The Role of Time in Self-Directed Personalized Learning Environments: An Exploratory Analysis

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Dedication

This dissertation is dedicated to my family: Houtan, Audrey, Emily, and Natalie. Your existence has fueled my drive and refined my interests, and your understanding, patience, and support has made this work possible. You bring my life greater happiness than I ever imagined possible – I love you more than words can express.

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Table of Contents

Abstract

The assumption that there is a relationship between speed and ability (i.e., that students who learn faster are smarter) is implicit in the foundational design of traditional standardized education environments. This assumption was rooted in the theories of early educational psychologists who helped shape curricula and assessments in classrooms, and standardize practices and policies that still influence education today. However, as education institutions increasingly shift from standardized approaches to more personalized ones, there are reasons to question the validity of the "faster is smarter" view of learning. Personalized learning environments have the potential to afford flexibility and opportunity to all students in ways that were previously unmanageable. Advancements in science and the development of new technologies have expanded what is possible, but in order to take advantage of these advancements, we must question the assumptions that have shaped our standardized institutions and critically evaluate whether to carry them over into personalized learning environments.

In this dissertation, I use data from 75 Algebra 1 students across 2 schools that have adopted a self-directed personalized learning model to examine questions of speed and ability. This dissertation study shows that while there was incredible individuality with respect to speed of learning, this individuality did not relate to overall academic achievement. Instead, what mattered most with respect to differences in achievement was whether the student reached mastery, regardless of how long it took. I found that in self-directed personalized learning environments, the factors that we expect should affect speed of learning and progress in the course (such as re-taking assessments multiple times) do not appear to make much difference, raising many questions about what kinds of cues, signals, and indicators teachers and researchers should consider in their practice and studies of these environments. The dissertation concludes by considering the implications that this insight has for issues of practice, research, and the future of personalized learning.

Executive Summary

Standardized educational environments distinctly value efficiency, and are organized around the assumption that speed[1] of learning is tied to students' abilities. This assumption about speed was a foundational theory that shaped how traditional schools were structured and how curricular materials were designed. Traditional models of school reflected the values of the industrial age, where scientific management[2] and standardization transformed every field it touched, optimizing education for efficient delivery of content and effective assortment of students into ability groupings based on speed of learning. As we enter an era of personalization, it is important to examine what assumptions we are carrying into the design of personalized learning environments. When students have the autonomy to direct their own learning, how does speed relate to their ultimate performance in the course? What influences the amount of time they spend learning course content? And is pace of learning stable for students across subject matters and over time? These are the kinds of questions I consider in my Exploratory Data Analysis through a combination of statistical methods that allow me to speak to group level findings, and visualization techniques that allow me to examine individual patterns of performance so that I could conduct more detailed examinations of the learning behaviors of the students in the sample.

To answer these questions, I analyzed a sample of 75 students in the 9th-grade across two schools who took Algebra 1 using a personalized learning platform. The platform allows students to learn the content of the course in a self-directed manner, and requires students to demonstrate the content knowledge they learned by applying it to projects and

[1] In this paper I use the term "speed" and "time" to refer to the amount of time it takes for a student in a self-directed learning environment to complete the material in the course. "Pace" refers to the amount of time over a specific duration.
[2] Scientific management was founded by Fredrick Taylor in the late 1800s and early 1900s in an attempt to manage the processes and workflows (namely of factories and labor jobs) in the most efficient way using human resources (Kanigel, 1997).

in-class activities. I used this data set to analyze the relationship between their speed of learning (how quickly they moved through the material) and performance (the overall quality of their work and ability to demonstrate their knowledge as judged by their classroom teachers), which addresses my first research question. To examine my second research question, I looked at whether pace of learning is stable over time (comparing speed of students at the beginning and end of the course) and across content areas (comparing relative speed of learning in one course with the same students' relative speed of learning in a different course with the same cohort of students). My third research question looked for what factors (such as, number of tries on an assessment, number of units taken, or interest in the course material) might be related to students' speed of learning.

My first research question examined the relationship between speed and performance. If speed is important, we should see a clear relationship between duration of a student getting through the course content and their performance in the course. The final course ratings, as defined in this study, assessed how students applied their knowledge of the content they learned in the personalized learning platform to projects and practical activities in class. Zero-order correlations initially seemed to indicate that students who spent longer tended to perform better; however, after taking several important control variables into account, this was not the case: speed did not predict performance – students who were faster during the course did not do any better, or worse, than students who took longer. My analysis revealed that in personalized learning environments, allowing students the appropriate conditions to master the content of the course is critical to their overall performance (their ability to demonstrate applied knowledge) in the course.

My second question explored whether speed was stable across course subjects and over time. I conducted a rank-order analysis of the students who took Algebra 1 in the 9^{th}-

grade as well as Chemistry in the 10th-grade to see if their rank order of speed changed across subject matters – were the students who were among the fastest in Algebra also the fastest in the Chemistry course? The results revealed that 74 students across both schools had relatively stable pace across content – students who were faster in 9th-grade Algebra were also faster in 10th-grade Chemistry. However, analyzing the two schools separately revealed that relative pace is not stable across content. There was a school by subject interaction such that in school 1, students who were faster to complete course material in 9th-grade Algebra were also faster in 10th-grade Chemistry; however, in school 2, students who were faster in 9th-grade Algebra were not the same students as those who were faster in 10th-grade Chemistry. To further examine the stability of speed over time I analyzed the speed of students in completing the first half of the Algebra course against their speed completing the second half of the Algebra course. Analysis of the full sample revealed that relative pace is stable over time; however, relative stability did not hold across the duration of the course – in each of the schools it was found that students who were faster in the first half of the course were not the ones that were faster in the second half of the course.

My third question examined the predictors of speed. For this analysis, instead of examining the student's overall course performance, I considered time as the outcome variable. Mastery (which is recognized as a student scoring 80% or higher on unit assessments) was a significant predictor of time. I then added other predictor variables that seem to be likely candidates for affecting time, such as the number of times a student retook an assessment, and the number of units the student decided to take. That analysis found that none of the variables had significant relationships of time, suggesting that factors that matter for predicting speed in personalized learning environments are not as obvious or straightforward as what we tend to examine in standardized learning environments.

The major takeaway of this dissertation is that personalized learning environments require us to revisit much of what we think we know about learning, both in the way we research learning, we well as in the way we organize learning experiences for students. A second takeaway from this study is that there was tremendous variability in the individual patterns of the data, and thus it seems that individuality needs to be better understood and examined, both by researchers as well as practitioners, in order to properly leverage the personalized learning environments in service of nurturing and developing students. If we expect that our knowledge about learning in traditional environments applies to personalized learning environments, we may be using false signals to decide whether to intervene, looking at irrelevant indicators of whether a student is on track or needs help, and could be overlooking important factors that matter for a student's ultimate success.

General Introduction

The amount of time it takes a student to learn has been the primary indicator of ability in traditional school models. Students who learn more quickly are viewed as more intelligent than those that take longer (Kavale & Flanagan, 2007). Traditional schools were built to educate the masses in American values and prepare them for work in the industrial economy (Osgood, 1997). Consequently, educational practices were standardized around efficiency: specific content is delivered to all students according to a predetermined schedule, students are allotted a fixed amount of time to learn that material, and are then given a narrow window of time to demonstrate their newly acquired knowledge (van der Ploeg, 2013). To make the instructional process as efficient as possible, students are systematically grouped by perceived intelligence and sorted by age into grade level cohorts where teachers generally deliver lockstep instruction to the entire class (Marland, 1971). The class of students is administered a fixed-time learning assessment at a predetermined date, after which, regardless of how well the students understood the concepts or how unprepared they are to move on, they are collectively directed to the next learning task in unison (Brophy, 1982; Brophy, 1983; Burk, 1913). The timed assessments are used to rank students according to ability and sort them into categories, often with top performers segregated into gifted programs and low performers categorized as "slow" or "disabled" and directed to remedial programs[3] (Beatty, 1998; Dudley-Marling & Burns, 2014; Gartner & Lipsky, 1987; Loveless, 1998). Students who are regarded as "disabled" in this system are afforded special circumstances for learning, often getting more time, as a civil rights issue (Kudlick, 2003), and their records are marked with an asterisk to reflect their departure from the rigidly standardized time constraints.

Standardizing the structure of schools around this view of speed and ability was no accident. Edward Thorndike, a prominent psychologist who became a leading influencer in the field of education for much of the 20th century, believed strongly that genetics dictated speed of learning, which is directly related to ability (Borland, 2004; Erickson, 1987; Galton 1869; Thorndike, 1911). The idea was that fast learners have genetically superior brains that allow them to make faster neural connections, making them more capable human beings (Anandalakshmy & Grinder, 1970; Thorndike, 2009; Thorndike, 1943). Thorndike espoused theories that oversimplified the basics of learning (Gibboney, 2006), and devised curricular and measurement materials that allowed for the easy adoption of his biased views by teachers (Tomilson, 1997).

[3] Ability grouping and tracking became institutionalized in schools in the 1960s; these kinds of categorical programs have been condemned for hindering learning and creating education systems that are unfair, inefficient, and inequitable for students (Loveless, 1998).

Statement of Problem

Thorndike possessed a mechanistic world view, wherein simple protocols are thought to reveal fixed qualities and abilities of a person, that rested on a technocratic vision, which presumed the elite should control society (Tomilson, 1997). His ideas about education were developed in a laboratory setting, and his views on learning were focused heavily on standardized mechanisms of measurement to identify the talented individuals and distinguish them from the less capable (Beatty, 1998; Gibboney, 2006). Learning, however, is not limited to laboratory settings, nor is it a phenomenon that happens independent of contextual dynamics. Several factors, including student interest (Arden & Sorenson, 1968; Harackiewics & Hulleman, 2010; Schiefele, Krapp, & Winteler, 1992), background knowledge (Bloom, 1984; Rotgnas & Schmidt, 2011), and a student's personal situation, such as socioeconomic status or home circumstances (Goldberg, Prause, Lucas-Thomspon et al., 2008), have tremendous influences on learning and must be considered when determining the effectiveness of instruction and assessment.

The recognition of the inadequacies of the educational system that Thorndike shaped have become increasingly apparent, and schools are being called upon to personalize learning in order to nurture and develop students rather than merely rank and sort them through a standardized process in search of the talented few (Bloom, 1976; Feiman-Nemser, & Floden, 1984; Hanushek, 1981). This shift requires reconsidering the standardized practices that traditional schools have been implementing for nearly a century. If we expect schools to nurture and develop students rather than merely rank and sort them, we must abandon the standardized model of education and look to models of personalized learning that support the needs of all students. First and foremost, this necessitates that we question longstanding foundational assumptions that have served as the foundation of the traditional school structure by empirically examining the relationship between speed and ability.

Goal of Dissertation

The goal of this dissertation is to critically examine assumptions about speed and learning. I do this by first systematically analyzing the speed of students in a personalized learning environment, and second, by considering the implications of the findings of this study as it relates to the re-evaluation of design of learning spaces. This study has practical implications for not only the way we think about students and view their potential, but also, the applied consequences for the pedagogical practices that dictate academic progression, the policies that are instituted around seat time[4], and the design and affordances of educational environments that aim to personalize learning.

Research Questions

My research questions focus on the relationship between speed and ability in personalized learning environments to determine if students who progress through course material faster perform better in the course. I continue the exploration of speed by examining whether speed is stable for individual students in order to determine if faster students are always faster over time and across different disciplines. And finally, I explore factors that are presumed to influence speed. I do so by empirically answering three

[4] As class subjects of instruction were broken up into even units of time in order to standardize the school day, "seat time" was used as a measure of the amount of time a student is exposed to instruction. It does not account for what students have learned or failed to learn, but rather, it accounts for the amount of time a student is required to be in attendance for a specific course of instruction. The impetus for standardizing "credit hour" and "seat time" units of measure was a generous $10 million grant by the Carnegie Foundation, who wanted to professionalize teaching and establish standards that provide common criteria for students, teachers, and schools (Silva & White, 2015).

questions: 1) Is there a relationship between time and performance? 2) Is pace of learning stable over time and across content? And 3) What are predictors of speed?

My first analysis examines the relationship between speed of learning and performance, with specific attention to inter-individual differences, to test the hypothesis that students who are faster perform better in the course. For my second analysis, I examine whether pace of learning is stable by individual over time and across academic content by examining the stability of a student's relative speed across different academic subjects and over the same academic subject. Third, I analyze predictors of time to examine the factors that may influence the speed of learning, using the analysis from question 1 to inform my exploration.

BACKGROUND

Historical view of time and ability

Introduction to the Two Views

There are two long-standing and views about speed of learning that each have very different consequences for schools. One view is that speed and ability are coupled – that students who learn faster are naturally smarter due to genetic advantage, and speed of learning is a function of how quickly a person's brain can make neural connections (Borland, 2004; Erickson, 1987; Galton 1869; Thorndike, 1911). The other view is that speed and ability are not coupled – the speed at which a student learns is not indicative of ability but rather attributable to factors such as environment, relationships, and quality of instruction (Bloom, 1985; Goldberg, Prause, Loucas-Thompson et al., 2008). These views seem contradictory because they carry very different assumptions about what students are capable of, and logically lead to different decisions about curricular design, class instruction, and how to treat students within the education system.

View 1: Speed and Ability are Linked

Throughout much of the twentieth century, one of the most influential figures in education has been Edward Thorndike, who is considered the father of educational psychology (Adams, 1987; Grau, 2001). His optimism, moral idealism, statistical training, and belief that science can improve education and society made him a well-regarded public figure. Persuaded by the ideas of Francis Galton[5] about natural ability and inheritance of mental traits, Thorndike championed the notion that intellect was hereditary and therefore

[5] As a student at Harvard, Thorndike was introduced to Galton and his written works, Hereditary Genius (1869), and Natural Inheritance (1889), which he proselytized (Sweeney, 2001). His own studies on heredity in 1903 and 1905 frequently quoted Galton (Beatty, 1998). Francis Galton (1822-1911) introduced sensory discrimination as a measure of intelligence, which was later elaborated upon by Thorndike (1874-1949) through his research (Jensen, 1987).

fixed, and for schools to be efficient they must sort students into groups by ability (Thorndike, 1911). He published studies on learning, using animal subjects to study initial theories of learning, and later human subjects and their family histories to promote the Galtonian view of inherited characteristics. He maintained that differences in mental capacity and innate rank-order differences in individuals should lead schools to identify by speed in which they learn (Thorndike, 1901). Thorndike's theories on the genetic limitation of student intellect led him to argue that education could not affect these stable, innate differences, and that providing equal education would allow the superior to progress to high stations in society and the inferior to low stations. His 1904 publication of *An Introduction to the Theory of Mental and Social Measurements* ushered in the era of standardization in education, wherein schools reflected factories in their sorting and ranking of students for social positions and jobs.

