The Research-Based Design of Mosaic™ by ACT®: Adaptive Academic Learning

Nola Daley, Dana Murano, Alex Casillas

About the Authors

Nola Daley, Ph.D.

Nola Daley is a Research Scientist in ACT's Center for Social, Emotional, and Academic Learning. She completed her PhD in Experimental Psychology with a concentration in Cognitive Psychology focusing on student learning. Her research focuses on examining techniques and instructional materials to support effective and efficient student learning.

Dana Murano, Ph.D.

Dana Murano is a Research Scientist in ACT's Center for Social, Emotional, and Academic Learning. She completed her PhD in Educational Psychology with a specialization in Learning, Development, and Instruction. Her research focuses primarily on the development and assessment of social and emotional skills in students.

Alex Casillas, Ph.D.

Alex Casillas is a Principal Research Psychologist in ACT's Center for Social, Emotional, and Academic Learning specializing in assessment design, behavioral predictors of performance and persistence in education and work settings, and implementation of SEL programming. His research increasingly focuses on helping historically underrepresented populations achieve more equitable outcomes in education and at work.

Conclusions

Mosaic™ by ACT®: Adaptive Academic Learning is grounded in best practices gleaned from learning science research. It incorporates tools supported by research on student learning, such as retrieval practice, spacing, interleaving, and knowledge segmentation. This document summarizes how the platform incorporates 10 of these research-based tools and provides a detailed discussion of the research examining each tool. Given the broad range of learners, learning conditions, and outcomes, not all tools are effective in all circumstances. Accordingly, the platform includes the few broadly applicable tools and many context-dependent tools that address the learners, learning conditions, and outcomes targeted by the platform.

So What?

Research on best practices for student learning can inform product design decisions and provide a strong foundation for facilitating effective student learning. A research-based approach is important, but with ever-growing literature on student learning, determining the value of tools for a specific platform is challenging. To evaluate the tools incorporated in the AAL platform, the discussion in this document is organized around three important questions that can help determine the value of a learning tool for a specific platform. These include the extent to which the effects of these tools vary across different student characteristics (e.g., age), learning conditions (e.g., materials), and/or outcomes (e.g., long-term retention).

Now What?

Research and theory provide a strong foundation for the AAL platform, but direct research examining the efficacy of the platform is an important next step. This step is critical because even a strong foundation cannot guarantee effectiveness of the overall platform. Efficacy research also informs further refinement of the platform. Efficacy research for the platform is informed by the platform's theory of action and grounded in ACT's Efficacy Framework (Mattern, 2019). Research questions aligned to this framework are discussed and current and future research efforts are described. By addressing each of these research questions, ACT continues to engage in research and collect efficacy evidence consistent with a sound efficacy argument. Our ultimate goal is to gather supporting efficacy evidence for each of the expected outcomes associated with Mosaic by ACT: Adaptive Academic Learning

Introduction

Problems Adaptive Academic Learning Addresses

The United States has relied on the same main education model over the last 100 years. For students, this one-size-fits-all approach to education may fail to meet their individual needs. With this approach, content that is either too difficult or too easy for the student can lead to suboptimal learning (Metcalfe, 2002). This one-size-fits-all approach also fails to provide students with timely, individualized feedback. Without objective feedback on their performance, students can be misled about their learning progress by cues such as their ability to bring information to mind easily (Griffin, Mielicki, & Wiley, 2019). Indeed, this monitoring process is difficult even for experienced learners, and younger students may have greater difficulty with this task (Prinz, Golke, & Wittwer, 2020). Making effective learning even more difficult, students are not often provided instruction about effective learning strategies (Kornell & Bjork, 2007; Lawson, Vosniadou, Van Deur, Wyra, & Jeffries, 2018). As a result, even students who accurately monitor their learning and determine they need additional practice may not have the knowledge to choose effective learning strategies. Consistent with this possibility, students often rely on ineffective and inefficient tools such as rereading (Blasiman, Dunlosky, & Rawson, 2017). The use of these tools can ultimately lead to lower levels of learning (Thiede, Anderson, & Therriault, 2003). Taken together, students need tools that are appropriately challenging, support accurate monitoring, and use effective learning strategies to support the repeated, intentional practice required for content mastery.

Mosaic™ by ACT®: Adaptive Academic Learning is designed to meet these needs and help students effectively master content. To provide appropriately challenging content, the technology-driven platform provides standards-aligned and individualized content by starting practice with an initial diagnostic testing student knowledge and providing questions during practice to track student learning accurately. Students are also automatically provided instruction when their performance is low near the start of practice. Additional support for students with low performance stems from automatic scaffolding on pre-requisite concepts based on the underlying knowledge map. When students reach mastery for specific concepts, the system advances them to new concepts within their assigned learning paths. To keep students informed about their learning progress, students by default receive immediate feedback during practice and after they complete assessments. As they complete practices, their progress towards weekly goals adjusts accordingly. Further, students have learning profiles that visually show which concepts they have learned. To help students learn efficiently and effectively, the platform incorporates various tools such as retrieval practice, spacing, and interleaving that are supported by research on student learning.

Purpose of this Report

The current report provides a detailed discussion of prior research on tools expected to underlie the target benefits of Mosaic by ACT: Adaptive Academic Learning. To provide context for this discussion, we first outline the platform's overall theory of action for students. This model outlines how students are expected to achieve the targeted learning goals using the platform. In particular, several of the platform's key features are expected to help students achieve these goals, such as differentiated practice, automatic scaffolding and enrichment, and technology-enhanced assessments. After discussing the overall theory of action, we describe how these key features in the platform incorporate various research-based tools. After describing how these tools are incorporated, we provide a detailed discussion of the research examining each tool. Although this discussion highlights the platform's potential benefits to two of the targeted outcomes, research is needed to directly examine the efficacy of the platform on these and other target outcomes. As such, we end by describing the ongoing research efforts on the platform. In particular, several interrelated lines of current and future research aim to test predictions about the platform based on the theory of action to provide evidence of efficacy aligned to ACT's Efficacy Framework.

Mosaic by ACT: Adaptive Academic Learning Theory of Action

The platform's theory of action specifies the expected outcomes associated with using the platform and describes how users are expected to achieve these outcomes by delineating features, uses, and user experiences associated with using the platform. Table A1 in the appendix presents the logic model summarizing the platform's theory of action for students. This model outlines several important features of the platform described by the input column, including differentiated practice, technology-enhanced assessments, automatic scaffolding and enrichment, standard and textbook alignment, and accessibility. Taken together, these features are expected to allow students to learn flexibly anywhere, anytime from individualized content that is relevant and accessible while staying engaged and monitoring their learning progress. These processes are summarized in the activity column. Students are expected to perceive these experiences as engaging and helpful for increasing their knowledge and tracking their learning progress. These perceptions are summarized in the user experience column. In turn, students are expected to demonstrate measurable changes to their knowledge, behaviors, and skills, as summarized by the outcome column. These outcomes are divided into three categories based on the time required (i.e., short-term < 1 year of use; medium-term 1–3 years following use; long-term 3 or more years following use). Short-term outcomes include the right resource for every learner, increased student engagement with content, and support for target learning outcomes. Medium-term outcomes include greater academic achievement in middle school, lower remediation, and higher digital literacy. Long-term outcomes include a more successful transition to high school, increased high school retention, and increased academic achievement in high school.

In the current document, we focus on how tools supported by research on student learning are incorporated in several of the key features outlined in the platform's theory of action. This research supports the platform's potential benefits on two of the targeted learning outcomes for students: support for learning outcomes and greater academic achievement in middle school. These are two of the short- and medium-term benefits expected to follow from using the platform directly. In addition, although the platform only targets content in grades K–8, benefits to these shorter-term outcomes are expected to underlie benefits to target long-term outcomes for students in high school. For instance, prior research shows that academic achievement in middle school is associated with a more successful transition to high school. Specifically, better middle school grades predict early high school grades (Casillas et al., 2012; McKee & Caldarella, 2016). Further, performance on standardized math tests in middle school predicts grades in 9th grade (McKee & Caldarella, 2016). Research also shows that both greater academic achievement in middle school and a more successful transition to high school are related to a lower likelihood of dropping out of high school, increasing the likelihood of high school retention (Rumberger & Lim, 2008; Kennelly & Monrad, 2007). These relationships underscore the importance of the two outcomes of focus in the current document: academic achievement in middle school and support for target learning outcomes. For a discussion of the research support for the platform's potential benefits to all student outcomes and the outcomes specified for educators and administrators, please see "Mosaic™ by ACT®: Adaptive Academic Learning Theory of Action."

Overview of Features in Mosaic by ACT: Adaptive Academic Learning

Differentiated Practice and Automatic Scaffolding

Differentiated practice in the platform starts with an initial diagnostic test and then continues with adaptive practice. Students start with a placement test that measures their knowledge of the independent concepts from their assigned learning path. If students demonstrate an understanding of a concept, that concept is labeled mastery-check ready and skipped during practice. This process allows for practice focused on what the student still needs to learn. Following this test, students continue with the adaptive practice, which uses an adaptive engine that supports blended learning models of instruction regardless of the core ELA and mathematics curriculum. This adaptive engine tailors learning paths to each student, adjusting with each problem they solve. Adapting the content that students see based on their performance on the placement test and during practice are two of the ways the platform incorporates differentiated instruction, one of the tools supported by research on student learning described further below (e.g., Deunk, Smale-Jacobse, de Boer, Doolaard, & Bosker, 2018; Smale-Jacobse, Meijer, Helms-Lorenz, & Maulana, 2019).

After students attempt to solve a problem, they receive immediate feedback telling them if they answered correctly by default. This feedback involves encouraging messages that praise student effort and persistence, which is one way the platform incorporates growth-mindset interventions. Both feedback and growth-mindset interventions are tools with substantial research support, as detailed below (e.g., Hattie & Timperley, 2007; Wisniewski, Zierer, & Hattie, 2020; Yeager et al., 2019).

