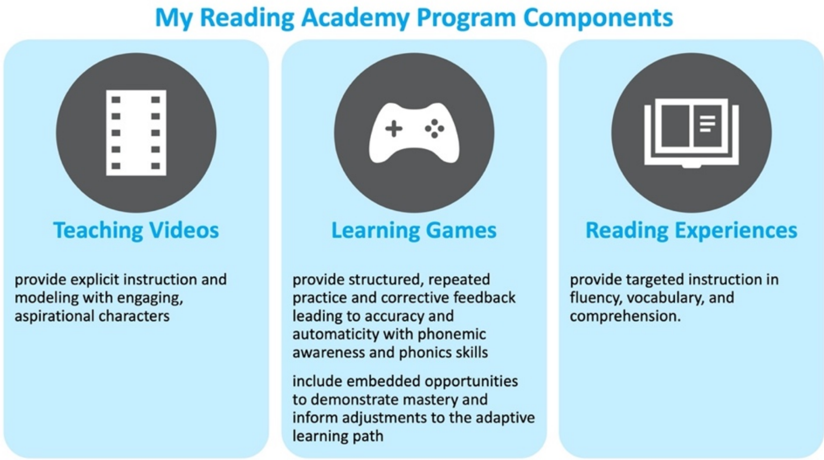

Figure 4: *My Reading Academy* Program Components

Learning outcomes for *My Reading Academy* are expressed in the form of specific learning objectives. Learning objectives are singular units of learning distilled to their most granular level. Each learning objective states something the learner will be able to do or something the learn will know (e.g., Learner understands that spoken words are composed of individual phonemes. Learner can identify a single phoneme within a spoken word.). Creating clear, singular objectives enable curriculum designers to sequence learning effectively and adjust sequencing in response to learner variability (Stavrou & Koutselini, 2016).

In this way, learning trajectories are made adaptive and responsive to the wide-ranging needs of learners as they acquire foundational literacy skills. Hypothetical learning trajectories through the content can be determined based on what the child (1) already knows, (2) needs to learn, and (3) needs to see next in order to keep them in their zone of proximal development (Simon, 1997). The actual learning trajectory for each individual learner is refined dynamically as learner performance is analyzed by the program. A learner who demonstrates the need for additional practice or instruction in predecessor skills, may engage with more instruction content and spend more time addressing each learning objective. A learner that demonstrates mastery will skip activities. Most learners will ebb and flow as different skills are presented. Game-based learning methodologies (Gee, 2007) provide an efficient and engaging way guide them to automaticity and accuracy. In the end, demonstrable mastery is the learning outcome for all.

Once a working prototype of a game activity is available, learning and data scientists define the data to be collected from game play. The game-based learning activities are made available to learners, and their game play data are captured and analyzed. Learning and data scientists use the data to develop new insights about how real-world learners in their varied, specific environments are learning. The resulting findings lead to insights that inform how the interdisciplinary team refines its original hypotheses and continue this cycle again and again, constantly iterating and revising.

As a model of the curriculum design, here we explore one phonemic awareness game in-depth. *Sound Hound* is a set of experiences in which teaching videos and different levels of game play guide learners to achieve the following phonemic awareness learning objectives:

- Learner understands that spoken words are composed of individual phonemes.
- Learner understands that each phoneme in a spoken word has a position within the word (i.e., initial/medial/final).
- Learner can identify a single phoneme within a spoken word (i.e., initial/medial/final).
- Learner can segment a spoken word into its component phonemes.

Sound Hound, and other phonemic awareness games in *My Reading Academy*, include digital manipulatives called *blurts*. These dynamic manipulatives allow learners to visualize phonemes, move them around, and link them together to form words. Blurts have no letters or symbols ensuring a singular focus on sound, not phonics. Figure 5 presents images from a teaching video in which blurts are used to show the sounds in the word *moon* (/'mu:n/).