Thorndike was credited with "successfully adapting Galton's and Pearson's statistics to the interests of a science of education" (Jonçich, 1968, p. 290) making him the leading figure in the measurement movement (Beatty, 1998). He participated in the production of standardized textbooks for the instruction of academic subjects like arithmetic and vocabulary, as well as teacher preparation books, rating scales to measure student performance on fundamentals such as handwriting and composition, testing protocols, and other materials necessary for schools to operate under his philosophy (Thorndike, 1909). The educational products that Thorndike was involved in creating were successful for two reasons: first, they were based on his empirical research and therefore viewed as scientifically sound, and secondly, they were easily implementable in the classroom. His influence on tests and texts permeated in schools throughout the country, and his standardized processes and results were argued to be fairer for the selection of ranking and sorting individuals for societal functions than subjective ratings that teachers could provide (Beatty, 1998). One of the basic tenants of Thorndike's philosophy was that a person's intellectual capacity is innate and therefore one's ability cannot be developed by schooling; schools can best serve society by sorting the elite from the average efficiently so that teacher's time and efforts are not diverted from the important task of educating the most intelligent (Tomilinson, 1997). In other words, faster learners who have genetically inherited more efficient brains were worth more educational resources, including human capital, in school settings (Haier et al., 2009; Jensen, 1987; Thorndike, 1911).

View 2: Speed and Ability are Not Linked

Views of learning, speed, and ability that challenged Thorndike's have been expressed by philosophers and psychologists like John Dewey, John Carroll, and Benjamin Bloom. Proponents of the position that speed and ability are not coupled believed that environmental upbringing, living conditions, and prior learning experiences profoundly impact a student's achievement have advocated changes to the standardized education practices (Goldberg et al., 2008), and argued that speed of learning is not related to ability (Bloom, 1968). Bloom, in fact, contends that, with very few exceptions, every student is capable of reaching high levels of achievement under the appropriate conditions[6] (Bloom, 1968). He develops a model of learning to support that claim, and carried out seminal studies to show that with individual tutoring, students were able to significantly outperform those in traditional school instruction (Anania, 1981; Burke, 1983). This study was profound in its findings, and more importantly, demonstrated that ability is not fixed, but rather, a

[6] Lev Vygotsky (1896-1934) identifies the conditions in which a learner is able to perform with the help of support – sometimes referred to as the edge of incompetence where a student is unable to demonstrate learning without assistance – as the "zone of proximal development" (Erickson, 1987; Vygotsky, 1978).

consequence of other factors including instruction. His model instigates a shift away from selecting talent through rank and sort methods, suggesting that ability is not coupled with time and that talent can be developed (Bloom, 1984).

Bloom's work garnered much attention for decades, with educators and researchers applying variations of his model in classrooms and studies and seeing positive results in cognitive outcomes, which was defined by student achievement on exams, and student affect, which was defined by measures of motivation (Damavandi & Kashani, 2010; Hoon, Chong, & Ngah, 2010). But with the publication of *Nation at Ris*k by the U.S. Department of Education in 1983 asserting failures of the educational system and raising urgent concerns about the rank of the United States against other industrialized nations, the emphasis on outcomes and standardized measures gained traction and Bloom's influence began to wane. This resulted in a shifting of priorities away from flexible mechanisms that support student development, and orienting toward efficiently preparing students to pass proficiency exams and standardized tests that simplify the sort and rank-order process (Stecher, 2010). The focus on rank order performance on standardized tests strengthened the belief in the view that speed and ability are linked, and it reinforced the rigid approach to education that Thorndike advocated.

Personalized Learning

The Buzzword of Education: Introducing Personalized Learning

Personalized learning has become a buzzword in education (Horn, 2017), and while there have been many organizations, districts, and states trying to implement personalized learning in schools (Hernandez, 2016), there is little coherence around a unified definition of personalization or what personalized learning entails (Basye, 2016). Some believe that personalized learning happens in classroom conditions where teachers differentiate instruction based on the learning style that is specific to each student (Keefe, 2007; Patrick, Kennedy, & Powell, 2013). Others believe that personalized learning involves the use of computers that utilize adaptive technologies that can tailor content to students based on their performance (Cavanagh, 2014; Nextgen Learning, nd; Pane, Steiner, Baird, & Hamilton, 2015). Others believe that personalized learning is time for students to self-govern their activities independently or in isolation (Walbergh, 1984). Some include in their description of personalized learning the cultivation of the whole-child, with consideration to social-emotional factors and the psychological well-being of the student (Rodriguez, 2018; ASCD, nd). Policy makers, philanthropic foundations, academic researchers, educators, and technologists agree that personalization should lead to better outcomes, but there is not a consensus on what personalized learning entails. This kind of incongruity around a definition is expected of novel and budding educational efforts, but attempts to personalize learning have been around for a long time.

New Wine, Old Bottle: History of Personalized Learning

Efforts in personalized learning have dated back to the origins of the educational system (Dockterman, 2018). Attempts to re-design schools to facilitate personalized learning have been going on for over a century, with ungraded classroom models intended to address the varied needs of students by highly qualified instructors (Osgood, 1997), self-directed learning programs inspired by a Montessori model education (Marshall, 2017), and curricula that emphasized student freedom and responsibility like the Dalton Plan (Lee, 2000). These models of personalized learning have been successful in their own right, engaging and developing students in ways that standardized rank-and-sort models do not allow for, but these efforts have remained largely on the fringe. The challenge of personalized learning has not been failure of determination or imagination, but no matter how effective efforts have been, they have not become the foundation of public education.

One example that highlights this point dates back to 1933. A diverse group of 29 schools participated in an 8-year study that experimented with the curriculum by blending subjects of instruction, class duration, space, numbers of students, and de-standardizing the use of time so students could work on personalized curricula with cross-subject material for the amount of time they needed. The consequence of this model was that teachers developed cross-departmental programs, students participated in decision making about school affairs and got engaged in community service activities, publications, and artistic productions, and the distinction between the formal and informal learning was dissolved (Kahne, 1995). Students who participated in this study were more active in collegiate social, artistic, and political life, and they did better in college than their traditional school counterparts (Tyack & Tobin, 1994). This example highlights that even when efforts are successful, if the general assumptions about individuals are couched in a limited view of time, ability, and scarcity of talent, even fruitful efforts that demonstrate better outcomes for students are explained away, overlooked, and fail to garner the widespread adoption needed for transformational change to take place.

Personalization ***Assumes*** View 2: Why that Matters

Personalized learning efforts have varied in many respects, but they have one thing in common – that they all assume that there is no relationship between time and ability, and they all focus on developing students. They reject the notion that education is about selection, do away with structures that merely rank and sort students, and they focus on altering the model of schooling to provide more flexibility in the learning environment. They do not require students who need more time or attention on a subject to be identified as needing special exceptions. They assume that students are capable, and they seek to provide the learning conditions, including time and supports, for all students to achieve at high levels. This assumption animates the way time is used, curricula, pedagogical practices, and programs that inform the diverse models of personalized learning, and they aim to produce different results than what is possible in standardized systems.

Key Components of Personalization

Even with common fundamental assumptions, the historical and current efforts in personalized learning may look very different in the products, practices, and approaches they use, but even despite these differences, there are areas of convergence where there appears to be implicit agreement. Three key components common to most efforts focused on developing the potential of all students have converged around are: mastery, autonomy, and interest.

Mastery. Mastery is a term often used to describe a high level of proficiency in demonstrating understanding of a skill or concept. As such, the process of attaining mastery is open to a variety of activities, with only one core requirement: that the student be given the time needed to meet the high standards of achievement.

The importance of mastery in developing students has prompted the development of various instructional approaches intended to facilitate mastery in schools, like the personalized system of instruction (Keller, 1968) and continuous progress (Cohen, 1977), but none have been as comprehensive and influential as Benjamin Bloom's learning for mastery model (Block & Anderson, 1975). Bloom provides a model of mastery with a robust body of support, that provides articulated, testable hypotheses supported by research[7].

Bloom intended for his model of mastery to challenge traditional beliefs about fixed student aptitude and demonstrate that the conditions of learning (rather than inherent ability or genetics) shape and ultimately determine student outcomes. Bloom's model of mastery accounted for three key elements – Cognitive Entry Behaviors (CEB), comprised of the accumulated types of prerequisite knowledge, skills, and competencies that the learner has previously acquired and that are essential to the learning of the new task, Affective Entry Characteristics (AEC), which refers to the combination of interests, attitudes, and self-views that a student possesses when encountering a new explicit learning opportunity, and Quality of Instruction (QI), such as the cues from the instructional material or instructor about what is to be learned and how the learner should proceed, reinforcement, feedback, and correctives that a student is given during the course of a learning task – whose interaction together would account for up to 90% of the variation in student achievement (Bloom, 1976). His goal was to demonstrate that under the right conditions, nearly all students are capable of high levels of achievement.

Bloom's model makes explicit the components of instruction as well as learning conditions that need to be in an environment to facilitate mastery. Bloom's mastery model requires the teacher to clearly define the objectives and content that the student is expected to learn, organize the material in units that are modular and relatively small, and creating parallel examinations that evaluate the knowledge acquired in different assessments. The

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[7] Two studies which tested Bloom's mastery model were conducted by Anania (1982) and Burke (1984). In both of the studies, students were randomly sorted into one of three instructional conditions – conventional (which follows the traditional classroom model), mastery (which applies Bloom's learning for mastery model to a class of students), or tutoring (wherein one tutor works with two or three students on the course material). Both studies found that the average student in the tutoring condition performed about two standard deviations better than the counterpart in conventional instruction, and the average student in the mastery condition performed about one standard deviation better than the counterpart in conventional instruction. These studies tested Bloom's mastery model and produced quantifiable results against his theory that nearly all students are capable of learning under the right conditions (Bloom, 1984).

learning conditions must be appropriately prepared, and must have the flexibility designed and teacher support in the environment in order to effectively in guide a student to mastery learning.

Autonomy. There is general agreement that students should have control over their learning, but the amount of control students should have, and what they have control over at any given age is not clear. Similarly, research on autonomy contains distributed and divergent definitions of the term. Early philosophers like Dewey and Rousseau, emphasized the responsibility of the individual to take initiative in their learning (Qi, 2012). The recognition of a learner's responsibility paved the way for an explicit definition of autonomy as "the ability to take charge of one's own learning" (Holec, 1981) which has since been revised and expanded by several researchers, including Little (1990), Kenny (1993), Benson (2001), Dickinson (1987), Gardner & Miller (1996) to include the need for personal meaning in learning, and discussion of the learner's rights and freedoms in the learning environment (Qi, 2012). Other theorists define the strategies necessary for learners to develop autonomy (Ellis, 1994), add ideas of constructivism and humanistic psychology that distinguish school knowledge from action knowledge (Barnes, 1976), and elaborate on the influence of teacher autonomy on learning (Benson, 2001). In theoretical discussions, the definition of learner autonomy has taken on a variety of meanings over time and has been subject to several philosophical debates (Huang & Benson, 2013; Ryan & Deci, 2006). Similarly, in practice, schools that allow for autonomy have existed for as long as these definitional debates, with models like Montessori and Democratic Schools providing students autonomy over different aspects of the educational experience. Although the debates in definition and differences in practice may suggest there is disagreement, they all coalesce around the acknowledgement that in order to develop their talents, students need more control over their learning than what standardized systems offer.

These efforts in defining and designing for autonomy have led to a deeper understanding of ways to cultivate it. In the simplest sense of the word, autonomy denotes a certain degree of independence and freedom in a learning environment for a person to take charge of one's own learning (Little, 1991). This degree of freedom and control requires internal faculties that the individual must acquire as well as external conditions be in place for the student to develop, advance, and exercise the autonomy. The internal faculties that a learner must possess are that of self-knowledge, which involves the metacognitive awareness to monitor and assess oneself and the learning process (Ceylan, 2015; Huang, 2005; Little, 1997; Rivers, 2001; Wenden, 1998), and self-regulation, which involves knowing how to conscientiously execute planned ideas, selecting strategies and behaviors that best guide one's own learning, actively evaluating of the process and adjusting as needed, and managing different learning goals, behaviors, and environmental factors in service of reaching the prioritized outcome (Dickinson, 1987; Holec, 1981; Knowles, 1975; Ridley et al., 2002; Rahimi & Katal, 2012). In order for a student to develop and strengthen their sense of autonomy, the environment must provide external opportunities for the learner to exercise these faculties in making meaningful decisions for themselves and about their own learning (Ryan & Deci, 2006), in an environment that allows an individual to make choices that are free from manipulation (Ryan, 1993). Developing student autonomy is more than merely providing students with choice, but rather, focusing on how to cultivate the self-knowledge and self-regulation in a personalized learning environment in order for the student to take full advantage of those choices.

Interest. It is widely believed that individuals will be motivated to learn if they are interested in the material. A theoretical framework for interest was conceptualized by Schiefele and colleagues as actions that involve personally valued activities that are accompanied by intentional positive emotions (Köller, Baumert, & Schnabel, 2001). Studies have found that achievement and self-perceived competence are both factors that can affect interest (Hacket & Campbell, 1987; Lopez, Lent, Brown, & Gore, 1997) in that students feel more drawn to areas that they perceive themselves to be capable (Harter, 1982). Research related to how to trigger interest in text-based environments indicate that some factors that matter include relatability (Anderson, Shirey, Wilson, & Fielding, 1984), unpredictability (Hidi, 1990), suspense (Jose & Brewer, 1983), imagery (Goetz & Sadoski, 1995), and ease of comprehension (Schraw, 1997). Relatively little is known about developing interest in non-text-based situations that are more natural and authentic to learning (Rotgans, & Schmidt, 2011). The notion that interest is essential to learning is posited by most learning theorists, and is supported by studies that found student interest enhances motivation and improves performance (Arden & Sorenson, 1968; Harackiewics & Hulleman, 2010; Schiefele, Krapp, & Winteler, 1992). Research specific to interest has found that it impacts attention (Hidi et al., 2004), student goals (Sansone & Smith, 2000) and learning outcomes (Renninger et al., 2002). There are differences in opinion with regard to how far to take the idea of catering to student interest, but the various attempts in how to create learning environments that allow for that reflect an acceptance of the importance of engaging students in material that they find engaging and relevant to their interests.