During this practice, the system automatically populates bite-sized instructional videos when student performance is low. Students can also choose to watch these instructional videos on demand when needed during practice. These short videos typically involve narration or text and pictures, diagrams, or other visual content. Presenting only a small amount of content in each video through both words and images incorporates knowledge segmentation and dual coding. Both knowledge segmentation and dual coding are tools with substantial research support, as detailed below (e.g., Guo, Zhan, Wright, & McTigue, 2020; Rey et al., 2019).

The platform offers at least 20 unique practice problems per concept. The adaptive practice mixes questions from different concepts the student is currently assigned instead of having them complete all questions for a single concept before moving to answer the next concept. Students also answer questions on the same concept across multiple practice assignments if they have yet to reach proficiency. Mixing questions from different concepts during each practice, prompting students to answer practice questions about concepts, and repeated practice of the same concepts across practices are some of the ways the platform incorporates interleaving, retrieval practice, and spacing, respectively. All three of these are tools with substantial or robust research support, as detailed below (e.g., Adesope, Trevisan, & Sundararajan, 2017; Brunmair & Richter, 2019; Carpenter, Cepeda, Rohrer, Kang, & Pashler, 2012; Pan & Rickard, 2018; Wiseheart et al., 2019).

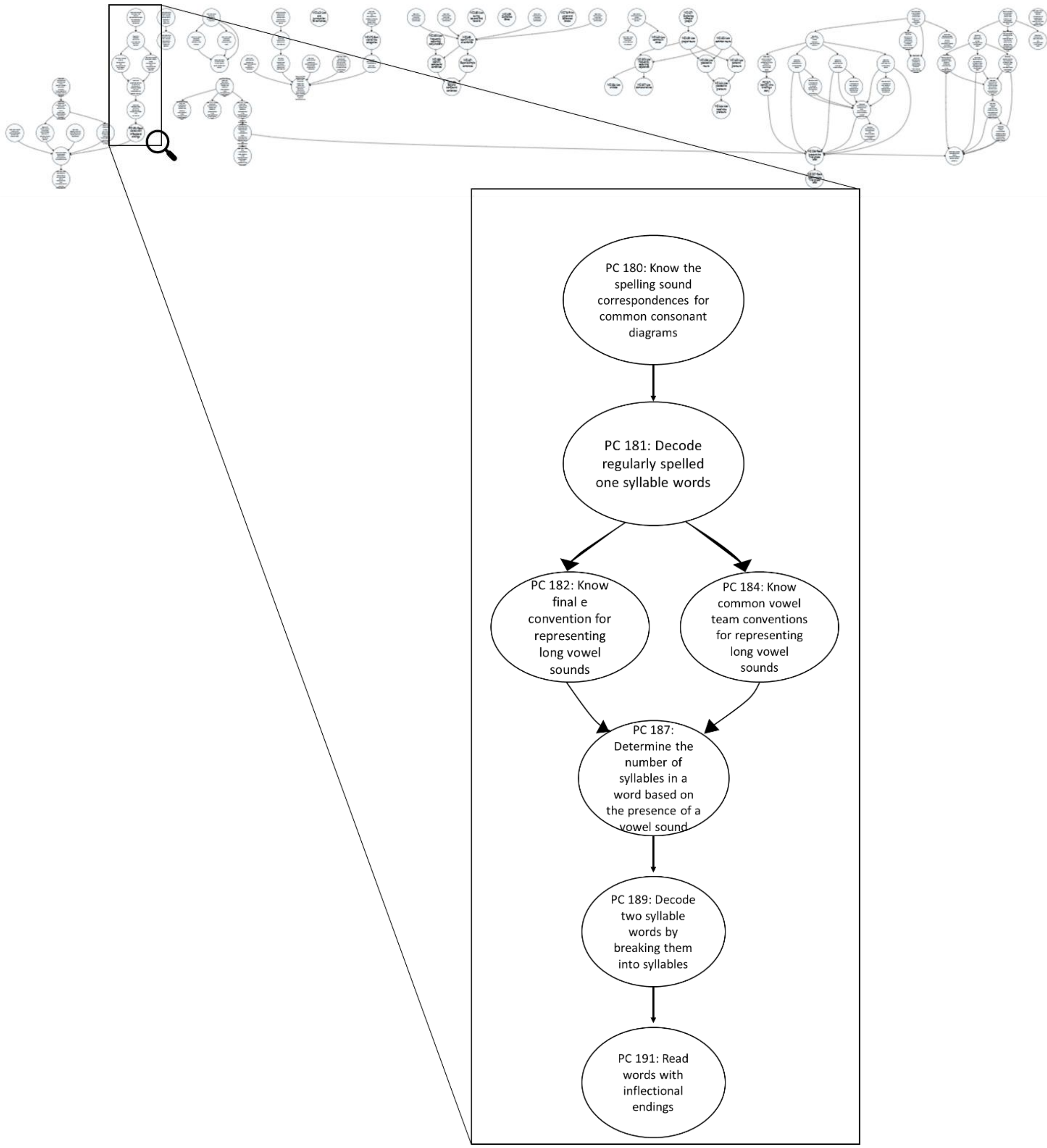
If students incorrectly answer practice problems about a concept near the beginning of practice, they will automatically receive an instructional video (i.e., just-in-time lesson). Based on low performance, an additional support that students can receive is scaffolding. Scaffolding occurs automatically during practice and involves practice on prerequisite concepts at or below the grade level of the target concept. Once they demonstrate knowledge of the prerequisite concepts, they can resume practice on the original concepts. Providing practice on prerequisite concepts at or below grade level is one way the platform incorporates computer-based scaffolding, a tool with substantial research support described below (e.g., Belland, Walker, Kim, & Lefler, 2017).

This overall approach to the platform's learning process, including continued practice until students reach mastery and automatic scaffolding and enrichment, are consistent with Bloom's (1984) mastery-based, one-on-one tutoring approach. The platform's differentiated practice approach is also consistent with Keller's Personalized System of Instruction which involves several important components. These components include materials that allow for student control over the learning process, meaningful units of content, self-paced instruction, unit mastery, and proctors to certify mastery (Keller, 1968; Kulik, Kulik, & Cohen, 1979).

The platform aims to ensure this learning experience is available to all students. Accordingly, the platform currently supports most Universal Design for Learning (UDL) guidelines (CAST, 2018). These guidelines are based on research on learning and aim to ensure that all learners can access learning opportunities that are appropriately challenging and meaningful. For those interested in specific details about the extent to which the platform currently meets UDL guidelines, please see Tables A2-A4 in the appendix.

Foundational Knowledge Map

Figure 1. Depiction of the ELA Knowledge Map (Top) and a Portion of that Map (Bottom) in Mosaic by ACT: Adaptive Academic Learning



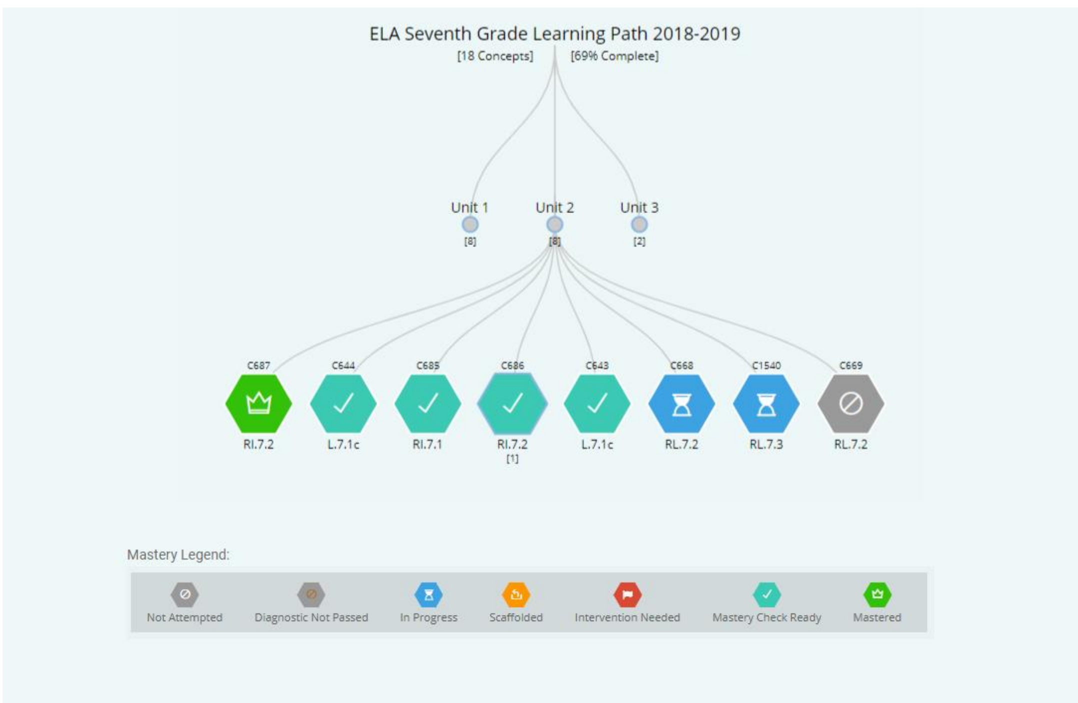
Differentiated practice and automatic scaffolding in the platform rely on a foundational knowledge map. This map organizes relationships between concepts to provide students with an appropriate sequence of instruction. For a depiction of a subset of this knowledge map, see Figure 1. The knowledge map was created by breaking each standard down into a set of specific concepts. For example, the 5th grade Common Core-aligned learning path covers the standard 5.G.B.4, which states, “Classify two-dimensional figures in a hierarchy based on properties.” This standard is broken down into three more specific concepts that specify a specific two-dimensional figure (e.g., “Classify triangles in a hierarchy based on properties”).

Individual concepts such as these are represented as nodes in the knowledge map linked together based on their relationships to other concepts. For instance, prerequisite concepts are linked to more advanced concepts.

The knowledge map that results from linking these concepts provides comprehensive and rigorous coverage of each standard. The platform offers ready-made learning paths based on this knowledge map that educators and administrators can assign to students.

Technology-Enhanced Assessment and Student Learning Profiles

Figure 2. A Depiction of the Student Learning Profile in Mosaic by ACT: Adaptive Academic Learning



Notes: Figure and data can be found: ACT. (2021). Real students, real remediation. Retrieved from https://www.scootpad.com/platform/how-it-works.