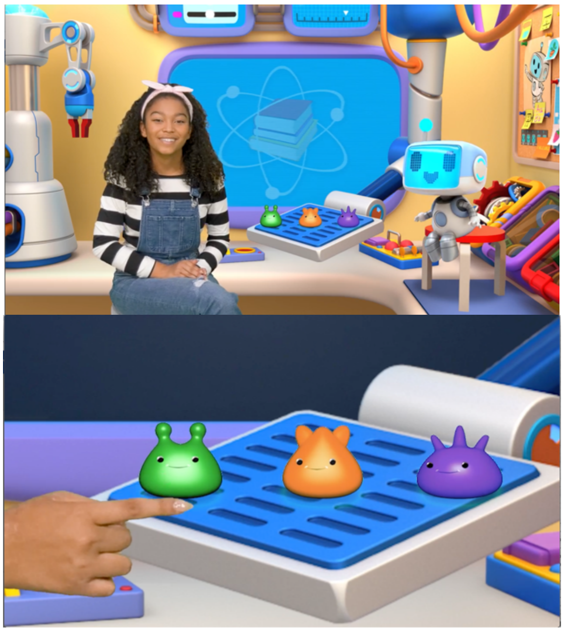

Figure 5: Images of Blurts Used in *Sound Hound* Teaching Video

During the first level of *Sound Hound* game play, learners must first feed the "sound hound" a bone (see Figure 6). A spoken single-syllable word is presented to the learner through voice over, then its onset and rime are pronounced separately. The learner is prompted to listen for the first phoneme in the word and select the blurt that "says" the targeted phoneme. Learners tap each blurt to hear its sound, then choose one to place in the first slot on the sound hound. If the correct blurt is chosen, the learner succeeds and practices with a different word in the next round. If the incorrect blurt is chosen, the blurts playfully gasp and wrong-answer feedback is provided. The word and its onset and rime are repeated with greater emphasis on the first phoneme and the learner is prompted to try again. If another incorrect choice is made, additional support is provided. The word is repeated, both onset and rime are repeated, and then the onset is provided again in isolation. The learner is then guided to tap the correct blurb. The round ends successfully, and data about the learner's correct and/or incorrect choices are collected.

Figure 6: Image of *Sound Hound* Game Play

The next levels of *Sound Hound* require learners to identify the blurt that sounds the final phoneme, then medial phoneme in words presented via voiceover. Later levels require learners to segment out the sounds in a consonant-vowel-consonant word and accurately sequence three blurts to recreate the word. Each round of each level includes two opportunities for support in the form of wrong-answer feedback ensuring that each round ends successfully.

Game play includes embedded opportunities to assess learners' growing skills. Every tap and drag a learner performs is recorded and those data are used to evaluate their developing proficiency and inform adaptivity. Both formative and summative data are needed to create an effective response to learner variability. Learner performance during regular game play provides formative data. It measures learners' immediate responses to the instruction provided in the teaching video and in the heavily scaffolded early levels of the games. Summative data are collected through "boss level" play. In the boss levels of each game, all scaffolds are pulled away and learners are able to show what they can do. Summative data are used to create and constantly adjust the learning trajectory for each learner.

Early Results and Next Steps

My Reading Academy has been available to young learners in various forms for nearly a year. To date over 1.6 million children, majority of them ages 4 – 7, have used the program. Upon entering *My Reading Academy*, learners take a short series of diagnostic pretests that assess their early literacy abilities at a granular skill level to place them appropriately into the system. One of assessed skills is phoneme segmentation. In this pretest, learners hear a recording of spoken word and are shown a picture representation of the word (i.e., "bug"). They are prompted to recreate the word by placing blurts representing each phoneme in order. To pass the pretest, children must correctly sequence the phonemes at least 4 out of the 5 words presented. Most learners have found this pretest difficult; only 20% of those who attempted it passed. Of the 48,788 children who did not perform well on the phonemic segmentation pretest, then progressed through the program to reach the *Sound Hound* phonemic awareness game, a large majority (83%) demonstrated mastery on the *Sound Hound* boss level after median 2.35 hours of practice (Mean = 3 hours, SD = 2.16) in *My Reading Academy* altogether. This is a promising result, suggesting that targeted instruction and adaptive practice with *My Reading Academy* can dramatically accelerate phonemic awareness development in young children.