Despite the copious evidence has been found for the importance of interest in learning, relatively little research has been done on how to develop interest in learners (Arnone et al., 2011; Hidi & Renninger, 2006). Educators recognize that simply inserting trendy examples into pre-existing curricular material is insufficient and ineffective. Project-based learning and approaches where students can opt into a topic of interest, learn about it in depth, and apply that knowledge to solve problems and create meaningful experiences are among the personalized learning practices that focus on interest (Alger, 2016), and are expected in personalized learning environments.

Taken together, it is apparent that personalized learning rests on a firm commitment that students are capable and there is not a relationship between speed and ability. Substantial progress has been made in understanding what types of conditions are expected of a learning environment wherein the goal is to develop the talent and abilities of all students rather than merely select or identify the talented few (Du Bois, 1903).

What's Different Now?

Given the amount of progress in converging around key components and practices of personalized learning, it may seem curious that personalized learning models have remained largely at the fringe of the educational system for so long. It raises the question, why would personalized learning today yield results that are any different than what was produced in the past? The primary advancement that has the potential to make modern efforts different is the kind of technology that is now available.

Many attempts to transform education have failed, not because they are unsuccessful in meeting their desired goals, but because they are not able to easily scale. Bloom himself noted that the cost of scaling the tutoring model that produced 2-sigma gains in student outcomes was prohibitively expensive at that time (Bloom, 1984). A system that has the flexibility and supports necessary to respond to each and every individual in ways that facilitate mastery, autonomy, and interest requires the kind of technology that until recently was not possible. For a long time, the most advanced technologies that were used in public education were paper and pencil, blackboards, and projectors – in other words, technologies that were easily usable by the masses. Producing for scale used to mean creating a one-size-fits-all model or product that is suitable for most, because customizing models or products that would be ideal for any single individual was impractical at scale. In a traditional school environment, for example, in order to scale a curriculum, age-appropriate textbooks that are standardized for the "average student" of a particular grade assume that all students are starting with the same background knowledge, will understand the content in the way that it was described in the textbook, and will follow the fixed curricular progression that is laid out. The system was designed for the "average student" and materials were standardized around that, despite the fact that an average student does not exist (Rose, 2016). In short, scale was made possible through depersonalization.

Modern technological advancements have enabled circumstances that could not have envisioned decades ago. The rise of networked digital technologies has changed what is possible in a fundamental way: their power lies in the ability to be flexible, adaptable, and responsive to individuals, making their greatest asset – their ability to personalize to each and every student rather than being rigidly designed for "the average student" – actually scalable. Consumer-facing platforms (e.g., Google, Facebook, Amazon) demonstrate how effective, scalable, and affordable personalization technologies can be when the goal is to get individuals to engage or act. The technology already exists, and modern web browsers can support the rich range of functionalities needed to scale personalization for free. The challenge education faces is not one of limited resources or excessive cost, it is about values – in order to integrate this technology into a scalable model of personalized education, we must genuinely believe that students are capable and aim to develop them in schools;

technology must be used in service of advancing students, not merely administering tests that more efficiently rank order and sort the best from the rest.

Recent examples of technology in service of education show promise and provide proof points for how technology can supplement and transform the standardized school approaches. The adoption of flipped classrooms – a model of instruction that requires students watch pre-recorded lectures at home and reserves school time for in-class exercises – has resulted in a number of online repositories of video lectures ranging in length and topic. The availability of video instructional explanations has allowed teachers to identify and assign relevant lectures that contain expected background knowledge required of students. *Khan Academy*, a dashboard of instructional video repositories and practice exercises has ready-to-use resources for students to engage with at their own discretion. *Assistments*, an online tutoring platform with built-in flexible assessments and that provide immediate feedback to students while also apprising the instructor of student progress, allow instructors to systematically ensure that students are progressing through course content by reaching mastery, engaging in material of interest to them, and are afforded the time, flexibility, and support to develop autonomy in the learning environment that transfers outside of the classroom conditions. The prevalence of online resources and the ease with which they can be created, adapted, and widely accessed makes it possible for a personalized education system to scale, and yet, rather than overhauling standardized education, the impact of these innovations have remained largely outside of education or remained in the periphery.

Revisiting the Role of Time

Traditional standardized systems rest on very different assumptions about student ability and the purpose of education than personalized ones. The two views about the relationship between time and ability have very different implications for the function of schools and lead to conflicting logical structures for how their curricular and physical design should be. In a practical sense, the two views are incompatible. One of the interesting gaps in the literature right now is that while there is a general sense of the lack of relationship between time and ability, the studies that give rise to this conclusion are either in specific laboratory conditions (for example, where the study lasts only a few of short-burst durations in highly controlled conditions), inferred indirectly (for example, Bloom's work shows students are capable but does not explicitly test the relationship between speed and ability), or else conducted in standardized environments, which may give an artificial sense for the true relationship that would exist in a personalized space. In order to maximize the technology that is available to create genuinely personalized learning environments that supplant standardized education models, we need to have a more accurate empirical understanding of the relationship between time and learning, and examine what kinds of factors are important to consider in our efforts to nurture and develop the potential of all students.

EMPIRICAL STUDY

Study Overview

There have been efforts to research personalized learning over the past few decades, often by injecting new technology or activities into a traditional, standardized environment. In stark contrast, very little research has been done within personalized learning environments themselves. The differences between standardized and personalized environments are substantial enough that we cannot assume the findings from research in one setting will hold in the other. In particular, the way we use time, how we structure the learning experience, and what kinds of affordances we offer the student are potentially very different in the two learning environments, making them non-interchangeable.

In this section I draw on the existing literature reviewed earlier around mastery and engagement to inform my examination of time in personalized learning environments. I use statistical methods and intersperse some visualizations that depict the patterns of student performance during the semester for my analyses, to examine the effect of speed on outcomes (how well students perform overall), the stability of speed over time and across different content areas, and I explore the predictors of time. The goals of this study were two-fold: first, to critically examine assumptions about speed and learning by systematically investigating the questions of interest in personalized learning environments, and second, to bring to bear implications of the findings of this study as it relates to the re-evaluation of design, development, and implementation of educational institutions and learning spaces.

The results of this study reveal the importance of allowing students the flexibility in time to reach mastery, and highlight the importance of creating effective mastery learning environments that promote the productive use of time, provide appropriate supports for the students, and assist the student in developing strategies for self-regulation and time-management that facilitate better learning.

Research Questions

My research questions examine the relationship between speed and performance to determine if students who progress through course material faster perform better in the course, whether speed is stable for individual students, to determine of faster students are always faster over time and across different disciplines, and what factors influence speed in personalized learning environments. I do so by empirically answering three questions:

1) Is there a relationship between speed and performance?

2) Is pace of learning stable over time and across content?

3) What are predictors of speed?

My first analysis examines the relationship between speed of learning and performance, with specific attention to inter-individual differences of the students in Algebra 1, to test the hypothesis that students who are faster perform better in the course. For my second analysis, I will examine whether pace of learning is stable for individual students over time and across academic content. This will be done by examining the stability of students' relative speed across different academic subjects (Chemistry and Algebra 1) and over the same academic subject (first half of Algebra 1 and the second half of Algebra 1). Third, I will analyze predictors of time to examine the factors that may influence the speed of learning, using the analysis from question 1 to inform my exploration.

Methods

Participants

Data from 75 students across two schools were used for my analyses[8]. The participants who were included in the study were selected from a larger dataset that contained information on the assessments of 114 students across 321 courses in 8 different schools, all of which were using the same personalized learning platform full-time and adhered to the practices and protocols that were required in order to use the platform in their schools. To ensure that I was capturing students who took the same courses in the same year of school, I narrowed my sample to 75 students across two schools who had taken Algebra 1 in their 9th-grade year. I chose to use data of students in Algebra 1 because students have to take it around the same time in their high school career, so enrollment in the course is not an affinity-based class that is limited to students who are particularly interested in it (in some states a student is not permitted to graduate high school without passing the class). Also, Algebra has some sequential characteristics to it, where a later chapter or unit is presumed to be contingent on the knowledge of an earlier one, which makes it interesting for personalized learning environments where students are given the autonomy to decide whether or not to follow the sequence that is recommended. This makes Algebra an ideal subject for testing not only my research questions, but also whether some of the assumptions about sequencing of content is as critical as we believe.

As the students use the personalized learning platform to engage in the course, a variety of detailed information is recorded. The amount of time they spend on different activities, their scores on short, often 10-question assessments of their learning, and a variety

[8] The data was collected from the personalized learning platform and deidentified prior to being made available to me, per terms of the data use agreement of the school.

of other information about their engagement in the platform are recorded in electronic learning logs. From the data that was captured on these 75 students, I devised a variety of speed and performance-related measures. The sample of 75 contains 35 students from school 1, a public school in Denver, and 40 students from school 2, a charter school in Minnesota.

Teaching and Curriculum Model

Both of the schools from which my sample was drawn adhered to the teaching and curriculum model that was a required part of the schools' agreement to participate in the Personalized Learning Platform. In this model, teachers are utilized as coaches, mentors, and facilitators rather than the deliverers of content, and the technology platform is utilized to introduce course content and offer flexibility in a student's progression through it. The model that schools must adopt in order to implement the Personalized Learning Platform is one in which the course is separated into two areas: content and projects. Course content is delivered through the on-line platform, which provides a playlist of the explanations and concepts of a course, broken into focus area units, that are provided in multiple modes of representation (for example, text explanations, video lectures, audio files, online presentations) that students can engage with until they have the learned the material. Students take content assessments of the focus area units to gauge their understanding and assess their learning. Each course has required focus area units, which make up the essential information that is expected to be learned in the course, and additional units, that students can take if they are interested in expanding or deepening their knowledge in the subject, but that are not a required part of the curriculum. Students are encouraged to complete all of the required focus area units, and to reach mastery on the material, which is done by scoring

80% or higher on the assessments. While students are encouraged to reach mastery on each unit before moving to the next in the sequence, the reality of student-driven learning environments showed that when students have autonomy and the ability to make their own choices about what work they do, how they sequence the units of learning, how long they spend on each unit, and how many times they re-take an assessment is different than the standardized process used in traditional learning environments. The divergence of student's approaches from what was expected exhibited a rich variability in the patterns of progress (examples of which will be included later in this section) and provided insight about student's learning behaviors.

Both schools provided students eight hours per week of personalized learning time within the school day, as this was also a required component that schools agreed to in order to use the Personalized Learning Platform. The eight hours of personalized learning time allows the student to learn the content of their courses in the order, pace, and sequence that they themselves direct. A progress timeline is identified in the platform to notify students of the speed at which they would be progressing at in a standardized environment, which is intended to help them stay on track to complete the course within the desired amount of time, but the content modules are available for them before and after the target timeline. If the student moves quickly through a focus area unit or wants to dig deeper in the subject, the student can take longer between units, move on to other units, or explore additional optional units that are related to the subject but are not required as part of the course curriculum.

The courses that are taught using the Personalized Learning Platform are accompanied by teacher-facilitated course activities that promote deep thinking about the course topics and material introduced in the personalized learning platform. Students use the weekly course time to showcase their understanding and, through projects, demonstrate their learning of the course concepts and content learned in the personalized learning platform. Each week students get the equivalent of 3 hours of course time, 8 hours of in-school personalized learning time, and are also encouraged to spend 8 hours per week using the personalized learning platform at home. Students also have one 15-minute check-in with mentors each week, to talk about their progress, challenges, and any matter of importance to the student. The mentors are able to view the student's activities in the personalized learning environment across all subjects, and help the students improve their time management and goal setting skills so that they can effectively navigate and leverage the personalized learning environment.

Demographics

While the teaching and curriculum model that schools must adopt in order to use the Personalized Learning Platform are identical, the demographic characteristics of the two schools in my study have some differences. School 1 is a public school in Denver whose 9th-grade cohort at the time of this study consisted of 99 students in total. The school was founded in 2015 (using the personalized learning platform from its start), serving a single cohort of students in the 9th-grade its first year of operation, progressively adding a grade level each year until the initial former-9th grade cohort reaches graduation (in other words, its second year of operation the school expanded to include 9th and 10th-grade students, and added an 11th grade cohort in its third year, and so on). A demographic report produced by the school describes that at the time of the study, 62% of the 9th-grade students were eligible to receive free or reduced meals, 22% of the students were English language learners, 10% of the students were labeled as having a "disability" in learning, and 63% of the students were considered to have a race/ethnicity that is other than White (36% Hispanic, 10% multiple races, 14% Black, and 3% other). Supplemental information that was found about the school indicates that the student-teacher ratio at this school is 14 to 1 (School Digger, 2018), and the gender breakdown is 41% female and 59% male (US News, n.d.).

School 2 is a public charter school in Minnesota, serving students in grades 6, 7, 8, 9, and 10. The school began as a middle school in 2013, and in 2016 opened its high school by progressive enrollment, beginning its first class of 9th graders and adding a grade level per year until the initial former-9th grade cohort graduates. At the time of this study, there were 257 total students in the school, with 70 students in the 9th grade. School-wide demographics described in the school's annual report discloses that across all the grades, 90% of students were identified as eligible for free or reduced meals, 25% were English language learners, 26% were labeled as having a "disability" in learning, and 92% of the students were considered to have a race/ethnicity other than White (51% Hispanic, 31% Black, 9% other). The annual report did not identify the student-teacher ratio or gender composition; however, supplemental information about the school designates the student-teacher ratio at this school is also 14 to 1 (School Digger, 2018).

Measures

The participants in this study had their learning behavior captured by the personalized learning platform over the course of the semester analyzed. A table listing the data that was captured and calculated from the personalized learning platform (Table A1) is provided in Appendix A. There were no additional assessments or activities introduced as part of this study, and no researcher was present in either of the schools over the period of time the data was being captured in order to ensure that there was no outside influence on the student's learning behaviors. Using the de-identified data that was captured by the personalized learning platform, I was able to calculate several variables related to time, learning behaviors, and assessments.