As students complete a minimum number of questions and demonstrate proficiency for concepts during practice, that concept is labeled mastery-check ready. Concepts labeled mastery-check ready are automatically tested with technology-enhanced assessments at least one day later to assess students' delayed retention. Following these assessments, students receive feedback on their overall performance and their performance for each question. They are also told the correct answers for each of the questions. Revisiting the same concept with new practice questions on the delayed mastery check and providing information on performance are additional ways the platform incorporates spaced study, retrieval practice, and feedback (e.g., Adesope et al., 2017; Carpenter et al., 2012; Hattie & Timperley, 2007; Pan & Rickard, 2018; Wiseheart et al., 2019; Wisniewski et al., 2020).

Once students demonstrate knowledge on this mastery check, students advance to more complex concepts within the learning path. Having students reach a certain level of proficiency on a concept before advancing to new concepts is one way the platform incorporates mastery learning. Mastery learning is a tool with substantial research support, as described in detail below (Batdi, 2019).

Following the technology-enhanced assessment, the platform automatically creates student learning profiles for each student. These learning profiles offer a graphic depiction of student progress that updates as students complete assignments and are based on data from multiple sources, including performance during practice, placement tests, interventions, and mastery checks. For a depiction of one of the views in a student learning profile, see Figure 2. As this Figure shows, students can see each concept's status, such as "in need of intervention" or "mastery check ready." In the additional views, students can also see the percentage of each unit completed, their score on each concept, the timeline of their progress, and results from placement tests. These views can help students and teachers differentiate what students know versus what they have left to learn. Additionally, the graphic representation offers a way to visualize progress. Providing students with updated information on their learning progress may support student learning, given that students often have difficulty monitoring their learning (Griffin et al., 2019). Accurate information about their learning progress may support more optimal study decisions and, ultimately, greater student achievement (Thiede et al., 2003).

Research on the Tools Incorporated by the Platform

Now that we have discussed how various tools are incorporated into the platform's features, we turn to a discussion of the research that has demonstrated the benefits of these tools on student learning. The use of tools supported by research on student learning is an important aspect of designing digital-learning platforms because they can inform many specific design decisions. For example, an instructional designer may have to decide on the sequence of instruction when teaching students how to find the volume of various shapes. On one hand, they can mix various shapes during practice. Alternatively, they can focus on one shape exclusively and then move on to the next. If they rely on student input, they would likely opt for the second option because it requires less effort and can lead to greater performance initially. However, research on interleaving shows that the first order is more beneficial for long-term learning (Brunmair, & Richter, 2019). As this example shows, those designing educational platforms and products should aim to use tools that have been demonstrated as effective for student learning versus relying on their intuition or even the students' intuition. Specific research-based tools provide a strong foundation for facilitating effective student learning.

A research-based approach is important, but with ever-growing literature on student learning, determining the value of tools for a specific platform is challenging. To decide on the potential value of a tool, three questions are helpful.

- First, which learners benefit from the tool? To what extent do the benefits of the tool depend on specific student characteristics? Regarding student characteristics, students come into learning situations with certain levels of background knowledge, certain abilities (e.g., working memory capacity, verbal and spatial ability), and different family circumstances (e.g., lower or higher socioeconomic status). These differences across students can influence which tools support learning most effectively.
- Second, what learning conditions lead to benefits of the tool? To what extent do the tool's benefits depend on the topic of the materials and different instructional approaches? Regarding learning conditions, students learn a variety of materials in school across different subjects (e.g., math, ELA), topics (e.g., geometry, present progressive verbs), and instructional approaches (e.g., problem-based instruction). These materials differ in complexity and structure, and these differences may lead to differential effects of certain tools.
- Third, what outcomes benefit from the tool? To what extent do the tool's benefits depend on the learning goal or goals? Regarding outcomes, students have varied learning goals and objectives, including remembering the specific content presented (i.e., retention) and applying content learned in new contexts (i.e., transfer). Given the variety of outcomes, some tools may be better suited for certain outcomes versus others.

These questions help determine if a tool is broadly generalizable or if benefits are context specific. Given the broad range of learners, learning conditions, and outcomes, most tools are not effective in all circumstances. Indeed, the platform incorporates arguably two of the most robust tools Identified by learning scientists: spacing and retrieval practice (e.g., Adesope et al., 2017; Carpenter et al., 2012; Pan & Rickard, 2018; Wisniewski et al., 2020). Many more tools are effective in specific circumstances. These tools are valuable to incorporate in a solution if they are effective for the students, learning conditions, and/or outcomes targeted. Additionally, in some cases, a tool has not been explicitly tested regarding the specific context targeted by a solution. These tools are still valuable to implement if research shows that the tool is generally beneficial.

To that end, the platform implements a full set of tools backed by learning science, including generalized and context-dependent tools that address the variety of challenges students face during learning. Table 1 provides a brief description of each learning tool and a relevant example from the platform. In addition to these examples, two examples of each tool are described below to provide greater coverage of the various ways the platform implements each tool. These examples are meant to be more specific than the general discussion above regarding how the tools are implemented. The table also gives a brief description of why each tool is important to students by delineating learning outcomes supported in the research literature. This list of outcomes is not meant to be comprehensive but instead focuses on outcomes most supported by prior research. In the written description below, information about the research bases for each of these conclusions and citations are provided. Each study cited either presents a comprehensive review, nationally representative study, or a recent meta-analysis summarizing the results of many individual studies.

The last column in the table provides a star rating of the research on each tool. These ratings are broadly consistent with previously established criteria used to evaluate various learning tools (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013). To earn a full three stars, the tool must be supported by a large body of research that consistently shows effects across various learner characteristics and learning conditions. To earn two stars, the tool must be supported by a substantial body of research that shows effects under certain conditions. To earn a single star, the tool must be supported by limited research that does not demonstrate effects consistently. Finally, the last line in the legend shows no stars. To earn no stars, the tool must be lacking any research basis. As the table below shows, the platform only incorporates tools with substantial research support that earned either a two- or three-star rating.

Importantly, these are general ratings regarding the amount of research support for each tool and the extent to which each tool is broadly applicable across materials and student characteristics. These star ratings are not meant to denote the extent to which each tool is effective for the specific learners, materials, and outcomes targeted by the platform. These ratings were primarily based on meta-analyses summarizing the results of many individual studies as cited below. All the meta-analyses cited below were published in 2017 or more recently, with most studies published in 2019 or 2020. Further, we conducted a forward search of all of these studies to confirm these are the most recent meta-analyses on each tool. As such, these studies provide the most comprehensive and current information about each of the tools discussed. In some cases, recent meta-analyses were unavailable for a tool, or recent nationally representative studies and comprehensive reviews provided important evidence regarding a tool. In these cases, we opted to include comprehensive summaries and nationally representative studies that provided more updated information than a meta-analysis or provided supplemental information to a recent meta-analysis cited.

Given that these star ratings are primarily based on reviews (quantitative and sometimes narrative) of research for each tool, these reviews' limitations also apply to these ratings. For instance, these studies did not conduct moderator analyses for variables relevant to this discussion in some cases. In those cases, we note that more research is needed on this topic. Additionally, we report effect sizes for relevant comparisons and outcomes here as reported in the original articles cited. When specific values were omitted in the original report, we describe the direction of the effect. When the original articles reported effect sizes, we include this numerical value but refrain from interpreting these values based on conventional benchmarks in keeping with recent recommendations (Kraft, 2019). We also refrain from comparing these tools based on the reported effect sizes in keeping with recent recommendations (Simpson, 2019). Finally, we start with early empirical studies of each tool to provide context for the research on each tool, but these studies' results did not influence the star ratings reported.

Table 1. Learning Tools Incorporated in Adaptive Academic Learning

Tool	Description	Mosaic by ACT Example	Why does it matter?	Research support
Retrieval Practice	A student brings target information to mind from their long-term memory	After an instructional video, students are asked, "What are the four parts of stories you should always compare?" and the video pauses for the student to answer. It then provides the correct answer.	• Enhances long-term retention • Enhances transfer of content to new contexts	★★★
Spacing	Revisiting the same concept after a delay versus immediately	The platform asks practice questions about evaluating claims in an informational text in an initial practice and then revisits this concept in subsequent practice.	• Enhances long-term retention • Supports a broad range of knowledge and skills	★★★
Interleaving	A schedule of practice that mixes different types of materials during a single learning session	A student switches between subtracting fractions, graphing pairs on a coordinate plane, and explaining patterns when using powers of 10.	• Supports problem solving at short and long delays • Supports transfer of items from learned categories	★★
Knowledge Segmentation	Instruction is presented in learner-paced segments versus presented without pauses	A student practices using graphs to analyze the relationship between dependent and independent variables then writing equations to express a dependent variable in terms of an independent variable instead of practicing all concepts related to each 6th-grade math standard at once.	• Enhances transfer of content to new contexts • Can support short-term retention and reduce cognitive load	★★
Dual Coding	Content presented via text and relevant visuals versus text alone	An instructional video on summarizing stories presents a verbal explanation and organization chart.	• Supports reading comprehension • Supports problem solving	★★
Mastery Learning	Students must reach proficiency on a concept	Before a student learns to multiply side lengths to find area, they must first learn how to count unit squares to find area and also use tiling to find area.	• Supports academic success and achievement	★★

	before moving to the next concept		• Increases retention and supports positive attitudes	
Computer-Based Scaffolding	A gradual decrease in computer-based instructional support as students gain new skills and knowledge	The platform assigns how to determine the meaning of figurative language used in a literary text. Through the student's responses, it is evident the student does not have the knowledge to move on at this level. The platform determines that a student does not have the knowledge to determine the meaning of figurative language.	• Supports retention • Supports problem solving for new and practiced problems	★★
Growth Mindset	The belief that abilities can grow with effort versus that they are unchangeable	A student sees the growth mindset quotes on their front page, "Life isn't perfect. Any failures you have are actually learning moments. They teach us how to grow and evolve."	• Greater likelihood of taking rigorous math courses • Supports a broad range of academic achievement areas	★★
Differentiated Instruction	Adapting learning activities to meet students' individual needs	Learning paths in the platform adjust the amount of time spent on content and amount of support given based on performance.	• Supports academic achievement of primary and secondary students	★★
Tech-Enhanced Practice with Feedback	Students answer questions of various formats and receive immediate automatic feedback during practice	A student is asked to graph a line and a transformation of that line. After plotting their answer, they are immediately told if their answer was correct.	• Supports student achievement, positive behavior, and can support motivation • Enhances transfer of content to new contexts	★★

Notes: Table originally published in: ACT. (2020). The science behind Mosaic by ACT: The science driving ACT's powerful personalized mastery learning platform. Iowa City, IA: ACT. Retrieved from https://success.act.org/s/article/The-Science-Behind-Mosaic-by-ACT-Adaptive-Academic-Learning-White-Paper

Retrieval Practice

What is retrieval practice?