Demonstrable mastery of key early reading skills is the goal for every learner—the paths to that goal are dynamic and customized for each learner. Figure 7 shows the path of a sample 4.5-year-old from her *My Reading Academy* pretest experience, in which she demonstrated no phoneme segmentation skill, through her demonstration of mastery in boss levels of the *Sound Hound* game. The learner engaged in varied instruction, practice, and levels of scaffolding—phonemic awareness experiences interspersed with other word reading skill experiences and language comprehension skill experiences—for five hours (across 73 activities) prior to demonstrating mastery.

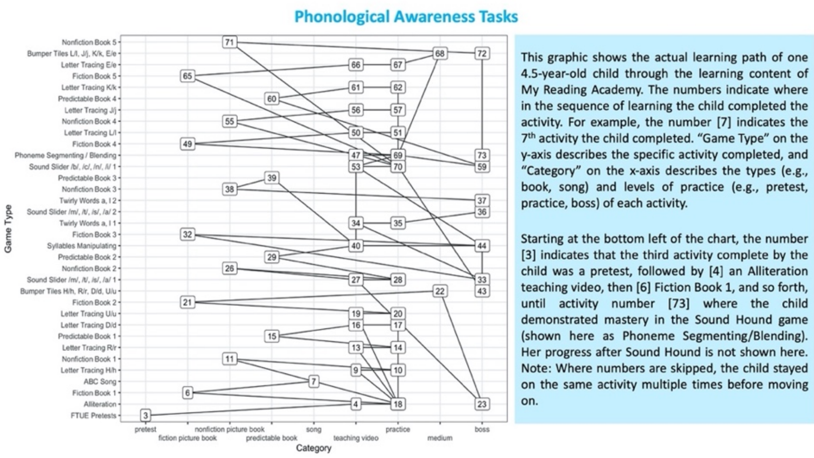

Figure 7: A 4.5-year-old's journey in *My Reading Academy*.

The cycle of research-informed design continues. The learning engineering team at Age of Learning is actively observing the performance and behaviors of learners in-game. Plans for continued research and refinement include several projects rooted in learning analytics and direct interaction with learners, teachers, and families. Research questions include the following:

• What does pretest performance reveal about the phonemic awareness skills of learners across different ages (e.g., a 4-year-old vs. A 6-year-old) as they enter the *My Reading Academy* system?
• How might the pretest sequence, mechanics, or content be adjusted to more accurately measure phonemic awareness skills?
• How might the pretest sequence, mechanics, or content be adjusted to measure receptive phonemic awareness abilities including those of toddlers revealed by the work of Kenner and colleagues (2017)?
• How can My Reading Academy teaching videos and digital game experiences be refined to more efficiently guide learners to demonstrable mastery of phonemic awareness tasks?

Conclusion

Reading is both complex and essential. Effective instruction of key early literacy skills is built upon deep understandings of both learners and content. Research-informed design requires interdisciplinary collaboration, clear learning objectives, and responsiveness.

Interdisciplinary Collaboration: Partnering across the fields of educational research, curriculum, engineering, art, game design, data analytics, and learning sciences, the

Age of Learning, Inc. team builds and tests research-based hypotheses about high-impact learning outcomes. They gather reliable data and respond with a range of tools (instructional changes, changes to game mechanics, artistic changes, etc.).

Clear Learning Objectives: Broad learning outcomes are distilled down very specific learning objectives that describe concepts, principles, skills, and data embedded within a learning, the team built *My Reading Academy* with small, focused activities. These activities are sequenced and customized to create highly differentiated learning trajectories for a variety of learners.

Responsiveness: The cyclical nature of research-informed design is essential. Practitioners must be willing and able to respond to new data gathered from literature or from direct interaction with learners. Hypotheses are constantly corrected, refined, or confirm. This nimble approach results in a product that is increasingly effective for an increasing broad swath of learners.

By bridging the gap between research and practice, practitioners are better equipped to meet the instructional needs of all learners (Seidenberg, 2013, 2018). Through systematic instruction across the elements of reading, including the high-impact skills of phonological awareness and phonemic awareness, young learners can be equipped for long-term success (Moats, 1999; National Reading Panel, 2000). Grounded in the science of reading and informed by the in-game performance of learners, *My Reading Academy* has the potential to provide effective instruction and adaptive learning trajectories to guide young learners to master the essential skills of early literacy at scale.

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