Measure of time. An important question that arose in my analysis was how to measure speed. In standardized environments where content is delivered at a common pace for all students, the definition of speed seems intuitive because there is very little opportunity to deviate from the class pace. In a personalized learning environment, however, where students have the autonomy to direct their own learning, there are many ways to consider speed.

One way to calculate speed is to look at the total time spent on assessments, which provides us with the sum of total minutes a student spent in the act of assessment-taking throughout the semester. This measure of time is useful when answering a question about the speed of demonstrating knowledge, but it does not tell us much about the learning aspect that comes before it, which is key to my question of interest.

Another measure of speed could be average minutes per assessment, which indicate the average amount of time it took for a student to complete an assessment that is required in the course, or the average minutes spent on an optional assessment in the course. These variables, however, also focus on the time for the demonstration of knowledge through assessment-taking, and overlook the time related to the learning that came before it.

Another measure of speed could be the average days between assessments, which gives an indication of frequency of involvement with the assessment material. The challenge with this measure, however, is that because students are able to take assessments as often as they like (even multiple times a day if they want), and are able to take various assessments on the same day, it may not accurately represent the consistency of the student's involvement with the material.

Another way to measure speed could be to examine how many days elapsed between the start of the semester and the day of the last assessment the student decided to take. This could give a measure of how many days were spent working on the material, but it also carries with it the assumption that students began working on the course material from first day of the course, which was not the case for many students (as ascertained post-hoc from the analysis of individual patterns of performance).

Another way to measure speed is to calculate the days between the first day of the semester to the first day that the student took their first assessment, which could give a sense for the student's strategy for learning (whether it is to start by studying material and then taking an assessment to check their learning, or whether they first dive in to an assessment in order to see what they know and what they have left to learn before they begin studying), but there is no way to tell whether the student began learning inside or outside the system before the first assessment was taken, so this approach carries many assumptions with it.

The measure of speed I used for my analysis was the calculation of the days between the first assessment a student took and the last assessment that a student took during the semester. This identifies time as the number of days that the student showed assessment activity in the system (be it strategically, to decide what to begin studying, or as a way to assess what was learned). I used the days between first and last assessment as the measure of time to calculate speed for two reasons: first, because it most accurately captured the number of days between when a student actively began participating in the online assessments and the last day of such engagement, so it is very reasonable to assume that learning of the course material happening in the days between. Secondly, I am interested in speed as it relates to learning in personalized environments; I did not use measures of assessment speed as my overall measure of time because they are related to the speed of recall or retrieval of what was learned rather than the process of acquiring new content of learning.

Other key measures. The key variables I considered in my analyses were informed by theoretical debates on factors that are believed to matter for performance.

Interest. A student's interest (or level of interest) is thought to play an important role in a student's engagement and enjoyment of learning, presumably leading to better outcomes. In my data, interest was measured by looking at whether a student chose to engage in one of the optional additional unit assessment that were not deemed a required part of the course. The student is considered to have demonstrated interest in the course if one or more of the optional units were attempted during the semester. Students who only attempted required units without engaging in any of the optional units, was considered to not exhibit interest.

Mastery. Mastery of course material plays a central role in debates about student ability and the effective use of instructional time in schools, making it a noteworthy variable to consider when examining questions related to time and ability. The student is considered to have demonstrated mastery of a unit by attaining a score of 80% or higher on any of the assessment attempts for that unit.

Performance. Overall performance in the course was a measure of applied knowledge, determined by the student's demonstration of the content learned in the personalized learning platform in practical application through projects or applied activities done in class time. The student's performance on the assessments in personalized learning platform only makes up 30% of the overall applied knowledge score; the other 70% is the determined by how the student demonstrates transfer of knowledge of the content learned in the personalized learning platform to activities that are assessed during the class time and projects that showcase the effectiveness of the student's knowledge in practical application, as evaluated by the instructor. The rubric that is used to assess how the student has applied cognitive skills to the demonstration of the course content is provided in Appendix B.

A table that describes the variables that were created based on the data that was captured is provided in Table 1.

Table 1

Variable names and descriptions

Variable	**Description**
School	The site number assigned to the school. One school is assigned a site name of 1; the other school is assigned site name of 2.
Final Score **[Applied knowledge]**	The student's final score in the class, made up of FA scores (30%), project scores demonstrating cog skills (30%), and course work scores (40%)
Days on Assessments **[Time]**	The number of days between when the student began taking assessments and stopped taking assessments (between the first and last assessment). Since students can start and end their assessments at any point in the semester, it gives a sense for the total number of days were spent in taking assessments. It does not account for time studying before the first assessment or reviewing after the last assessment was taken (because that data is not captured in the system).
	The number of days between the start of the semester and when the first assessment was taken. This could be an indication of the strategy that a student is using for learning. For example, if the student begins taking an assessment immediately (as a formative tool) it could be a way of gauging what they need to know and identify what they should work on. Alternatively, a student could wait to take the assessment until after they review all of the material and feel ready to be assessed. The time between the start of the semester and the first assessment could give a sense for the student's learning strategy, using the assessment either as either a formative tool to gauge what should be learned, or a summative tool to gauge whether the material of the unit has been learned.

	The number of days between the start of the semester and when the last assessment was taken. This would give an indication of the total amount of time a student spent learning in the system, and how much later into the semester the student continued engaging with the material. However, the student could have started late in the semester for any number of reasons, we cannot assume that the start of the semester is when the student began engaging in the material.
	Average number of days between assessments. This calculates the sum of the number of days between an assessment and the assessment before it, and divides it by the number of assessments that were taken. This calculation gives an indication of frequency of engagement in the course material, it does not differentiate by number of unique assessments, or whether the assessments were power or additional. Students generally took multiple assessments on the same day, and often took multiple unit assessments at the same time (they did not complete one unit to mastery before starting the next) so this variable alone (without looking at patterns of performance) may be giving an inaccurate picture of the student's learning and assessment behavior. Observing patterns of individual performance may be more telling.
Total minutes on all assessments	Total number of minutes spent taking focus area unit assessments. This is calculated by taking the number of minutes spent taking (and re-taking) power and additional focus area unit assessments.
Total minutes on required assessments	Total number of minutes spent on power focus area assessments. This is calculated by taking the number of minutes spent taking (and re-taking) power focus area unit assessments. Additional focus area units, which are optional, are not included in this calculation.
	Total number of minutes spent on additional focus area assessments. This is calculated by taking the number of minutes spent taking (and re-taking) additional focus area unit assessments, which are optional. Power focus area units are not included in this calculation.
Average minutes per assessment	Average number of minutes spent on an assessment. This is calculated by taking the average time spent on each focus area (the sum of the number of minutes across all attempts on that focus area, divided by the number of times a student took that focus area), and dividing it by the number of unique focus areas taken, including both power and additional focus areas. This was used as the calculation for average time (rather than summing all of the minutes spent on all assessment attempts across all focus areas and dividing it by the number of attempts) because it reduces the impact of anomalies in assessment times, such as when a student left an assessment unfinished for the day).

Average minutes per required assessment **[assessment speed]**	Average number of minutes spent on a power assessment. This is calculated by taking the average time spent on each power focus area (the sum of the number of minutes across all attempts on that focus area, divided by the number of times a student took that focus area), and dividing it by the number of unique power focus areas taken. The minutes spent on additional focus areas is not included in this time calculation; it only includes the averages of the power focus areas (which are the focus areas that are required).
Average minutes per optional assessment	Average number of minutes spent on an additional assessment. This is calculated by taking the average time spent on each additional focus area (the sum of the number of minutes across all attempts on that focus area, divided by the number of times a student took that focus area), and dividing it by the number of unique additional focus areas taken. The minutes spent on power focus areas is not included in this time calculation; it only includes the averages of the additional focus areas (which are the focus areas that are optional).
	Average number of attempts per focus area. This is calculated by taking the sum of the number of times the student tried each focus area unit, and dividing it by the total number of unique focus areas that the student took. This includes the power focus areas as well as the additional focus areas.
Average attempts per optional FA/unit	The average number of attempts per additional focus area. This is calculated by taking the sum of the number of times the student tried each additional focus area unit, and dividing it by the total number of unique additional focus areas that the student took. It does not include the power focus areas in the calculation.
Average attempts per required FA/unit **[attempts]**	The average number of attempts per power focus area. This is calculated by taking the sum of the number of times the student tried each power focus area unit, and dividing it by the total number of unique power focus areas that the student took. It does not include the additional focus areas in the calculation.
	Number of unique focus areas the student took, including power and additional units. This variable does not account for the number of times a student took a unit, it only calculates the different units that were taken.
Number of required units taken **[amount of units]**	Number of unique power focus areas the student took. This variable does not account for the number of times a student took the unit or how the student performed on the assessments, it only calculates the number of total power units that the student attempted to take. (This variable is calculated as a percentage, that captures the percent of required units that the semester that the student worked on, rather than an absolute number of units.)
Number of optional units taken	Number of unique additional focus areas the student took. This variable does not account for the number of times a student took the unit or how the student performed on the assessments, it only calculates the number of total additional units that the student attempted to take.

Interest (Y/N)	This is a binary variable for interest. 1 indicates the student has demonstrated interest in the course by attempting at least one of the additional units, that were optional. 0 indicates that not a single additional unit was attempted.
Mastery	This variable indicates how many power focus area units a student mastered. This is the number of units for which the student earned a score of 80% or higher on an assessment for that unit.
Amount of optional units taken	Number of unique additional focus areas the student took. This variable does not account for the number of times a student took the unit or how the student performed on the assessments, it only calculates the different power units that were attempted/taken. This variable is turned into a percentage, to capture what percent of the total available optional units were taken, rather than an absolute number of units.

Statistical Analysis Plan

Prior to conducting inferential statistical analyses, I checked for potential model violations by examining the distributions of each variable and the bivariate relationships between individual predictors and outcome variables for the questions of interest. Overall, the data appeared to be fairly consistent with the underlying regression assumptions of linearity, homoscedasticity, and normality. I used correlation and multiple regression techniques to examine interrelationships between my selected time variable and other key variables as well as relative contributions of each measure in accounting for variability in the outcome.

Results

Descriptive Statistics

Descriptive statistics for the measures used in this study for each of the two schools, as well as for the full sample of students in both schools combined, are shown in Table 2, Table 3 and Table 4.

The academic achievement of students from the two schools in the Algebra I class was measured by combining performance on the assessments in the personalized environment (a computer-generated score based on the number of items answered correctly on the unit assessments), performance on projects (a rating given by the classroom teacher based on a common rubric), and performance in the course work units (also rated by the classroom teacher based on a common rubric), resulting in the student's applied knowledge score, which is the final score they receive in the course. The two schools used different but equivalent versions of 9th-grade Algebra 1 curriculum that were aligned with the common core standards[9]. In school 1, the course material was broken up into 6 units, while school 2 broke it into 7 units. I adjusted for this by converting the number of required units taken into percentages, so that a student's progress in the course would be calculated by the percent of required units a student engaged in rather than the absolute number of units taken.

Students in school 1 ranged in final score from 48 to 85, had a mean final score of 69 and a standard deviation of 8.7 (M = 69.17, SD = 8.69), which is generally lower than the performance of students in school 2. Students in school 2 ranged in final score from 58 to

[9] The Common Core State Standards define the skills and knowledge that students must have in order to succeed in college and work training programs. Common Core standards were initiated by the National Governors Association Center for Best Practices (NGA Center) and the Council of Chief State School Officers (CCSSO) which is comprised of state leaders, including governors and state commissioners of education from 48 states, two territories, and the District of Columbia (corestandards.org, nd; Summit Public Schools Year-End Summary 2017-2018).

98, had a mean final score of 83.5 and a standard deviation of 10.2 ($M = 83.55$, $SD = 10.16$). A t-test for independent groups showed that there was a statistically significant difference in final scores for students between school 1 ($M = 69.2$, $SD = 8.7$) and school 2 ($M = 83.6$, $SD = 10.2$); $t(73) = -6.54$, $p < 0.000$. The distribution of differences in final scores is illustrated in the box plot in Figure A1 in Appendix A.

The amount of time students in school 1 spent on assessments ranged from 53 days to 109 days, with a school mean of about 97 days and standard deviation of about 15 days. This is about half of the spread of school 2, who ranged from 14 days to 125 days and had a school mean of about 105 days, and a standard deviation of 23 days. A *t*-test for independent groups showed that there was not a significant difference in the amount of time for students between class 1 ($M = 96.75$, $SD = 14.93$) and class 2 ($M = 105.41$, $SD = 23.12$); $t(73) = -1.90$, $p = 0.062$. The distribution of differences in time is illustrated in the box plot in Figure A2 in Appendix A.

Whether or not a student indicated interest in the course by taking an optional additional unit was coded as a binary variable. A value of 1 signified that the student optionally engaged with extra material at in the course by taking one or more additional assessments during the semester, and a value of 0 signified that the student did not choose in to engage with any optional additional assessments during the semester. I chose to define interest as having taken at least one of the additional assessments because those are entirely optional, indicating that a student is voluntarily engaging in extra work because they are interested in learning more, challenging themselves, or pursuing their curiosity on the subject matter, without any external incentive or directive to do so. Given the completely voluntary nature of the engagement, any amount of optional engagement seemed appropriate to indicate interest and selecting a larger cutoff number for students seemed arbitrary. The school 1 mean of the interest variable is 0.63, and of school 2 is 0.45, both with a standard deviation of approximately 0.50, meaning that students in the sample from school 1 indicated a bit more interest in optional material than the sample from school 2. In other words, 63% of students in school 1 tried at least one additional unit, compared to 45% of students in school 2. While this difference seems large, a t-test showed that there was not a significant difference in the interest scores between school 1 ($M = 0.63$, $SD = 0.49$) and school 2 ($M = 0.45$, $SD = 0.50$); $t(73) = 1.55$, $p = 0.1253$.

The average number of unit assessments that were mastered in the two classes were similar, and the range of how many units were mastered ranged from 0 to 6 in both schools. In school 1 the mean number of units mastered was nearly 4 with a standard deviation of nearly 2 units ($M = 3.97$, $SD = 1.87$). In school 2, the mean number of units that were mastered was about 4 with a standard deviation of about 1.5 units ($M = 3.75$, $SD = 1.37$).