Roediger and Karpicke (2006) conducted an influential study on retrieval practice. In this study, students read two passages. After reading each passage, students reviewed the passage either once (experiment 1) or three times (experiment 2). In the restudy condition, students studied the passage again. In the retrieval practice condition, students tried to recall as much of the content as possible for the same amount of time. Across two experiments, performance on delayed memory tests was greater when students used retrieval practice versus restudy. In this and other studies, retrieval practice can be defined as a tool that involves a student bringing target information to mind from their long-term memory.

Which learners benefit from retrieval practice?

A recent meta-analysis involving 15,427 students found positive effects of retrieval practice for students from first grade through postsecondary (grades 1–6: Hedge's *g*[1] = .64; grades 7–12: *g* = .83; postsecondary: *g* = .60; Adesope et al., 2017). Similarly, a recent meta-analysis focused on classroom studies involving 48,478 students found positive effects in elementary school through college (elementary: *g* = .33; middle: *g* = .60; high *g* = .66; college: *g* = .49; Yang, Lou, Yu, Vadillo, & Shanks, 2021).

What learning conditions lead to benefits of retrieval practice?

A recent meta-analysis found consistent positive effects of retrieval practice across a variety of comparisons. Importantly, the authors found positive effects of retrieval practice in both studies conducted in laboratories (*g* = .62) and the classroom (*g* = .67; Adesope et al., 2017). Similarly, a positive overall effect was found in a recent meta-analysis restricted to studies conducted in classrooms (*g* = .50; Yang et al., 2021). Additionally, effects were shown both when feedback was provided during practice and when feedback was absent in two recent meta-analyses (Adesope et al., 2017; Yang et al., 2021) with larger effects found when feedback was provided in the analysis focused on classroom studies specifically (Yang et al., 2021). Further, effects of retrieval practice were present across a variety of practice and final test formats including free recall (practice test: *g* = .62; final test: *g* = .71), cued-recall (practice test: *g* = .58; final test: *g* = .62), multiple-choice (practice test: *g* = .70; final test: *g* = .56), short-answer (practice test: *g* = .48; final test: *g* = .67) and mixed formats (practice test: *g* = .80; final test: *g* = .78; Adesope et al., 2017, for similar results see Yang et al., 2021).

What outcomes benefit from retrieval practice?

In recent meta-analyses, retrieval practice had positive effects on retention and transfer. Across 243 comparisons, retention performance was greater for those who used retrieval practice versus various

[1] Hedges g is an effect size metric, and values can be interpreted in the same manner as the Cohen's d metric, but the computation applies a correction for small sample sizes.

control conditions (*g* = .63, Adesope et al., 2017). Additionally, across 192 comparisons, performance on transfer tests was greater for those who used retrieval practice versus a variety of control conditions (Cohen's *d* = .40; Pan & Rickard, 2018). Based on the research reviewed here, we assigned retrieval practice a full three-star rating.

How is retrieval practice implemented in the platform?

As one example of retrieval practice, a 6th-grade student is assigned to the Common Core-aligned learning path. They receive instruction on analogies. During the instruction, a video provides several examples of analogies, including "cold is to hot as wet is to dry" and "flamingo is to bird as grizzly is to bear." Later in the video, the student is asked to recall the relationships from the previously described analogies. The student recalls that cold is the opposite of hot, the same way wet is the opposite of dry, and that flamingos are a type of bird the same way as a grizzly is a type of bear. Another example of how the platform implements retrieval practice can be seen in math instruction. For instance, a 7th-grade student in Indiana is assigned to a learning path mapped to the state standards. She is learning about absolute values and how far numbers are from zero on a number line. Afterward, she completes the following practice question: "Which of these values is located five units left of zero on a number line? Use absolute value to determine the answer." She selects -5, remembering that distance is a measurement that tells you how far you've gone from one point to another and that five places from 0 on the left of a number line is -5.

Spacing

What is spacing?

The earliest known research on spacing was conducted by Ebbinghaus (1964; originally published in 1885). He examined how the timing of learning sessions affected the time it took him to relearn a set of simple verbal materials. He found relearning was faster when he spaced practice of the materials over multiple days versus completed all practice sessions in a single day. In this and other studies, spacing can be defined as revisiting the same content on two or more occasions that are separated in time versus spending the same amount of time studying the material in a single session.

Which learners benefit from spacing?

Recent reviews indicate effects of spacing have been demonstrated with learners from preschool through adulthood (Carpenter et al., 2012; Wiseheart et al., 2019). Additionally, a recent meta-analysis examined research on spaced retrieval practice, which involves the combination of retrieval practice (as described above) and spacing. In preschool through college aged-students, a positive effect of spaced retrieval practice was found in comparison to massed retrieval practice (adjusted effect *g* = .74 across 39 comparisons; Latimier, Peyre, & Ramus, 2021).

What learning conditions lead to benefits of spacing?

A recent review indicates spacing has positive effects on a broad range of materials, including verbal materials such as word recall, fact learning, second language learning, and text comprehension. In addition, spacing has a positive effect on learning in math, science, and literacy. Finally, spacing has a positive effect on motor skill learning (Wiseheart et al., 2019). Consistent with results from these reviews, a meta-analysis focused on spaced retrieval practice found positive effects for materials involving pairs (e.g., face-name or translated words) and other materials such as math problems and prose passages (Latimier et al., 2021).

What outcomes benefit from spacing?

This comprehensive review summarized effects across studies of spacing and noted effects of spacing on a broad range of knowledge and skills and long-term retention (Wiseheart et al., 2019). In particular, the estimated effects for those who used spacing over massed practice were as follows: verbal skills (d = .85), intellectual skills such as math and science (d = .50), motor skill learning (d = .50), and social and emotional skills (d = .20). Additionally, a recent meta-analysis focused on spaced retrieval practice found positive effects across various retention intervals (Latimier et al., 2021). Based on the research reviewed here, we assigned spacing a full three-star rating.

How is spacing implemented in the platform?

As one example of spacing in the platform (specifically, spaced retrieval practice), a 4th-grade student is learning about present progressive verbs. The platform asks practice questions about present progressive verbs in an initial practice and then revisits this concept 48 hours later or more in a subsequent mastery check. As another example, a 7th-grade student learns to determine an author's point of view in instructional texts. The platform provides instruction on determining an author's point of view through initial instruction and then revisits this concept in subsequent practice.

Interleaving

What is interleaving?

Rohrer and Taylor (2007) conducted an early study examining the effects of interleaving on learning with math materials. In their second experiment, students learned to find the volume of four different solids. Students completed four questions for each type of solid. Questions about one type of solid were presented in a row, or questions about different solids were intermixed. Performance on a delayed test of learning was greater for the mixed versus blocked practice. In this and other studies, interleaving can be defined as mixing different concepts during a single learning session versus completing all practice on one concept and then moving to the next concept's practice.

Which learners benefit from interleaving?

A recent meta-analysis examined interleaving and included 8,466 students with mean ages ranging from 9.5 to 37 years old. This study found a strong relationship between the mean age of the study sample and the size of the effect of interleaving. The effect was larger for younger participants. However, more research is needed to draw definitive conclusions about how the effects of interleaving relate to age (Brunmair & Richter, 2019).

What learning conditions lead to benefits of interleaving?

A recent meta-analysis indicates positive effects of interleaving on visual categories, including paintings (g = .67), naturalistic photographs (g = .35), and artificial pictures (g = .31). Positive effects were also found for mathematical tasks (g = .34). In contrast, this analysis failed to find effects on learning from text (g = .21) and found negative effects on word learning (g = -.39; Brunmair & Richter, 2019).

What outcomes benefit from interleaving?

In a recent meta-analysis, interleaving had positive effects on retention, problem-solving, and classification. Across 238 comparisons, performance across these outcomes was greater for interleaved practice versus practice of only one topic during a learning session (g = .42; Brunmair & Richter, 2019). Based on the research reviewed here, we assigned interleaving a two-star rating.

How is interleaving implemented in the platform?

As an example of interleaving in the platform, a student in 6th grade works on an adaptive practice that involves identifying terms in an expression, using rate language in the context of a ratio, and reporting the number of observations in a data set. As another example, a student in 3rd grade works on an adaptive practice that involves using word families when spelling words, describing sequence connections between sentences, and recounting the key details of an informational text.

Knowledge Segmentation

What is knowledge segmentation?

Mayer and Chandler (2001) conducted an early study on knowledge segmentation. In this study, students with low prior knowledge learned about lightning formation from a multimedia presentation involving a narrated animation. Students in their second experiment either watched the full 140-second presentation or watched the same presentation broken into approximately 10-second sections (i.e., segmented group). Students in the segmented group were shown one section at a time and pressed a button to go to the next section. Performance on an immediate short answer test of transfer was greater following two presentations of the segmented versus continuous version. In this and other studies, knowledge segmentation can be defined as breaking down instruction into small units to allow the learner to digest one concept before moving to the next.

Which learners benefit from knowledge segmentation?

A recent meta-analysis including 7,713 participants from a mean age of 9 to 25.5 suggested that the effects of segmenting are greater for those with more prior knowledge (high prior knowledge retention $g = .73$, transfer $g = .51$; low prior knowledge retention $g = -.12$, transfer $g = .17$). However, more research is needed to further examine if the effects of knowledge segmentation depend on age and other student characteristics (Rey et al., 2019).

What learning conditions lead to benefits of knowledge segmentation?

Most studies examining segmenting focus on natural and social sciences, and some focus on mathematics. The extent to which the effects of segmenting generalize to other topics is less clear (Rey et al., 2019).

What outcomes benefit from knowledge segmentation?

In a recent meta-analysis, knowledge segmentation had positive effects on short-term retention, transfer, and cognitive load (Rey et al., 2019). In particular, retention was greater for segmented versus non-segmented presentations ($g = .32$). Additionally, transfer performance was greater for segmented versus non-segmented presentations ($g = .36$). In addition, students felt segmented presentations required less mental effort, as evidenced by lower reported cognitive load for segmented versus non-segmented presentations ($g = .23$). Based on the research reviewed here, we assigned knowledge segmentation a two-star rating.

How is knowledge segmentation implemented in the platform?

As one example of knowledge segmentation in the platform, an 8th-grade student learns how to form and use verb moods. In one practice, the student learns how to form and use verbs in the interrogative mood. In a different practice, the student learns how to form and use verbs in the imperative mood. As another example, a 4th-grade student is learning how to work with measurement. In one practice, the student learns how to express mass measurements in a larger unit in terms of a smaller unit. In a different practice, the student learns how to express distance measurements in a larger unit in terms of a smaller unit.

Dual Coding

What is dual coding?

Mayer (1989) conducted an early study on dual coding. In this study, students with low prior knowledge learned about brake systems from either text alone or this text and a labeled diagram depicting the brake system's main parts. Performance on an immediate short-answer test of transfer was greater for those who did versus did not see the labeled diagram. In this and other studies, dual coding can be defined as presenting content via text and relevant visuals versus text alone (the research literature also refers to this as multimedia learning).

Which learners benefit from dual coding?

A recent meta-analysis examined the effects of dual coding on reading comprehension and included 39 independent effect sizes from experiments involving 2,103 1st grade through high school students. Although effects were found across age groups, they were less pronounced for elementary and secondary students than adults (elementary: g = .27; secondary: g = .23; adults: g = .52; Guo et al., 2020). Similarly, a recent meta-analysis examined the effects of dual coding on problem solving and included 54 independent effect sizes from experiments involving 38,987 primary through college aged students (Hu, Chen, Li, & Huang, 2021). Although education level was not a significant moderator, effects were non-significant for primary school students (g = .18), whereas effects were significant and positive for college students (g = .47) and students of other ages (g = .32).

What learning conditions lead to benefits of dual coding?

A recent meta-analysis by Guo et al., 2021 indicates the effects of dual coding depend on the type of images. Effects of dual coding were smaller for mixed graphics (i.e., a combination of more than one graphic type such as pictures and diagrams, g = .14) compared to pictorial diagrams (g = .63), flow diagrams (g = .63), and pictures (g = .37). Additionally, the type of image was highly correlated with the type of materials, which the study did not explicitly examine (Guo et al., 2020). Similarly, Hu et al., 2021 found both representational pictures which provide concrete illustrations of information in text (g = .24) and organizational pictures that provide a visuospatial representation of information in text such as charts (g = .52) positively impacted response accuracy whereas information pictures that contain details needed to solve problems did not significantly impact response accuracy (g = .12). However, type of image was not a significant moderator overall.

What outcomes benefit from dual coding?

A recent meta-analysis explicitly focused on reading comprehension and found greater performance on this important outcome for presentations involving text and images versus text alone (g = .39, Guo et al., 2020). A recent meta-analysis focused on problem solving found benefits to response accuracy (g = .32) but not response time (g = -.04; Hu et al., 2021). Based on the research reviewed here, we assigned dual coding a two-star rating.

How is dual coding implemented in the platform?

As an example of dual coding in the platform, a student learns to find a cylinder’s volume. They watch a video with the screenshot shown in Figure 3. This screenshot shows the student a diagram of a cylinder and a written text describing how to find the volume. As another example, a student is learning about interpreting personification in context. They watch a video with the screenshot shown in Figure 4. This screenshot shows the student an image and corresponding text example of personification.

Figure 3. A Screenshot from a Lesson in Mosaic by ACT: Adaptive Academic Learning on Finding the Volume of a Cylinder that Uses Dual Coding

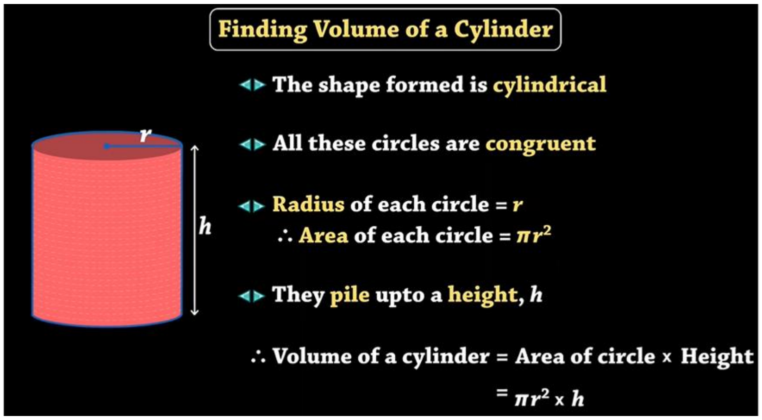


Figure 4. A Screenshot from a Lesson in Mosaic by ACT: Adaptive Academic Learning on Interpreting Personification in Context that Uses Dual Coding

Mastery Learning

What is mastery learning?

Some of the earliest work on mastery learning is described by Bloom (1984). Bloom described research that compared a mastery-based approach to a traditional teaching approach (Bloom, 1984). He reports that the average student performed one standard deviation better with this approach. In this and other studies, mastery learning can be defined as an approach that requires students to reach proficiency on a concept before moving to the next concept.

Which learners benefit from mastery learning?

Although mastery learning may be effective for students of various ages, more research is needed to determine how effects of mastery learning generalize across age (Batdi, 2019).

What learning conditions lead to benefits of mastery learning?

In addition, more research is needed to examine the generalizability across learning conditions (Batdi, 2019).

What outcomes benefit from mastery learning?

In a recent meta-analysis, mastery learning had positive effects on academic achievement, retention, and positive attitudes (Batdi, 2019). Retention was greater for those who used a mastery-learning approach than a traditional approach ($g = 1.46$). Additionally, academic achievement was greater for those who used a mastery-learning approach than a traditional approach ($g = .89$). Finally, attitudes were more positive with a mastery-learning approach than a traditional approach ($g = .72$). Based on the research reviewed here, we assigned mastery learning a two-star rating.

How is mastery learning implemented in the platform?

As one example of mastery learning in the platform, a 3rd-grade student first learns to recognize and generate simple equivalent fractions before explaining why fractions are equivalent. As another example, a 5th-grade student first learns to identify the type of structure used in a text before comparing and contrasting the structure used in two different texts.

Computer-Based Scaffolding

What is computer-based scaffolding?

The term scaffolding was originally used to refer to contingent support from a more capable individual to a less capable individual involving three main components: contingency, intersubjectivity, and transfer of responsibility (Wood, Bruner, & Ross, 1976). In brief, these components mean that the level of support provided is based on students' current abilities, students can recognize their progress, and students can eventually complete the task successfully. An early study on scaffolding using this approach involved a tutor who helped children learn to build three-dimensional figures (Wood et al., 1976). The tutor provided instruction as needed, starting with verbal instruction and then intervening more directly when needed. They also let the child know when they were on the right track and gave them the independence to solve the problems. More recent work has substituted scaffolding via a one-on-one tutor with computer-based scaffolding. Consistent with contingency involved with this original work, computer-based scaffolds provide instruction on prerequisite concepts at or below the grade level of the practiced concept based on gaps identified in student knowledge. Additionally, the platform incorporates intersubjectivity during scaffolding by providing students with feedback on their performance following practice on prerequisite concepts. The platform also incorporates transfer of responsibility by moving students back to the original concept after they reach proficiency on these concepts.

Which learners benefit from computer-based scaffolding?

A recent meta-analysis involving 144 individual studies found effects of scaffolding across the ages examined, including primary school through adulthood (*g*s ranged from .37 to 86). However, they found smaller effects of computer-based scaffolding for students denoted as underperforming (*g* = .28) based on lower levels of prior knowledge compared to traditional students (*g* = .48). In contrast, similar effects of scaffolding were found for students from low-income families (*g* = .51) and for underrepresented students (*g* = .41; Belland et al., 2017). Similarly, a recent meta-analysis focused on scaffolding in higher education, found benefits of scaffolding in online learning environments across 64 comparisons for undergraduate and graduate students (*g* = .87; Doo, Bonk, & Heo, 2020).

What learning conditions lead to benefits of computer-based scaffolding?

More research is needed to determine if the effects of computer-based scaffolding differ based on the type of materials. Some evidence for this stems from a recent meta-analysis focused on scaffolding in higher education. This analysis found that while effect sizes varied by discipline, positive effects were found in the disciplines they examined (communication-related, computing, education; Doo et al., 2020). Still, more work is needed to examine effects across a broader range of disciplines that includes students from lower grade levels. Another recent meta-analysis with a larger sample was conducted, but focused specifically on STEM education (Belland et al., 2017). This study found benefits across different instructional approaches, although effects were somewhat smaller for problem-based instruction in which students are asked to come up with a conceptual solution to a problem before they are given direct instruction (*g* = .27) versus project based where students create an artifact following instruction (*g* = 1.33; Belland et al., 2017).

What outcomes benefit from computer-based scaffolding?

In a recent meta-analysis, computer-based scaffolding had positive effects on retention and problem solving (Belland et al., 2017). Across 125 comparisons, retention performance was greater for those who received computer-based scaffolding versus those who did not receive scaffolds (*g* = .40). Additionally, across 41 comparisons, performance on tests that involved solving new problems was greater for those who receive computer-based scaffolding versus those who did not receive scaffolds (*g* = .44). Additionally, based on a meta-analysis focused on computer-based scaffolding in higher education, while benefits were found across outcomes these benefits were larger for meta-cognitive outcomes (*g* = 1.60) in comparison to affective (*g* = .67) and cognitive outcomes (*g* = .65). Based on the research reviewed here, we assigned computer-based scaffolding a two-star rating.