Table 2

Descriptive statistics for both schools combined (n = 75)

Variable	**Mean**	**SD**	**Range**
Applied Knowledge	76.8	11.9	48 – 98
Speed (days spent in semester)	101.4	20.1	14 – 125
Amount of required units (%)	0.8	0.2	0.2 – 1
Amount of additional units (%)	0.2	0.3	0 – 1
Mastery	3.8	1.6	0 – 6
Interest	0.5	0.5	0 – 1
Assessment speed (avg min)	1733	2100	8 – 11244
Optional assessment speed	915	2110	0 – 11711
Avg required unit attempts	5.4	3.8	1.5 – 26
Avg optional unit attempts	1.6	3.0	0 – 18
Average unit score	0.50	0.2	0.2 – 0.8
Average optional unit score	0.20	0.3	0 – 0.9

Table 3

Descriptive statistics for school 1 (n = 35)

Variable	**Mean**	**SD**	**Range**
Applied Knowledge	69.2	8.7	48 – 85
Overall speed (days spent)	96.8	14.9	52.99 – 109.3
Amount of required units (%)	0.9	0.2	0.166 – 1
Amount of Additional units (%)	0.1	0.2	0 – 1
Mastery	4.0	1.9	0 – 6
Interest	0.6	0.5	0 – 1
Assessment speed (avg min)	95	80	8 – 342
Optional assessment speed	97	278	0 – 1440
Avg required unit attempts	5.5	5.1	1.5 – 26
Avg optional unit attempts	1.5	2.5	0 – 14
Average unit score	0.6	0.1	0.32 – 0.8
Average optional unit score	69.2	8.7	48 – 85

Table 4

Descriptive statistics for school 2 (n = 40)

Variable	**Mean**	**SD**	**Range**
Applied Knowledge	83.6	10.2	58 – 98
Overall speed (days spent)	105.4	23.1	14 – 125
Amount of required units (%)	0.7	0.2	0.3 – 1
Amount of Additional units (%)	0.3	0.4	0 – 1
Mastery	3.8	1.4	0 – 6
Interest	0.5	0.5	0 – 1
Assessment speed (avg min)	3166	1961	680 – 11244
Optional assessment speed	1631	2693	0 – 11711
Avg required unit attempts	5.3	2.2	2 – 12.8
Avg optional unit attempts	1.7	3.4	0 – 18
Average unit score	0.4	0.1	0.2 – 0.7
Average optional unit score	0.04	0.1	0 – 0.4

Visualizations

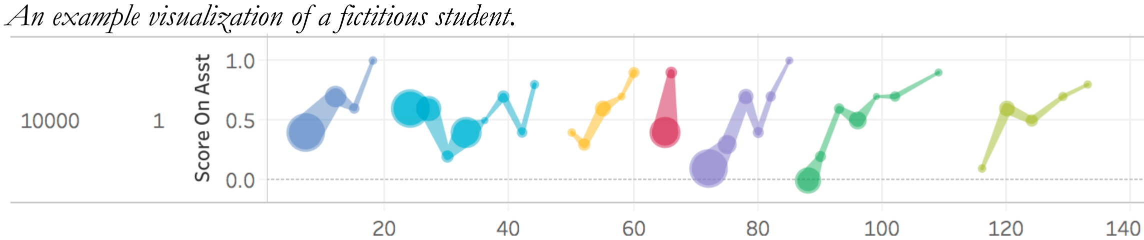
Descriptive statistics provide valuable information about the group characteristics of the aggregate samples, but do not provide information about individual students as they directed themselves through the personalized learning environment. In order to reveal the journey of individual students as they progressed through the semester in the self-directed environment, I used visualization techniques to supplement the general descriptive characteristics with a range of targeted individual illustrations.

Description. Visualizations of individual patterns of student progress demonstrate the variability in the ways that students engaged with the personalized learning environments. The diagrams below showcase some examples that highlight some of the differences in strategies, processes, and approaches of students in the Algebra 1 course. The x-axis designates time scale in number of days of the semester, with the first day of the semester at the first vertical line, which represents day 0, and the end of the semester on the right side, with the last horizontal line at the 140-day mark. Vertical lines are present at 10-day increments. The y-axis denotes the percentage scale, wherein the score on each assessment attempt is indicated by where the dot is positioned, a 0 is the lowest point of the y-axis indicating the student scored 0% on the assessment, and 1 is the highest point on the y-axis indicating the student scored 100% on that assessment. The area of each dot represents the amount of time in minutes that the student spent on that assessment attempt, ranging in scale from 1 minutes to 260 minutes. A key that denotes the size distinctions of the diameters is provided in Figure A3 in Appendix A. Assessments that took longer than 260 minutes were given the same area as 260-minute assessments in order to reduce the visual obfuscation of long assessments on the assessments around them. The colors represent the different units in the course (key of assessment topics and the color key for each unit can be found in Figures A4 and A5 in Appendix A); the color red represents optional additional units that the student took, all other colors represent required units for the course. The lines that connect the dots denote that the assessments attempts are of the same unit. Because the differences in the colors may not be easily discernable, the lines that connect the assessment attempts related to the same unit may more easily show which attempts are part of the same unit.

An example of a visualization from a fictitious student, student 10000, is provided as below for illustrative purposes (Figure 1). This student began taking assessments in the first week of the semester and continued steadily working on assessments through the end of the semester, mastering one unit before progressing to the next. In this example, each unit was attempted numerous times (between two and eight times depending on the unit), with assessments often taking longer the first few attempts and speeding up on later attempts as the student works toward mastery. This is an example of the kind of pattern of engagement I would expect to see in the data of a student in a traditional school environment that is oriented toward mastery learning.

Figure 1

An example visualization of a fictitious student.



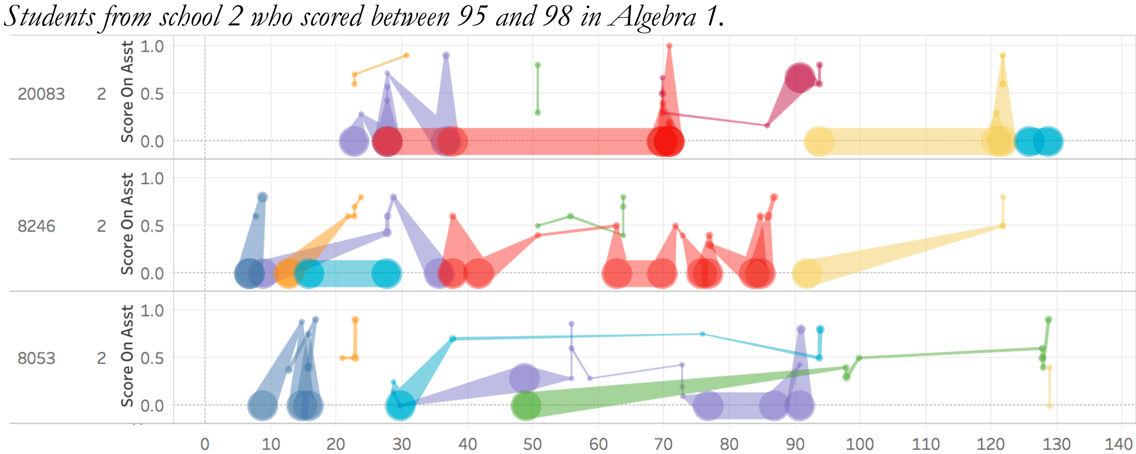
The visualizations of students from personalized learning environments, where students have the autonomy to direct their own learning, reveals patterns that are considerably different than this. Below I display the patterns of progress of students that scored the highest on Algebra 1 in each school, and the students from both schools who scored in the mean of the complete sample. The visualizations demonstrated in these figures showcase the tremendous variability in the individual patterns of progress of students whose ultimate applied knowledge scores in the course were similar. A complete list of visualizations of all of the students in the study in Algebra 1 is presented in Figure A6 in the Appendix A.

Examples.

Highest scores from School 2. Figure 2 shows the pattern of the top-ranking students in school 2, who received the highest final scores in Algebra (these are also the students who scored the highest of all of the students in the complete sample). Student 20083 scored 98, student 8246 scored 97, and student 8053 scored 95.

Figure 2

Students from school 2 who scored between 95 and 98 in Algebra 1.



Student 20083, spent 106 days between the first and last assessments in the course, attempted 7 different units in total, 2 of which were optional. The student began the first assessment 23 days into the semester, taking assessments as many as 10 times. Many attempts lasted several hours and resulted in assessment scores of 0, but ultimately the student mastered 86% of all the units attempted. In a few instances, the student began working on a new unit before mastering the previous unit, meaning the student was working on multiple units simultaneously, and on occasion took multiple assessments on the same day. The overall speed of student 20083 was approximately the mean speed of students in school 2, and 10 days faster than the median of the school, which was 116 days. This student attempted 71% of the required units in the Algebra 1 course, and elected to take 33% of the optional units available.

Student 8246 spent 115 days between the first and last assessment in the course, and attempted 7 different units in total, 1 of which was optional. The student began the first assessment 7 days into the semester, taking assessments as many as 18 times. The student took assessments a total of 34 times during the semester; nearly half of the attempts lasted several hours and yielded a score of 0 on the assessment. Ultimately, the student mastered 86% of the units that were attempted. Throughout most of the semester, the student was working on multiple units simultaneously. The overall speed of student 8246 was around the 50^{th} percentile of students in school 2. This student got started earlier than 75% of the students in that school, attempted 86% of the required units and elected to take 17% of the optional units available.

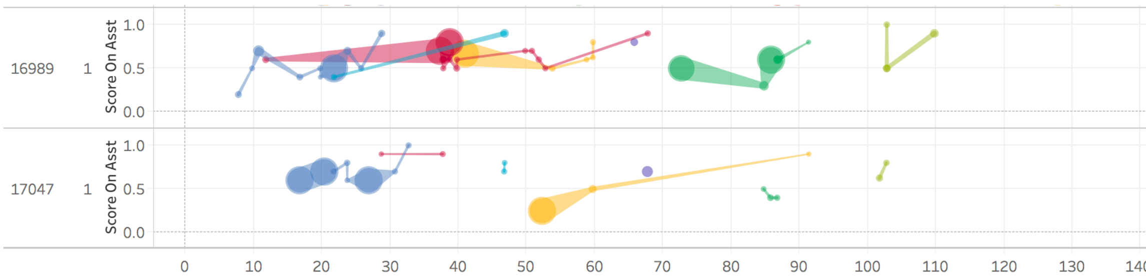
Student 8053, began taking assessments 9 days into the semester, spent 120 days between the first and last assessment in the course, attempted 6 required units and did not take any additional optional units. This student re-took assessments as many as 15 times, often times dropping in score between attempts on the same unit assessment. The student often worked on multiple units simultaneously and ultimately mastered 83% of the units that were taken during the semester. The overall speed of student 8053 was in the 75th percentile of students in that school (meaning 2/3 of the students in that student's class progressed through the course more quickly). This student got started at the same time as half of the students in that school, attempted 86% of the required units and did not elect to take any of the optional units available.

The students who earned the highest overall scores in school 2 (and also in the complete sample) had some commonalities in their patterns of progress. They all worked on multiple units simultaneously, often taking assessments for different units on in the same day and then going long periods of time (sometimes ten or more days) without engaging in any assessments. All of these students scored 0 on many of their assessment attempts, and re-took the assessments until they reached mastery on most of the units. Not all of these students engaged in the additional, optional units, and the overall days spent working on the course differed for these students.

Highest score from school 1. Figure 3 shows the two students (students 16989 and 17047) who received an overall score of 85 in Algebra 1, which was the top score of students in school 1.

Figure 3

Students from school 1 who scored 85 in the Algebra 1 course.



Student 16989, spent 102 days between the first and last assessments in the course, attempted 7 different units in total, 1 of which was optional. The student began the first assessment 8 days into the semester, taking assessments as many as 14 times. Only a couple of the attempts lasted several hours, none of which resulted in assessment scores of 0, and ultimately the student mastered all the units attempted. In a few instances, the student began working on a new unit before mastering the previous unit, meaning the student was working on more than one unit simultaneously, but rarely took assessments of different units on the same day. The overall speed of student 16989 was five days slower than mean speed of students in school 1 (and two days slower than the median, which was 100 days). This student attempted 100% of the required units in the Algebra 1 course, and elected to take 17% of the optional units available.

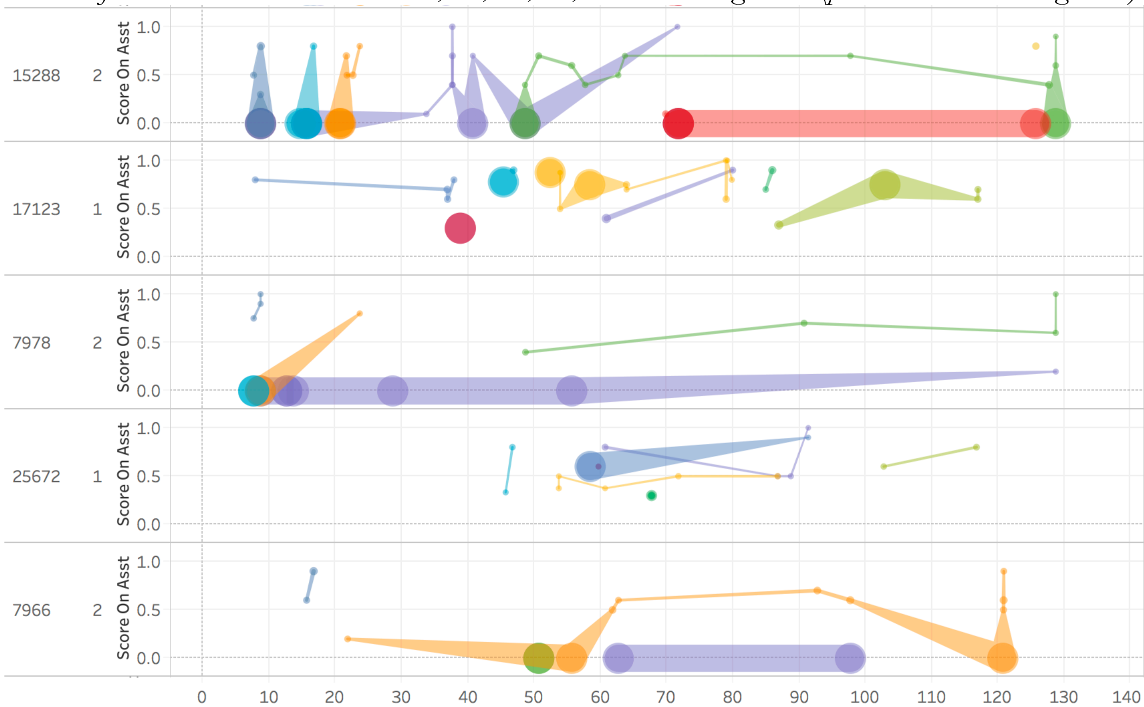
Student 17047, spent 86 days between the first and last assessments in the course, attempted 7 different units in total, 1 of which was optional. The student began the first assessment 17 days into the semester, taking assessments up to 8 times. A few of the attempts lasted several hours, none of which resulted in assessment scores of 0, and ultimately the student mastered 67% of the units attempted. In only a couple instances, the student began working on a new unit while still working on another unit, however this student never took assessments of different units on the same day. The overall speed of student 17047 was 11 days slower than mean speed of students in school 1 (and 14 days faster than the median). This student attempted 100% of the required units in the Algebra 1 course, and elected to take 17% of the optional units available.

The patterns of performance of the students who received the highest scores in school 1 show that the students attempted all of the required units, most of their assessment attempts were less than 45 minutes, and none of the attempts resulted in a score of 0 on the assessment. Both of the students engaged in an optional unit. Student 16989 mastered all of the units attempted, and student 17047 mastered 67% of the units attempted. They varied considerably in the amount of time they spent working on the course, and they differed in how much time they spent between units and between assessment attempt within the same unit.

Mean scores from complete sample. The mean score of the full sample of students was 77. Figure 4 shows students from both schools whose final score was around the full sample mean (who scored 77 in the course +/- 1 point).

Figure 4

Students from both schools who scored 78, 78, 77, 77, and 76 in Algebra 1 (presented in descending order).



Students 15288 and 17123 both received the same final score in the course (both of them received a score of 77 on how they applied the knowledge they learned in the personalized environment). The patterns of performance of these two students, one from each school, throughout the semester are notably different. Both students began taking assessments within a week of the start of the semester. Within days, student 15288 took the first assessment four times until reaching mastery, with the first attempt taking many hours and resulting in a score of 0, then progressively getting better on each attempt until reaching mastery. This student followed a similar pattern throughout the rest of the semester, generally focusing on one unit at a time and taking some unit assessments as many as 12 times before moving on to the next. There were a few instances of overlap in units throughout the semester, and the student rarely worked on two different units on the same day. This student took 8 units in total, 2 of which were additional, and reached mastery on 75% of the units taken. Student 17123 waited about 30 days between the first and second assessments taken in the semester. At no point in the semester did the student score 0 on any assessment that was attempted, and this student made a maximum of 10 attempts on a unit's assessment. This student took seven units in total, one of which was optional, and reached mastery on 86% of the units taken. One notable observation about these students is they both continued to re-take the unit assessment even after reaching or exceeding the mastery threshold of 80% on the assessment, sometimes resulting in a drop in assessment score on subsequent attempts. This may suggest that even though the student scored highly on the assessment, the student may be aware that several of the guesses were lucky, and taking subsequent assessments would allow the student to better evaluate whether the assessment score is indicative of how confident the student is about the learning that actually took place.

Students 7978 and 25672 scored 77, which was the mean score of the full sample of 75 students. The patterns of performance of these two students, from different schools, throughout the semester are visibly different. Student 7978 began taking assessments within 5 days of the start of the semester, and worked on four assessments within the subsequent ten days, and spending several hours on assessments that resulted in a score of 0. This student worked on a total of 5 units and took no optional units, and re-took assessments up to 7 times. This student spent 121 days between the first and last assessment, and ultimately mastered 75% of the units taken. Student 25672 began taking assessments 46 days of the semester, and spent 71 days between first and last assessment in the course, with nearly all of the assessments happening 46 to 91 days into the semester. This student took a total of 7 units, one of which was an optional unit, and mastered 57% of the units taken.

Student 7966 scored 76, took 4 units in total, none of which were optional, and attempted one of those units 10 times. This student began taking assessments 16 days into the semester and spent 105 days between the first and last assessments. The student mastered two of the four units that were taken in the personalized learning platform.

There are not many similarities in the patterns of the students from the full sample whose final score in Algebra 1 was near the mean score of 77. There are, however, notable similarities in the patterns of the students by school. Students from school 1 (17123, 25672) did not work on multiple assessments on the same day, generally go through assessments quickly, but never scored 0 on any of the attempts. Students from school 2 (15288, 7978, 7966) generally spent several hours and scored 0 on at least one of the attempts for each unit that the student tried, and made multiple attempts over many days on each unit. Beyond that, however, the visualization of the five students reveal that very different patterns can lead to a similar final score in the course.

Zero-Order Correlations

Prior to my regression analyses, I examined the zero-order correlations between time, applied knowledge, and the other variables in my study. The results of the complete matrix of key variables, presented in table 2, show that many variables are significantly related to the applied knowledge scores. Variables with positive correlations included the number of overall days in the course ($r = 0.30$, $p = 0.01$), indicating that students who spent more days between their first and last assessments tended to score higher in the course, the average speed on required assessments ($r = 0.40$, $p < 0.001$), indicating students who averaged more minutes per required assessment (meaning they were slower to complete assessments) scored higher in the course, the number of required units taken ($r = 0.33$, $p =$

0.004), meaning students who took more units did better in the course, and the number of units mastered ($r = 0.37$, $p = 0.001$), indicating that students who mastered more required units scored higher in the course. Variables with negative correlations included the average attempts on required units ($r = -0.05$, $p = 0.70$), which indicates that students who took fewer assessment attempts did better in the course, and the student's average score on required units ($r = -0.20$, $p = 0.09$), indicating that students who averaged lower assessment scores tended to do better in the course. The negative correlation between average score on a unit and final score in the course would be confusing in a traditional school environment, but in a learning environment where students are able to take assessments multiple times, it makes sense that many assessment attempts where the student did not achieve mastery, combined with one assessment where the student scores 80% or higher, would result in a low average score for the assessments of that unit. Many of the variables were also correlated with each other, thus my analysis will shed light on how much power each of these variables will offer in the context of a multiple regression model. A correlation matrix that includes various other potential time variables is provided in Table 2.

Table 2

Pearson correlations among measures for students in both schools (n = 75)

	1	2	3	4	5	6	7	8	9	10	11
1. Applied knowledge	1.00										
2. Overall speed (days)	0.30**	1.00									
3. Avg. min. on required assessment	0.40***	0.20	1.00								
4. Avg. min. on optional assessment	0.44***	0.22	0.24*	1.00							
5. Avg. required unit attempts	-0.05	0.17	0.20	-0.07	1.00						
6. Avg. optional unit attempts	0.35**	0.12	-0.03	0.73*	-0.06	1.00					
7. Required units taken	0.33**	0.37*	-0.11	0.18	0.08	0.22	1.00				
8. Required units mastered	0.37***	0.36*	-0.08	0.24*	0.16	0.30*	0.79*	1.00			
9. Optional units taken	0.17	0.10	-0.12	0.30*	0.02	0.35*	0.32*	0.41*	1.00		
10. Interest	0.18	0.13	-0.19	0.41*	0.07	0.50*	0.39*	0.43*	0.73*	1.00	
11. Avg score on required unit	-0.20	-0.02	-0.66*	-0.15	0.004	0.07	0.20	0.43*	0.25*	0.35*	1.00
12. Avg score on optional unit	-0.07	-0.14	-0.46*	-0.07	0.05	0.34*	0.24*	0.26*	0.45*	0.64*	0.55*

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Research Question 1

Is there a relationship between time/speed and performance?

For my first study I examine the relationship between speed and performance, as measured by applied knowledge, to see whether students who learn content faster than their peers perform better in the overall course. To determine whether there is a relationship between speed of learning and performance, I examine the time it takes for a student to complete the content units of an Algebra 1 course using the personalized learning platform, to see if students who move through the course content more quickly (in terms of days spent learning the material) performed better in the course with regard to the applied knowledge scores.

The correlation coefficients from the matrix presented earlier showed that a number of the speed-related variables were correlated with the overall performance scores, revealing a general relationship that indicates students who took longer performed better. But we also noted that many of the variables were intercorrelated, and we had noted earlier that the performance scores differed overall between the two schools. To better understand the relationships between the variables, I conducted multiple regression analyses.

Multiple regression models. To develop a better understanding of the relative contributions made by key variables outlined above (autonomy, mastery, interest) on the outcome of achievement, as measured by the applied knowledge score, I ran a series of multiple regression analyses (results presented in Table 6).

I used the applied knowledge score as the outcome variable because applied knowledge scores are determined by a number of factors that all involve different ways of demonstrating the content knowledge that is acquired in the self-directed personalized learning environment. For a math course, the assessment performance in the personalized environment typically accounts for 30% of the final score. The course project (which requires students to demonstrate the content knowledge they acquired in the course through application of course content into an applied project), and the student's performance on course work in a group setting, make up the remaining 70% of the student's final course score, which reflects the student's overall applied knowledge of the course material. The core math content that is available to students in the personalized learning environment is assessed multiple ways to determine the student's applied knowledge, making it a good outcome variable.

The key predictor variables I tested in my model alongside time were mastery and interest. Mastery was a key variable to test because of its central role in debates about the use of instructional time during school hours, and because of the critical role of mastery in personalized learning environments. Interest was also a key variable to test because of the purported effect of interest and engagement on performance.

I began by fitting a control model (model 1) where school and time were entered simultaneously as covariates. This approach provided a baseline model that controls for differences between the schools and gives an estimate of the relationship between time and achievement, to which I can add other key variables to compare the relative importance of other predictors. In this baseline model, time was not a significant predictor of achievement ($\beta = 0.101$, $p = 0.073$), but school was ($\beta = 13.505$, $p < 0.001$). The time coefficient of 0.101 suggests that students who took more time tended to get higher final scores in the course; however, this trend was not strong enough to be statistically significant. The school coefficient tells us that students in school 1 scored 13.5 points higher than students in school 2, which is consistent with the descriptive statistics. This baseline model accounted for about 40% of the variance in applied knowledge ($R^2 = 0.397$, $F(2, 72) = 23.70$, $p < 0.001$), and school provided about 37% the explanatory power in this model ($R^2 = 0.369$, $F(1, 73) = 42.74$, $p < 0.001$).

Next, I addressed the potential role of mastery on overall achievement measured by applied knowledge scores (model 2) in which the standardized mastery score was added as a new predictor to the existing baseline control model. In this model, mastery was a significant predictor of applied knowledge scores ($\beta = 3.051$, $p < 0.001$), even after controlling for speed and school. The inclusion of mastery increased the explanatory power of the model by 17% ($R^2 = 0.538$, $F(3, 70) = 27.21$, $p < 0.001$). In this step we see that students' scores on the mastery tests appeared to be more important than speed (being the amount of time they spent in the semester on the course material).

The third step in my analysis was to examine the influence of interest on applied knowledge scores. I estimated a model (model 3) that included the interest predictor in addition to all of the other variables identified in the previous model. Recall that the interest variable was a simple indicator of whether the student attempted an optional unit in the course. The result suggests that interest is not a significant predictor of applied knowledge for students in Algebra 1 (β = 3.136, p = 0.146). Mastery and school maintained their significance as predictors of applied knowledge (β = 2.660, p < 0.001, and β = 15.389, p < 0.001, respectively), but time was still not significant (β = 0.004, p = 0.944). This model accounted for 55% of the variance in applied knowledge (R^2 = 0.5524, F(4, 69) = 21.29, p < 0.001).

I then added variables to the model (model 4) that controlled for the average assessment speed, average assessment attempts, and average assessment score. I included those in my model because those are the typical signals that can be observed in standardized environments to gauge whether a student is going to do well in a course. If students re-take a unit's assessment multiple times, spend a long time taking the assessments, and do not score well on most of the assessment attempts, it is assumed by those indicators that the student is not going to perform well in the course. The results in model 4 reveal, however, that average speed on assessment (β = 0.001, p = 0.922), number of attempts to re-take an assessment (β = -0.31, p = 0.257), or score on the multiple attempts (β = 3.22, p = 0.756), are not statistically significant predictors of the final grade in the course.

In all of my models thus far, the school was a significant predictor, mastery was a significant predictor, but time and interest were not. Adding the additional variables to the model provides 1% additional predictive power; model 4 accounts for 56% of the variance in applied knowledge scores (R^2 = 0.5628, F(7, 66) = 12.14, p < 0.001). In this model, school has a coefficient of 15.6, indicating that there is a nearly 16-point difference in final score performance depending on which school the student was enrolled in for the Algebra course (β = 15.597, $p < 0.001$). Mastery has a coefficient of 2.6, indicating that a one-unit difference in the number of required units a student mastered is associated with a nearly 3-point difference in the final score (β = 2.637, $p = 0.001$). The finding of a stable effect of mastery here supports the assertion that mastery is important and has critical consequences for outcomes. The key finding here is that the amount of time a student takes does not have a significant effect on final score; the student being interested in the material does not have a significant effect on the final score; but allowing a student to master the material in the unit has significant effects how the student performs in the class.

Next, I considered whether there were interaction effects. I evaluated the possibility of interaction effects in the data by estimating three additional models that included variables representing the cross-product between several key variables. I tested interactions with the schools to see if there was a differential effect of mastery, time, or interest by school. I first ran the interaction terms one-at-a-time, and then added the three interaction terms together to model 4 to create model 5.

School-by-Mastery. I created a school-by-mastery variable wherein I test for an interaction effect of school by mastery, to see if the effect of mastery differed by school. In a model with only school, mastery, and school-by-mastery, the interaction variable was not significant (β = -0.61, $p = 0.616$). The null hypothesis tested that the regression coefficient for the interaction term is zero (the null hypothesis is that there is no school by mastery interaction). Given the p-value of $p > 0.05$ I do not reject the null hypothesis. I thus endorse the model that does not include the school-by-mastery interaction.

School-by-Time. I then tested for an interaction effect of school by time, to see if the effect of time differed by school. In a model with only school, time, and school-by-time, the interaction term was not significant (β = 0.138, $p = 0.273$). The null hypothesis tested the null hypothesis that there is no school by time interaction. Given the p-value of $p > 0.05$ I do not reject the null hypothesis. I thus endorse the model that does not include the school-by-time interaction.