How is computer-based scaffolding implemented in the platform?

As one example of scaffolding in the platform, a 1st-grade student struggles with learning how to subtract 100 from a given number. The platform automatically scaffolds the student. The student now learns how to subtract ten from a given number, which is a prerequisite concept. As another example, a 7th-grade student struggles with learning to explain how word choice and tone help establish an author’s perspective.

The platform automatically scaffolds the student. The student now learns how to recognize statements and word choices that signal an author's point of view, which is a prerequisite concept.

Growth Mindset

What is a growth mindset?

An early study investigating a growth mindset intervention was conducted by Good, Aronson, and Inzlicht (2003). In this study, students in 7th grade taking a computer class were mentored by college students via email and in-person twice. Students assigned to the growth mindset intervention learned that intelligence is malleable and about how the brain can form new connections from their mentors. Those assigned to the control group learned anti-drug information. Following these interventions, both math and reading standardized test scores were greater following the growth mindset versus anti-drug information. In this and other studies, a growth mindset refers to the belief that abilities can grow with effort as opposed to the belief that abilities are fixed.

Which learners benefit from a growth mindset?

A recent meta-analysis involving 57,155 participants found similar effects of growth mindset interventions for adolescents (d = .08) and adults (d = .08) and across academic risk status (ds ranged from .06 to .17). They did find evidence that the effects of growth-mindset interventions might vary based on socioeconomic status. Effects were larger for those from a lower socioeconomic status (e.g., those qualifying for free or reduced-priced lunch g = .34 compared to middle-class and upper-class students d = .03; Sisk, Burgoyne, Sun, Butler, & Macnamara, 2018).

What learning conditions lead to benefits of a growth mindset?

More research is needed to determine if the effects of growth mindset interventions depend on the course in which interventions are implemented (Sisk et al., 2018).

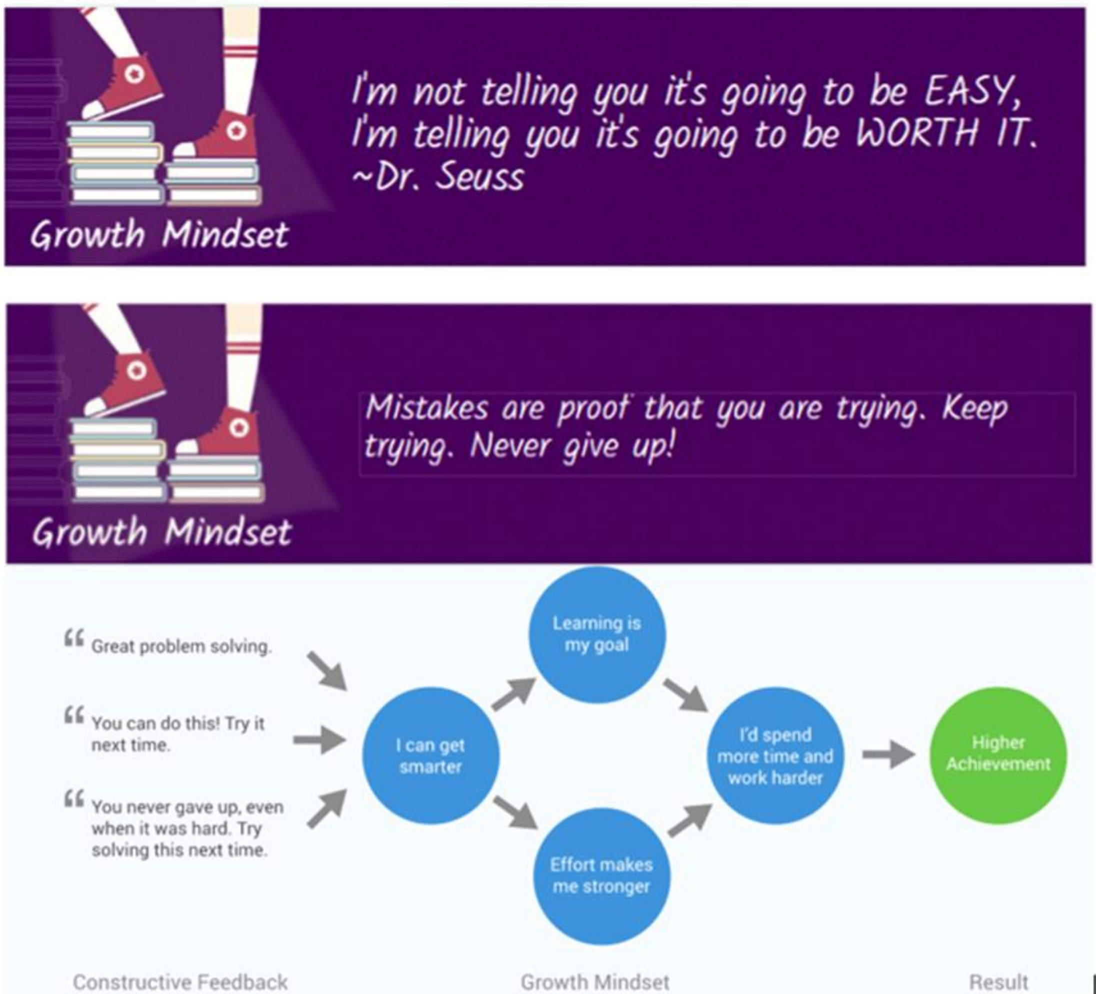
What outcomes benefit from a growth mindset?

Growth mindset interventions have positive effects on academic achievement and may increase the likelihood of taking more rigorous coursework. Regarding academic achievement, a recent meta-analysis summarizing 43 comparisons found greater academic achievement for those who received a growth mindset intervention versus those in the control groups (d= .08, 2019; Sisk et al., 2018). Additionally, a large nationally representative study involving over 12,000 9th graders examined the impact of two 25-minute computer-based growth mindset lessons (Yeager et al.,). For lower-achieving students, they found that GPAs were greater for those who received the intervention versus those in the control group. Additionally, students who received the intervention were more likely to take a challenging math course (i.e., algebra 2 or higher) by three percentage points in 10th grade. Based on the research reviewed here, we assigned growth mindsets a two-star rating.

How are growth mindset interventions implemented in the platform?

Figure 5 shows that the platform incorporates growth mindset interventions in multiple ways. The top two images display growth mindset quotes students would see when they log into the system. For instance, a student might see the quote: “Mistakes are proof that you are trying. Keep trying. Never give up!” In addition, during practice, the platform provides encouraging feedback that emphasizes hard work. For instance, a student may see the message: “You never gave up, even when it was hard!”

Figure 5. Growth Mindset Interventions in Mosaic by ACT: Adaptive Academic Learning



Notes: The top two images show quotes displayed to student and the lower model shows how constructive feedback provided in the platform encourages a growth mindset.

Differentiated Learning

What is differentiated learning?

An influential study on differentiated learning examined the effect of a reading program called SEM-R designed to incorporate differentiated learning (Reis et al., 2011). The program had several key components, including a broad range of differentiated learning experiences and differentiated instruction in weekly teacher conferences, including instruction on specific strategies. They compared this program to a business as usual control group that involved up to five hours of additional whole-group instruction. Despite the additional time spent on whole-group instruction in the control group, benefits of SEM-R were found for reading fluency and comprehension in a subset of the five schools studied. In this and other studies, differentiated learning can be defined as a tool that involves adapting learning activities to meet students' individual needs.

Which learners benefit from differentiated learning?

Differentiated learning affects both primary (Deunk et al., 2018) and secondary students (Smale-Jacobse et al., 2019). Still, some forms of differentiated instruction may be ineffective for low-ability students in primary school, and a recent systematic review with secondary students did not examine differences by student characteristics.

What learning conditions lead to benefits of differentiated learning?

Most studies on differentiated learning for secondary students involve mathematics and science. The extent to which effects generalize to other materials is less clear (Smale-Jacobse et al., 2018).

What outcomes benefit from differentiated learning?

Although differentiated instruction potentially affects several important outcomes, the primary focus in recent reviews is academic achievement (Deunk et al., 2018; Smale-Jacobse et al., 2019). For primary students, based on 21 comparisons, academic achievement was greater for those who received differentiated instruction versus those in control groups (d = .15). For secondary students, based on 15 comparisons, academic achievement was greater for those who received differentiated instruction versus those in control groups (effects ranged from d = .51 to .74). Based on the research reviewed here, we assigned differentiated learning a two-star rating.

How is differentiated learning implemented in the platform?

Learning paths in the platform adjust the amount of time spent on content and the amount of support given based on performance. For instance, a student in 7th grade starts off their math practice with a placement test. They correctly answer questions about the concept described as, "Find all factor pairs for a whole number in the range 1–100." Based on their performance, this concept is marked as mastery check ready and not included in the adaptive practice. As another example, a 5th-grade student is struggling to determine the meaning of figurative language, including metaphors and similes. Based on his performance, the platform provides additional instruction to the student, followed by additional practice questions.

Technology-Enhanced Feedback

What is technology-enhanced feedback?

Several types of feedback have been investigated in previous research. A recent meta-analysis organized these different types of feedback into three categories: reinforcement, corrective feedback, and high-informational feedback (Wisniewski et al., 2020). Reinforcement feedback provides minimal information and instead relies on aversive or pleasant consequences to correct and incorrect answers. Corrective feedback generally involves telling students if their answer was correct and providing students with the correct answer to the question. Finally, high-informational feedback provides the same information as corrective feedback and additional information on monitoring attention or motivation. Roper (1977) conducted an early study examining the effects of feedback in computer-assisted instruction. In this study, students learned about statistics from a computer program and either received corrective feedback providing the correct answer following an answer attempt or received no feedback. On a final post-test, performance was greater following the corrective feedback versus no feedback. In this and other studies, technology-enhanced feedback can be defined as a tool that involves students answering questions of various formats and receiving information about their performance. The platform specifically incorporates corrective feedback.

Which learners benefit from feedback?

More research is needed to determine if the effects of feedback depend on student characteristics (Wisniewski et al., 2020).

What learning conditions lead to benefits of feedback?

Although a recent meta-analysis found effects across various feedback types, the largest effect was found for high-informational feedback (Wisniewski et al., 2020). High-informational feedback provides information on self-regulation, such as information about monitoring attention or motivation (d = .99). Nevertheless, benefits were also found for corrective feedback (d = .46) and reinforcement feedback (d = .24).

What outcomes benefit from feedback?

A recent meta-analysis including 994 comparisons based on primary research included in 24 previous meta-analyses of feedback found effects on student achievement, positive behaviors, and motivation (Wisniewski et al., 2020). Student achievement was greater for those in groups who received feedback versus control groups (d = .55). Additionally, motivation was greater for those in groups who received feedback versus control groups (d = .33). Additionally, behaviors were more positive for those in groups who received feedback versus control groups (d = .48). In addition, a systematic review of research on feedback indicated feedback also supports transfer (Hattie & Timperley, 2007). Based on the research reviewed here, we assigned technology-enhanced feedback a two-star rating.

How are technology-enhanced practice items with feedback implemented in the platform?

As one example of feedback in the platform, a 6th-grade student answers a question that involves constructing a histogram to represent a set of data. The student receives immediate feedback as to whether the histogram was constructed correctly. As another example, a 6th-grade student answers a question that involves highlighting a part of a passage to identify an unsupported claim. The student receives immediate feedback as to whether they highlighted the correct part of the passage.

Summary of the Generalizability of Tools

Table 2 provides an at-a-glance summary of each of the tools and their generalizability. For each of the tools, this table provides a rating in terms of generalizability across the three variables discussed above: learner characteristics, learning conditions, and learning outcomes. These ratings are based on the research cited above, which also provide the basis for the star ratings. Tools rated "generalizable" demonstrate efficacy across a broad range of settings and populations. For instance, retrieval practice is rated generalizable on each variable due to the research reviewed above demonstrating the benefits of this tool across different learners, learning conditions, and outcomes. Tools rated "context dependent" demonstrate evidence of effects under certain circumstances. For instance, interleaving is rated as context dependent for learner characteristics and learning outcomes because Brunmair and Richter (2019) found that the effects of interleaving were larger for younger versus older participants and math and visual categories versus other types of materials. Finally, tools rated "research needed" require additional research to judge the stated variable. For instance, differentiated learning is rated as research needed for learning conditions. Prior research on this tool has focused mostly on math and science and has yet to examine generalizability to other domains (Smale-Jacobse et al., 2018).

Consistent with the star ratings, this table shows that the platform incorporates two widely generalizable learning tools, retrieval practice, and spacing. In addition, the platform incorporates many more context-dependent tools that earned two stars. This combination of empirically supported learning tools provides comprehensive and rigorous coverage of important learning outcomes aimed at helping students achieve their learning goals.

Table 2. Generalizability of Learning Tools Regarding Implementation Characteristics, Student Characteristics, and Learning Outcomes

	Student Characteristics	Learning conditions	Outcomes
Retrieval Practice	G	G	G
Spacing	G	G	G
Interleaving	C	C	G
Knowledge Segmentation	C	R	C
Dual Coding	C	R	R
Mastery Learning	R	R	G
Computer-Based Scaffolding	C	R	C
Growth Mindset	C	R	G
Differentiated Learning	R	R	C
Tech-Enhanced Practice with Feedback	R	R	G

Notes: A rating of (G) stands for generalizable and indicates the available evidence demonstrates the generalizability of this tool regarding the variable under consideration. A rating of (C) stands for context dependent and indicates the available evidence demonstrates effects under certain circumstances. A rating of (R) stands for research needed and indicates more research is needed to inform a judgement regarding the stated variable.

Future Research Directions

Importance of Continuous Research

As detailed above, Mosaic by ACT: Adaptive Academic Learning is supported by a strong foundation of learning science evidence. However, supporting student learning effectively must go beyond the initial design. Once a product is built, testing the actual efficacy of the solution becomes an important next step. This step is critical because even a strong foundation cannot guarantee effectiveness for various reasons, including differences in the environments, the interactive effects of various tools, and the fidelity of implementation. To that end, current and future research efforts are aimed at testing the efficacy of the platform grounded in ACT's Efficacy Framework (Mattern, 2019).

ACT Efficacy Framework

ACT's Efficacy Framework (Mattern, 2019) grounds all present and future efficacy research. As defined by this framework, efficacy is the degree to which evidence supports the claim that a learning tool such as the platform improves intended learning outcomes. The intended outcomes are specified by the theory of action, such as increased academic achievement. In the current paper, we describe research support for the platform's possible benefits on two expected outcomes for students, including support for target learning outcomes and increased academic achievement. In addition to these outcomes, the theory of action specifies other expected outcomes for students. For instance, the platform is expected to increase student engagement due to features such as the coins that students earn as they complete practices.

To test the extent to which the platform improves these intended learning outcomes, the efficacy framework specifies seven sources of efficacy data. These include evidence based on user experience, content, personalization, learning, use and implementation, relationships to other variables, and results/impact. These sources of evidence are aligned to Kirkpatrick's evaluation model. Table 3 defines each of the seven sources of efficacy data and related research questions regarding Mosaic by ACT: Adaptive Academic Learning. Our ultimate goal is to conduct efficacy studies addressing each of these research questions, resulting in supporting efficacy evidence for each expected outcome and a sound efficacy argument for Mosaic by ACT: Adaptive Academic Learning. In addition to testing efficacy, examining these research questions provides actionable data to drive continuous improvement in the platform.

Current and Future Research

The last column in Table 3 provides a brief example of the state of research on the platform regarding each source of data. For several sources of data, foundational evidence already supports the efficacy of the platform. These sources include evidence based on user experience, content, personalization, and learning. In some cases, foundational support stems from features of the platform. For instance, the platform's adaptive engine provides individualized content to students and provides foundational evidence based on personalization. In other cases, evidence stems from case studies conducted with users of the platform. For instance, in case studies with 30 users, 80% of the interview participants reported increased student engagement, motivation, or enjoyment, providing foundational evidence based on user experience (ACT, 2021c). Finally, in some cases, foundational evidence stems from prior research examining how tools incorporated in the platform's features affect target outcomes, such as the research on the tools described in this document.

For two additional sources of data, current research is being conducted to provide efficacy evidence. We are examining data from the platform to provide evidence based on use and implementation. For instance, we can examine different usage patterns in the platform and examine if these patterns differentially relate to learning growth. Additionally, data-sharing agreements are being reached to examine efficacy with existing users to provide evidence based on relationships to other variables. For instance, we are currently partnering with a school district that uses the platform to collect standardized test scores and other data to examine target outcomes.

Finally, future research will aim to provide evidence of impact from large-scale efficacy studies. In these studies, some students will be assigned practice with the platform. Their performance will be compared to students who did not use the platform. In addition to large-scale efficacy studies, we will continue to conduct structured interviews with existing users to provide further data, especially regarding evidence based on user experience. We will also continue to examine data within the platform and combine this data with external sources of data from data sharing agreements and efficacy studies to understand the platform's impact better. These interconnected lines of research aim to support the expected outcomes associated with the platform and drive continuous improvement of the platform.

Table 3. Seven Sources of Efficacy Data and Example Research Questions and Current Efficacy Evidence for Mosaic by ACT: Adaptive Academic Learning

Type of Evidence	Description	Example Mosaic by ACT Research Questions	Example of Current Efficacy Evidence
Evidence Based on User Experience	Do individuals find the learning experience engaging, favorable, and relevant?	Are all students engaged with Adaptive Academic Learning content, and do they positively react to Adaptive Academic Learning? Do students from underserved backgrounds have similar levels and patterns of engagement with Adaptive Academic Learning and do they react similarly to Adaptive Academic Learning?	The platform incorporates research-based tools to support student motivation, including the coin system, the leaderboard, and avatar customization (Birk & Mandryk, 2018; Subhash & Cudney, 2018). Current efficacy evidence based on user experience supports the intended benefits of these features. In case studies with 30 users, 80% of the interview participants reported increased student engagement, motivation, or enjoyment (ACT, 2021c).
Evidence Based on Content	Is the content high-quality and aligned to target standards and curriculum?	Does Adaptive Academic Learning provide content aligned to target standards and curriculum?	Current efficacy evidence based on content stems from the content alignment and review process. Content in Adaptive Academic Learning is aligned to standards and textbooks. Two reviewers ensure content fully covers the concept of interest.
Evidence Based on Personalization	Does content adapt to each learners' current and changing knowledge, skills, abilities and other characteristics?	Does Adaptive Academic Learning provide content that corresponds to all students' knowledge and skills and adapt content progression? Does Adaptive Academic Learning provide content that corresponds to underserved students' knowledge and skills and adapt content progression?	Current efficacy evidence based on personalization stems from the adaptive learning engine that provides content based on students' current levels of knowledge and skills (ACT, 2021b).

Evidence Based on Learning	Do students acquire intended knowledge, skills, abilities and other characteristics by using the learning tool?	Is content proficiency greater following practice in Adaptive Academic Learning? To what extent are learning gains maintained on the mastery check? Does practice in Adaptive Academic Learning lead to similar gains in content proficiency and maintenance of these gains for underserved students?	The platform incorporates a variety of learning tools and best practices from learning science. Current efficacy evidence based on learning supports the intended benefits of these features. In case studies with 30 users, many users specifically mentioned benefits to student performance or academic achievement (ACT, 2021c).
Evidence Based on Use and Implementation	Do benefits of the learning tool depend on implementation, contextual factors, and student characteristics?	Does learning growth in Adaptive Academic Learning depend on the amount of student usage and student characteristics?	Current research aims to examine how different usage patterns and student characteristics affect growth in Adaptive Academic Learning.
Evidence Based on Relationships to Other Variables	Is performance on the learning tool related to target outcomes?	Is Adaptive Academic Learning performance related to all student grades, performance on benchmark tests, lower rates of remediation, higher rates of high school graduation, and lower rates of learning loss due to COVID-19? Is the relationship between Adaptive Academic Learning performance and these outcomes similar for underserved students?	Current and future data sharing agreements will provide data to examine the relationship between Adaptive Academic Learning performance and target outcomes.
Evidence of Results/Impact	Do intended outcomes improve as a result of using the learning tool?	Does Adaptive Academic Learning use increase student grades, performance on benchmark tests, rates of high school graduation, and reduce rates of remediation and learning loss due to the COVID-19 pandemic? Does Adaptive Academic Learning use result in similar gains for underserved Students?	Future research aims to conduct large-scale efficacy studies to examine how Adaptive Academic Learning affects target outcomes.