School-by-interest. I also tested for an interaction effect of school by interest, to see if the effect of interest differed by school. In a model with only school, interest, and school-by-interest, the interaction term was not significant (β = -6.502, $p = 0.123$). The null hypothesis tested that the regression coefficient for the interaction term is zero (the null hypothesis is that there is no school by interest interaction). Given the p-value of $p > 0.05$, I do not reject the null hypothesis. I thus endorse the model that does not include the school-by-interest interaction.

Finally, estimated model 5, in which, I added all of the interaction variables to model 4, to see if there were any significant interactions when testing the terms in the complete model. Model 5 reaffirms that none of the interactions were significant; mastery, however, was (β = 5.32, $p = 0.028$). This suggests that while mastering the modules in the personalized learning platform is important for a student's ability to demonstrate applied knowledge in the course, that the effect of mastery on the overall performance is not moderated by which school the student attended. After checking for possible interactions, it still holds that neither the amount of time a student takes, nor the student's interest in the material have a significant effect on final scores, whereas allowing a student achieve mastery has significant effects how the student performs in the class.

Table 6

Results of fitting a taxonomy of multiple regression models predicting applied knowledge in Algebra 1 (n = 75)

Variable	Model 1 **β** **(SD)**	Model 2 **β** **(SD)**	Model 3 **β** **(SD)**	Model 4 **β** **(SD)**	Model 5 **β** **(SD)**
School	13.51*** (2.22)	14.85*** (1.99)	15.39*** (2.01)	15.60*** (3.09)	0.05 (5.06)
Speed/Time	0.10 (0.06)	0.01 (0.05)	0.004 (0.05)	0.01 (0.05)	-0.40 (0.22)
Mastery		3.05*** (0.64)	2.66*** (0.69)	2.64** (0.78)	5.32* (2.36)
Interest			3.14 (2.13)	3.04 (2.17)	12.39 (7.08)
Avg min on assessment				0.00 (0.00)	-0.0004 (0.001)
Avg attempts per unit				-0.31 (0.27)	-0.34 (0.27)
Avg score on required unit				3.22 (10.31)	-8.03 (11.21)
School-by-Mastery					-1.70 (1.53)
School-by-Time					0.25 (0.13)
School-by-Interest					-5.90 (4.32)
Constant	45.91*** (6.01)	41.79*** (5.36)	41.00*** (5.35)	39.91*** (8.12)	71.53** (21.63)
R^2	0.40	0.54	0.55	0.56	0.60

Note. * $p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

Model 5 indicated that school did not moderate the effect of mastery, interest, or time on outcomes, so I ran another regression in which I removed school from model 4 to determine whether this affects the importance of mastery or the insignificance of time. When I do not control for school in the model, mastery remains significant (β = 3.092, p = 0.001), and two additional variables become significant: average minutes per assessment (β = 0.002, p = 0.007), and average number of tries per assessment (β = -0.662, p = 0.035). Speed, interest, and average score on assessments maintain no predictive power on applied knowledge scores in Algebra 1. The mastery coefficient of 3.1 indicates that mastering one required unit is associated with a nearly 3-point higher final score. Average minutes per assessment had a very small coefficient of 0.002, indicating that students who averaged two-hours longer per assessment only predicted a quarter of a point lower on their final scores (averaging one minute faster on assessments predicted 0.002 points higher on final scores). The coefficient for average number of tries per assessment was -0.7, indicating that students who averaged one less attempt on assessments scored almost one-point higher final score in the course. This model had the lowest explanatory power of all of the models (R^2 = 0.3940, F(6, 67) = 7.26, p < 0.001), therefore I did not include this model in the figure.

Discussion of research question 1. In personalized learning environments where students are learning Algebra 1, the amount of time that students took to complete the course was not related to their overall performance in the course. Some students progressed more quickly while others took their time, but there was no simple relationship between students' speed through the course work and overall performance in the course. The more important factor that mattered for performance in the course is whether a student masters the content, irrespective of how long that takes. Students who master material more quickly are not any more likely to perform better in the course than students who take longer to reach mastery.

Accepting that a student's speed of learning is not related to performance, and that mastery is important does have very practical implications for learning environments. While it may seem obvious that mastering material would lead to better performance in the class overall, traditional systems of education often do not give students the space to be self-directed or the supports to continue their efforts until they reach mastery. If we genuinely believe that mastery matters, we need to create learning environments that do not arbitrarily limit the time it takes a student to learn and require them to move on before they are ready; we need to rethink the way we use time to ensure we are providing the opportunity to truly learn in ways that produce the kinds of learning results we want.

Research Question 2

Is pace of learning stable across time and content?

Researchers have long recognized that there are individual differences in pace of learning (see Gettinger, 1984 for review). Early educational models assumed pace of learning is generally stable for an individual (Caroll & Spearritt, 1967; Arlin, 1984), but limited attention has been paid to whether individuals are stable in their pace of learning, or whether pace of learning fluctuates from time to time. If students who proceed through the material faster are always consistently faster over time and across different subjects, then efforts to enhance the effectiveness of the traditional fixed-pace classroom environments, honors programs that deliver curricular content at an accelerated speed, or remedial courses that provide instruction at a consistently slower pace, may be effective in reaching students.

But if a student's speed varies over time or across contexts, the predetermined pace of progress that traditional learning environments prescribe may be unfavorable for many learners, and efforts to enhance their efficiency may be misguided. To address my second major research question, I will examine whether students exhibit relative stability in pace, or if their relative speed of learning changes over time or across different academic courses.

Analysis of speed across content. To examine whether the pace of an individual is stable over time and across content, I expanded my analysis of students who took Algebra 1 in the 9^{th}-grade to include their data from the Chemistry class those same students took together in their 10^{th}-grade year of school. Of the complete sample of 75 students who took Algebra 1, there was one student who did not take Chemistry with the rest of the cohort of peers, and therefore was not included in this analysis, leaving 74 students in the sample for this analysis. There were 35 students from school 1, and 39 students from school 2.

I used Spearman's rank order correlation to test whether there were relationships between a student's relative speed over time and across content. The students who took both Algebra 1 and Chemistry were rank ordered by speed (in total number of days) in each of the courses. I then examined whether students who were relatively speedy in their work in Algebra 1 were also those who were relatively speedy in their work in Chemistry.

Speed was measured by the number of days a student spent between the first and last assessments in the course; the student with the smallest number of days, who spent the least amount of time on the course and therefore was the fastest, was given a rank of 1, and the student who spent the greatest number of days between first and last assessments was given the rank of 74. Chemistry speed of all 74 students in the complete sample was also ranked using this technique.

Each course is made up of units that are designed to be covered in one semester. The Algebra 1 and Chemistry curricula are broken out into a different number of units depending on the school, and the amount of content within each unit is not explicitly designed to take the same amount of time, so rather than comparing relative speed per unit, I tested the number of days spent taking assessments in the personalized learning platform, and considered the student's relative stability of rank order speed across the different subjects/classes. I examined the results for the combined entire sample of students, and I also conducted analyses for each school separately, wherein the sample of students from each school were ranked against their peers in each class.

Combining both schools. Testing the full sample of students from both schools, there was a small significant positive relationship between a student's rank order of speed in Algebra 1 and their speed in Chemistry $r_S(74) = 0.27, p < 0.05$. There was a small trend such that students who were faster in Algebra were also faster in Chemistry, although the magnitude of this relationship was rather small.

School 1. For the students within school 1, the consistency was a bit stronger, $r_S(35) = 0.45, p < 0.05$. Students who were faster in Algebra were also faster in Chemistry, and the relationship was moderate.

School 2. For school 2, the results indicated that the relationship was not as strong as in School 1 $r_S(39) = 0.24, p > 0.05$. Among students in school 2 there was only a weak trend, so we cannot conclude for this school that the students who were faster in Algebra were faster in Chemistry.

Analysis of speed over time in same content. To test rank order of speed over time in the same subject, I distilled my sample to focus on the students who completed six required focus area units in Algebra 1. In a personalized environment where students can direct their own learning, students have the autonomy to choose which of the modules they focus on in and to what extent they will engage in the unit. Consequently, the students do not always decide to complete all of the units that are required in the personalized learning system. This could be due to students already knowing the content and choosing to manage their time in ways that are most effective for the acquisition of new material, or it could be indicative of a lack of interest in the course content, or an indication that the student was not able to manage time in a sufficiently effective manner that would lend to the completion of the units in the personalized learning platform. Regardless of the student's reasons, in order to limit the unnecessary assumptions about my data, and to ensure the students being tested in this analysis can be appropriately ranked, I selected on those students who completed six of the required Algebra 1 focus area units in the personalized learning platform. Limiting the participants to the students who completed six required units reduced my full sample to 34 students in total from both schools, 21 students from school 1, and 13 students from school 2.

In a self-directed environment, students are able to decide for themselves the order in which they progress through the learning units, so they do not always follow the recommended sequence. Therefore, I tested the rank order of speed in two ways: first, by grouping the first three units the student chose to complete as self-selected "chunk 1" and the next three units the student chose to complete as self-selected "chunk 2" and testing their rank order in speed across the two student-selected chunks. By comparing speed through the first "chunk" (the first three self-selected units that the student chose to work on during the semester), I may not be comparing common units because each unit does not contain the same amount of content and is not necessarily expected to take the same amount of time. In order to address this issue, I also grouped learning units another way. The second way I investigated speed over time was to break up the semester in two modules, wherein I grouped the first three units that were in the recommended sequence as "module 1", and the next three units in the recommended sequence as "module 2." This measure allowed me to compare speed across a group of units that were intended to be taken in the first half of the semester and what was intended to be taken in the second half of the semester, irrespective of whether they were taken in the recommended order, so the amount of material in the units being compared are the same.

Combining both schools. I investigated whether there were any relationships between the rank order of speed of students taking the first self-selected chunk of units in Algebra (the first three units the student chose to complete) and the second self-selected chunk of units the student completed in the course. A two-tailed test of significance indicated the there was a significant positive relationship between the rank order of speed of students completing the first self-selected chunk of the units and the second self-selected chunk of units in the course $r_s(34) = 0.68, p < 0.05$. The students who were faster completing the first chunk of units were faster completing the second chunk of units. When examining the complete sample of students across both schools, when choosing their own sequence, the students who completed the first three units more quickly were also faster to complete the second set of three units. The size of this relationship was moderately large.

I also tested Spearman rank-order correlations to determine if there were any relationships between the rank order of speed of students taking the first module (the first three units of the recommended sequence), and the second module (their rank order of speed on the last three units of the recommended sequence). The correlation coefficients indicated that there was a very strong relationship between how quickly a student completed module 1 (the units that were sequenced to be done in the first half of the course), and how quickly they completed module 2 (the units that were sequenced to be done in the second half of the course) $r_S(34) = 0.91$, $p < 0.05$. In the complete sample that included both schools, students who were faster in completing the first module of the course material were also faster in completing the second module of the course material. The magnitude of this relationship was very large.

The strong relationship in the rank order of students' speed over time on the same subject could be a due to school differences, either in the kinds of strategies for time management that are developed in the schools, or differences in the kinds of students that attend the schools. To see if the strength and stability of the rank order relationship still holds when broken down by school, I ran rank order analyses of students by each of the two schools.

School 1. Conducting Spearman's rank-order correlations of the 21 students in school 1 who completed six required units revealed that there was no relationship between the rank order of speed of students who completed the first self-selected chunk of the units quickly and the students that completed the second self-selected chunk of units in the quickly $r_S(21) = 0.11$, $p > 0.05$. In school 1, the students who were faster to complete the first chunk of units were not faster on the second chunk of units.

There was also not a significant relationship between how quickly a student completed the first module of units, and how quickly they completed the second module of units in the course $r_s(21) = 0.20, p > 0.05$. In school 1, students who were faster in completing the first module of the course material were not faster in completing the second module of the course.

School 2. Testing rank-order correlations for the 13 students in school 2 who completed six required units revealed that there was no statistically significant relationship between the rank order of speed of students completing the first self-selected chunk of the units and the second self-selected chunk of units in the course $r_s(13) = 0.18$ $p > 0.05$. In school 2, students who were faster to complete the first chunk of units were not faster on the second chunk of units.

There was also not a significant relationship between how quickly a student completed the units in the first module of the course, and how quickly they completed the units in the second module of the course $r_s(13) = 0.51, p > 0.05$. In school 2, students who were faster in completing the first module were different than those who were faster in completing the second module.

Discussion of research question 2. When comparing the rank order of students drawing from the full sample of students in both schools across content, students who were faster in Algebra were also faster in Chemistry. In school 1, Students who were faster in Algebra were also faster in Chemistry. However, in school 2, the students who were faster in Algebra were not the same students who were faster in Chemistry.

When comparing the rank order of all of the students over time across the full sample of students in both schools in their speed through the two halves of the semester, there was a significant relationship between speed in the first half of the semester (whether chunked by the student's self-selected ordering of content, or grouped by the sequential modules that were recommended) and speed in the second half of the semester. When combining the full sample of students from both schools, 46% of the variance in the speed of students that were faster in chunk 1 was explained by the speed students who were faster in chunk 2, and 83% of the variance in the speed of students who were faster on module 2 was accounted for by the speed of students who were faster on module 1.

However, when comparing the rank order of the students within each school, there was no relationship between speed of students in the first half of the course (either in the order the students themselves chunked the first half of the units, or when ordered in the sequence that was recommended by the modules) and their speed in the second half of the course. In both of the schools respectively, students' changed rank order in how fast they were relative to their peers throughout the semester.

While in the aggregate there is a significant correlation between speed over time and across content, that relationship does not hold at the school level. There was a clear difference in the findings when analyzing the combined sample of students from both schools and the findings when separating students by school. These differences may be attributable to teacher differences, differences in strategies students were taught in the different schools regarding time management, differences in self-knowledge that students developed in the school environment about how to direct their own learning habits, differences in certain characteristics of students enrolled at the schools, or any number of other factors that were not captured in my data. What is clear from this, however, is that we cannot predict a students' speed within a subject or between subject/content areas without knowing more. The lack of consistent statistically significant relationships at the school level underscores the limits of what we can infer about a student's speed of future learning based on speed at previous times or other subjects.

Research Question 3

What are predictors of speed/time?

It was established in the earlier analysis with research question 1 that speed of learning is not predictive of a student's final applied knowledge score in a course. While this is an important finding that affects the kinds of flexibility we afford students in a classroom environment, time is also a precious commodity that should be used effectively, particularly within school hours where students are required to be in attendance. Understanding what factors influence time in a learning environment may be able to shed light on where the leverage points to affect speed of learning are situated. My third analysis examines what other factors are related to speed.