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Appendix

Table A1. Logic Model for Students for Mosaic by ACT: Adaptive Academic Learning

Inputs What makes Mosaic by ACT: Adaptive Academic Learning special?	**Activities** What will users do with Mosaic by ACT: Adaptive Academic Learning?	**User Experiences** What do the data tell us about experiences using Mosaic by ACT: Adaptive Academic Learning?	**Outcomes** What does research tell us about the potential benefits of Mosaic by ACT: Adaptive Academic Learning?
Differentiated Practice • Personalized learning approach includes: • Adaptive and automated learning paths • Teacher-driven enrichment • Just-in-time instructional videos • Increasing levels of competence • Adaptive learning algorithm • Evidence-based learning techniques	**Learn Anywhere and Anytime** • Students can access 24/7 from most internet enabled device except for phones • Safe and secure data storage • Use research-based techniques • Supports most Universal Design for Learning (UDL) guidelines	**Knowledge and Skills** • Adaptive Academic Learning use helps students gain knowledge by incorporating evidence-backed learning techniques that support knowledge acquisition	**Short Term Outcomes** • The “right resources” for every learner (based on fit to learner needs) • Increased student engagement with learning content • Support for target learning outcomes
Technology-Enhanced Assessments • Automated & teacher-driven assessments include: • 50+ item types that are automatically graded • Formative, interim, and comprehensive • Mastery checks strategically placed • Learning profile from adaptive diagnostic	**Track Learning Progress** • Access learning profiles to see which concepts have been mastered • See real-time updates on progress towards weekly learning goals • Receive immediate feedback during practice	**More Accurately Track Learning Progress** • Adaptive Academic Learning helps students accurately gauge their learning progress with reports and real-time updated and immediate feedback	**Medium Term Outcomes** • Greater academic achievement in middle school • Lower remediation rates • Higher digital literacy
Automatic Scaffolding and Enrichment • Automatic scaffolding process involves: • Detecting knowledge gaps • Just-in-time instruction • As needed instruction on prerequisites • Enrichment with harder content as students reach mastery within learning paths	**Engage with Learning Content** • Earn coins for learning progress that can be traded for rewards • Move up on the class leaderboard • Customize avatars and trade in coins for animated avatars	**Engagement, Motivation and Enjoyment** • In case studies about Adaptive Academic Learning with around 30 schools, over three quarters specifically mentioned student	**Long Term Outcomes** • More successful transition to high school • Increased high school retention • Increased academic achievement in high school

		enjoyment, engagement, and/or motivation
Standards and Textbook Alignment • Comprehensive coverage of K–8 includes: • Common Core standards • Unique state-specific standards (14) • Aligned to popular Math & ELA textbooks (20) **Accessible** • Text-to-speech support for specific content • Accessibility tools including: zoom, color contrast, screen reader, masking	**Individualized Content** • Management of learning resources to ensure alignment to leaning goals • Local teachers can further customize content to match what is being taught at your school • Assessment resources	

Table A2. Crosswalk for Adaptive Academic Learning and UDL Guidelines Regarding Engagement

Engagement	Coverage	Example of Coverage in Mosaic by ACT: Adaptive Academic Learning
Recruiting Interest (7)	3 of 3	Adaptive Academic Learning currently provides strong support for recruiting interest.
Optimize individual choice and autonomy (7.1)	Yes	Students can choose from various rewards based on their coins, including animated avatars, games, wallpapers, and different colors.
Optimize relevance, value, and authenticity (7.2)	Yes	Several features in Adaptive Academic Learning ensure each learner receives content that addresses their individual needs, including differentiated practice, automatic scaffolding and enrichment, and aligned practice.
Minimize threats and distractions (7.3)	Yes	Students are given set weekly goals and can see progress updates in real-time to provide a predictable learning experience. Students are also given reminders automatically to inform them of upcoming and time-sensitive action items.
Sustaining Effort & Persistence (8)	4 of 4	Adaptive Academic Learning currently provides strong support for Sustaining Effort and Persistence.
Heighten salience of goals and objectives (8.1)	Yes	Student learning profiles visually display student progress to allow students to see their progress easily.
Vary demands and resources to optimize challenge (8.2)	Yes	Teachers can adjust both the rigor of practice (i.e., the minimum number of practice questions required) and the mastery criteria. Additionally, automatic scaffolded supports are provided based on student knowledge.
Foster collaboration and community (8.3)	Yes	Opportunities for peer interaction are encouraged via the class wall. Students can post a message to the class on the class wall and respond to a teacher or peer's message. Students are also able to flag and like messages via the thumbs up feature.
Increase mastery-oriented feedback (8.4)	Yes	Growth mindset feedback messages are provided after each practice question and students see growth mindset quotes that emphasize student effort.
Self-Regulation (9)	2 of 3	Adaptive Academic Learning currently addresses criteria 9.1 and 9.3.
Promote expectations and beliefs that optimize motivation (9.1)	Yes	Educators can tack positive and negative student behaviors such as student outbursts.
Facilitate personal coping skills and strategies (9.2)	No	N/A
Develop self-assessment and reflection (9.3)	Yes	Students have access to various feedback displays, including graphics, charts, and question by question feedback on performance.
Engagement	9 of 10	Overall, Mosaic by ACT: Adaptive Academic Learning currently supports student engagement in multiple ways.

Table A3. Crosswalk for Adaptive Academic Learning and UDL Guidelines Regarding Representation

Representation	Coverage	Example of Coverage in Mosaic by ACT: Adaptive Academic Learning
Perception (1)	2.5 of 3	Adaptive Academic Learning currently addresses criteria 1.1 and 1.2 and provides support for criteria 1.3 for some content.
Offer ways of customizing the display of information (1.1)	Yes	Adaptive Academic Learning provides tools for students to display information in flexible formats, including a magnifier, zoom, font size controls, color contrast, highlighter, and masking features.
Offer alternatives for auditory information (1.2)	Yes	Students watch short informational videos that involve text and various visuals, including pictures, diagrams, and charts.
Offer alternatives for visual information (1.3)	Possibly	To support the teaching and learning for all students, text-to-speech is available for applicable content.
Language & Symbols (2)	1.5 of 5	Adaptive Academic Learning currently addresses criteria 2.5 and provides some support for criteria 2.3.
Clarify vocabulary and symbols (2.1)	No	N/A
Clarify syntax and structure (2.2)	No	N/A
Support decoding of text, mathematical notation, and symbols (2.3)	Possibly	To support the teaching and learning for all students, text-to-speech is available for certain content
Promote understanding across languages (2.4)	No	N/A
Illustrate through multiple media (2.5)	Yes	Students watch short informational videos that involve text and various visuals including pictures, diagrams, and charts.
Comprehension (3)	4 out of 4	Adaptive Academic Learning currently provides strong support for comprehension.
Activate or supply background knowledge (3.1)	Yes	To connect unknown concepts to known concepts, instructional videos use relevant analogies and metaphors.
Highlight patterns, critical features, big ideas, and relationships (3.2)	Yes	Instructional videos make use of signaling to emphasize key concepts.
Guide information processing and visualization (3.3)	Yes	Bite-sized instructional videos break down content into small units to allow the learner to digest one concept before moving to the next.
Maximize transfer and generalization (3.4)	Yes	Students have multiple practice opportunities for each concept spaced over time involving different questions and question formats.
Representation	8 of 12	Overall, Mosaic by ACT: Adaptive Academic Learning currently supports comprehension and representation, whereas additional supports are needed for language and symbols.

Table A4. Crosswalk for Adaptive Academic Learning and UDL Guidelines Regarding Action & Expression

Action & Expression	Coverage	Example of Coverage in Mosaic by ACT: Adaptive Academic Learning
Physical Action (4)	.5 out of 2	Adaptive Academic Learning currently provides some support for criteria 4.2 as it is touch screen compatible.
Vary the methods for response and navigation (4.1)	No	N/A
Optimize access to tools and assistive technologies (4.2)	Possibly	Adaptive Academic Learning is compatible with most tablets that use touch screens.
Expression & Communication (5)	2.5 of 3	Adaptive Academic Learning currently provides some support for criteria 5.1 and 5.3 and provides some support for criteria 5.2.
Use multiple media for communication (5.1)	Yes	Students answer questions in over 50 different formats, including more traditional multiple-choice questions like creating a graph or shading in part of a shape. Additionally, the interactivity class wall allows students to post messages and interact with their peers' messages.
Use multiple tools for construction and composition (5.2)	Possibly	Spell check is available for applicable content. Additionally, text-to-speech is available for certain content.
Build fluencies with graduated levels of support for practice and performance (5.3)	Yes	During practice, practice problems are used to identify gaps in student knowledge. Adaptive Academic Learning provides automatic scaffolded support on prerequisite concepts at or below the grade level of the practiced concept to fill these gaps.
Executive Functions (6)	2 of 4	Adaptive Academic Learning currently provides some support for criteria 6.1 and 6.4.
Guide appropriate goal setting (6.1)	Yes	Students see their weekly goals on their main dashboard, along with their current progress.
Support planning and strategy development (6.2)	No	N/A
Facilitate managing information and resources (6.3)	No	N/A
Enhance capacity for monitoring progress (6.4)	Yes	Students frequently complete practice problems and receive immediate corrective feedback. Student learning profiles and weekly goal monitors track progress visually over time.
Action & Expression	5 of 9	Overall, Mosaic by ACT: Adaptive Academic Learning currently has some supports for executive functions, expression, and communication, whereas additional supports are needed for physical action.