Regression model development. To gain an understanding of factors that are related to the speed that students used in working through the course material, I ran a series of multiple regression analyses (results presented in Table 7). I began by drawing on the full model (model 4) that I developed in research question 1 to inform my model development for this analysis. I fitted a model (model 6) by entering the variables of mastery, interest, average time on assessment, average number of assessment attempts per unit, average score per unit, and school from model 4 as covariates, but used speed as measured in total number of days from first assessment to the last assessment as the outcome variable rather than a predictor. The results of this multiple regression model, which controlled for school (β = 8.587, p = 0.224), mastery (β = 4.382, p = 0.012), interest (β = 1.321, p = 0.791), assessment speed (β < 0.0004, p = 0.830]), number of tries on an assessment (β= 0.575, p = 0.356), and average score on assessments (β = -2.475, p = 0.917), revealed that the only statistically significant predictor of time was mastery. Mastery had a coefficient of 4.38, meaning that every unit that a student mastered extended the time to complete the course by about 4 days (β= 4.38, p = 0.012). The results of this regression model denote that the predictors explained 20% of the variance in speed (R^2 = 0.2033, F(6, 67) = 2.85, p = 0.0157). This model establishes that in personalized learning environments where students are learning Algebra 1, the total time it takes a student to complete the course depends on whether the student is mastering the course material. It is not surprising that learning material to a level of mastery takes longer; what is surprising, however, is what seems like it should be significant but that was not. The seemingly obvious predictors of overall time, such as the number of tries a student takes on an assessment, the average speed of taking assessments, average performance on assessments, and interest, are not predictors of how long a student will take in the semester.

Next, I added the number of required units that were taken in the course in order to control for seemingly natural influencers on time. It seems logical that the more units a student takes, the longer it will take to complete the course. The results of this model (model 7), shows that when controlling for the amount of required units taken, none of the variables are statistically significant predictors of time. What is surprising about this analysis is what is not significant that we would expect should be. The number of assessment attempts is not a significant predictor of total time (β = 0.622, p = 0.313), meaning re-taking an assessment multiple times does not actually result in a student taking more overall days. Scoring lower on assessments on average does not increase the overall time in the course either (β = 15.829, p = 0.546); the lack of significance of this variable makes sense given lower scores on attempts often means the student will be re-taking the assessment more times and the model reveals that the number of attempts is not significant. Speeding through assessments more quickly (or taking longer on the assessments) also has no statistically significant relationship with the total time (β = 0.001, p = 0.598). Students who showed interest in the course by taking additional assessments, which one could assume would lead to taking more days because time is being utilized on extra units of interest, also did not have a significant effect on overall time in the course (β = 0.417, p = 0.933). Similarly, the mastery of units, which could require a student to take more days on the material in order to reach mastery, is also not a significant predictor of time (β = 0.737, p = 0.797). School had a coefficient of 14.4 (β = 14.38, p = 0.071), meaning that while there was a 14-point difference between the schools, it also lacked significance in this model. The overall fit of this model increased by about 3% (R^2 = 0.2322), meaning that the predictors explained about 23% of the variance in speed (F(7, 66) = 2.85, p = 0.0116). An important insight that this model establishes is that when students are learning Algebra 1, we cannot rely on indicators that seem as though they would be meaningful based on our observations in traditional, standardized environments to predict how long a student will take in a personalized learning environment. The seemingly obvious predictors of overall time, such as the number of units taken, the number of tries a student takes per unit, the average speed of taking assessments, average performance on assessments, interest, and mastery, are not predictors of how long a student will take in the course.

The next step in my analysis was to consider all of the factors that could influence time. I produced one more model (model 8) this time adding variables that account for the amount of optional units taken (this is the percent of the optional units that the student took from all of the optional units available), the average speed on optional units, the average number of tries on optional units, and the average score on the optional units. Similar to the model preceding it, none of the variables were statistically significant predictors of time at the 0.05 alpha level.

Even though the coefficient of required units and for average score on assessments both seem large (β = 34.11 and β = 25.05, respectively) indicating that working on a larger percentage of the required units would lead to more time in the course, or that scoring higher on assessments on average would require a student to take longer in the course, the p-values indicated that neither was significant (p = 0.103 and p = 0.378, respectively). The negative coefficient for optional units (β = -1.58) and for average score on optional assessments (β = -24.542) would suggest that students who worked through more optional units would take slightly less time in the semester, and that students who averaged higher scores on optional assessments would speed through the semester more quickly, however the model revealed that those, also, were not significant (p = 0.906 and p = 0.129, respectively). The other variables – average number of attempts on the required units (β = 0.624, p = 0.328), the average number of attempts on optional units (β = 0.676, p = 0.617), the average speed on required assessments (β = 0.001, p = 0.467), the average speed on optional assessments (β = -0.0003, p = 0.883), the average number of times a student re-took a required assessment (β = 0.624, p = 0.328) or an optional assessment (β = 0.676, p = 0.617) – had very small coefficients and were also all insignificant in predicting the speed of a student through the course. In this model, school was not significant either (β = 8.706, p = 0.318), meaning that even though there was a nearly 9-day difference in the amount of time students took between the schools, the time difference was not significant enough to overpower the variance in the model. The overall fit of this model was R^2 = 0.2676, meaning that all of the predictors in this model explained almost 27% of the variance in speed ($F(11, 62) = 2.06$, $p = 0.0372$). This model establishes that in personalized learning environments, the factors that influence the speed (the total amount of time it takes for student to complete the units of a course) are not the same seemingly obvious predictors we tend to look for in a traditional, standardized environment.

Table 7

Results of fitting a taxonomy of multiple regression models predicting speed of students in Algebra 1 (n = 75)

	Model 6	Model 7	Model 8
Variable	β **(SD)**	β **(SD)**	β **(SD)**
School	8.58 (7.00)	14.38 (7.84)	8.71 (8.66)
Amount of required units		31.06 (19.69)	34.11 (20.62)
Mastery	4.38* (1.70)	0.74 (2.86)	-0.01 (3.09)
Interest	1.32 (4.97)	0.42 (4.95)	7.26 (10.67)
Avg min on req assessment	0.001 (0.002)	0.001 (0.002)	0.001 (0.002)
Avg attempts per req unit	0.58 (0.62)	0.62 (0.61)	0.62 (0.63)
Avg score on required unit	-2.48 (23.63)	15.83 (26.09)	25.05 (28.19)
Amount of optional units			-1.58 (13.34)
Avg min per optional unit			-0.0003 0.002
Avg attempts per optional unit			0.68 1.35
Avg score on optional unit			-24.54 15.95
Constant	67.93*** (16.66)	39.60 (24.37)	44.40 (25.40)
R^2	0.20	0.23	0.27

Note. *$p < 0.05$, ** $p < 0.01$, ***$p < 0.001$

Discussion of research question 3. The aim of this analysis was to build on the findings from the earlier research questions to identify the predictors of speed. In research question 1 it was established that speed does not predict the final applied knowledge score in Algebra 1, and in research question 2 it was established that we cannot assume relative stability of rank in speed over time and across subject matters. That finding challenges the notion that speed is inherent to a student; it suggests that speed not an attribute or characteristic of a student, but rather a consequence of other factors, many of which have not yet been examined in personalized environments. The aim of this final research question was to explore factors that affect speed. What can be learned from this study is that what is happening at the individual level in terms of influencing speed is not being captured by analyses that only focus on the aggregate. If we want to design learning environments that make effective use of time, we must develop an understanding of what predicts time, and it is clear from this analysis that the typical indicators we look for in standardized environments, that we can easily assess by passive observation, are not sufficient. In personalized environments we must draw on tools and techniques that can help us understand the dynamics of individual learning and carefully consider how to measure and assess questions of interest in new ways.

DISCUSSION

Synthesis of Findings

The Relationship Does Not Hold

Ultimately, this research shows that Thorndike's view that students who learn faster are naturally more capable did not hold for students who were using the personalized learning platform. This study found that in personalized learning environments, speed is not indicative of ability; students who progressed faster through the material did not necessarily perform better in the course. The rank-order speed of students within a course is not stable among their peers, and the factors that affect a student's speed are not the obvious indicators that would often be observed in a traditional standardized learning environment. What is clear from this study is that the relationship between speed and ability in these personalized learning environments is not as Thorndike believed. Even though the core design of the education system was built around the assumption that speed and ability are coupled, and has been optimized for the efficient ranking and sorting of students into positions in society, the findings of this study support the assertion that a student's speed does not necessarily reflect what the student is capable of accomplishing. For educational institutions to support and develop all students, it must abandon the false notion that speed is indicative of ability and allow for flexibility in its design so that all students have the time needed to achieve mastery.

But It's Not Just Time

Flexibility in time is a necessary component of mastery but time alone does not lead to improved outcomes. While having time is essential, time alone is not enough. The way time is utilized is critical to achieving the desired outcomes. This underscores the need for a better understanding of the drivers of achievement and a greater focus on identifying the elements that determine best practices for mastery-learning. In this section, I will focus on two promising concepts that my research suggests would be good candidates for helping create more effective and efficient personalized learning environments – the first is the components of a model that are needed to make mastery-learning effective, and the second is individuality.

Implication 1: Mastery

Importance of Mastery

My research found that the more material a student mastered, the better the student performed in the course. Given the important role that mastery plays in achievement, it is worthwhile to evaluate some of the best practices for mastery-learning and consider what components are essential in a mastery-learning model that is intended to be implemented in a personalized learning environment. Significant research has been done on mastery-learning, leading to the promotion of a wide range of recommended practices and the development of various mastery models (Slavin, 1987). The person who has produced the most comprehensive, empirically testable, and sophisticated theory of mastery is Benjamin Bloom. Bloom developed a mastery model of learning that has had a lasting effect on perceptions of what students can accomplish, and the practices within education that can facilitate that.

Bloom's Mastery Model

One of the most influential proponents of the notion that ability and talent can be nurtured within a school environment was Benjamin Bloom (1968), whose theory of achievement was grounded in strong and well-tested research base (see Arlin, 1984, for a review). Bloom believed that the widely distributed achievement differences within schools were predominantly a product of the educational environment; he theorized that under favorable learning conditions almost all students could reach a high level of excellence (Brandt, 1985). In his seminal work in this area, Bloom was able to demonstrate that students who were randomly assigned to one-on-one tutoring instruction performed two standard deviations better on achievement measures than those provided with typical classroom group instruction (Bloom, 1976). Although its advantages were clear, Bloom recognized that individual tutoring was not a feasible approach to execute at scale; therefore, he focused his own subsequent research on identifying mechanisms that would help to bridge the gap between group instruction environments and individual tutoring – he called this the 2-Sigma Problem (Bloom, 1984).

To begin tackling this challenge, Bloom developed an approach that could help bridge the achievement gap between individuals in tutoring conditions and those in classroom group instruction. He created a model around mastery-learning (Bloom, 1968) that proposed that three alterable factors – cognitive entry behaviors, affective entry characteristics, and quality of instruction – could be manipulated within an instructional environment and explain up to 90% of achievement differences (Bloom, 1976). Cognitive entry behaviors (CEB), being the learned concepts, preconceived ideas, and background knowledge unique to each person's understanding at the start of a course, make up the foundation on which new academic knowledge is built. It is shown to be the strongest predictor of student performance, accounting for 50% of the differences in achievement (Bloom, 1975). Affective entry characteristics, being one's the belief in the ability to accomplish learning tasks, motivation to work, and the confidence to approach a challenge, affect the extent to which a student is engaged in the learning process and the motivation to learn new tasks. Alone, it is shown to account for 25% of variation in school achievement, but when combined with CEB are thought to account for 65% of variation (Bloom, 1976). Quality of instruction, meaning the appropriate use of cues, encouragement, and reinforcement that are optimal for a learner, accounts for 25% of variation in school achievement, but when combined with cognitive entry behaviors and affective entry characteristics under ideal conditions is believed to account for up to 90% of the variation in achievement (Bloom, 1976).

Many researchers have tested aspects of Bloom's mastery model and although most of them had positive results (Block & Burns, 1976; Guskey & Gates, 1986; Guskey & Pigott, 1988; van Rossum, 2010), there were inconsistencies in certain findings (Donovan, Sousa, & Walberg, 1987; Livingston & Gentile, 1996). Mastery group participants had varying degrees of success over those in the control groups in part because not all of the studies tested the entire model with complete fidelity to Bloom's framework. Oftentimes efforts at mastery-learning emphasize the temporal flexibility necessary for students to learn, believing that it is merely the extra time for learning that will lead to better outcomes. What my current analysis highlights, however, is that time alone does not lead to improved outcomes. More modern initiatives, such as Idaho's state-wide initiative to move to a mastery-based education program (Idaho State Department of Education), embrace mastery as a core component of personalized learning, but do not employ a complete model of executing mastery-learning, leaving schools and teachers to define the approaches that best help students "demonstrate competency" in the subject of instruction. For mastery-learning to really work, it requires addressing at least three often overlooked factors, discussed in Bloom's Learning for Mastery model: 1) setting the bar, 2) the type of feedback, and 3) the role of background knowledge.

Overlooked Factors

Setting the bar. Perhaps the most straightforward factor to tend to when establishing mastery criterion is what level of content knowledge constitutes mastery. Some course subjects are of a progressive nature, in which a later unit builds off the understanding of ones sequentially presented earlier in the course, thus making the earlier unit a prerequisite for mastery of the latter, while other subjects are somewhat more interchangeable in sequence. Bloom acknowledged that the level of mastery should be set depending on the nature of the material of instruction. If the bar for mastery is set too low, students may not develop sufficient basic knowledge necessary, upon which later units of instruction build. If, on the other hand, the mastery bar is set too high, perfecting understanding of the content may come at the expense of student attitude toward the material and ultimately have long term implications for interest in the subject (Block, 1972). In my review of the past three decades of studies based on Bloom's mastery model by Anderson, Barrett, and Hutson (1992), Changeiywu, Wambugu, and Wachanga (2010), Damavand and Kashani (2010), Keter, Barchock, and Ng'eno (2014), Lai and Biggs (1994), Mehar and Rana (2012), Sankian and Gahlawat (2014), and Yildiran and Aydin (2004), I observed that studies differed in what they set as the bar for mastery, ranging from 60% to 100%, and that using 80% as a bar for mastery most often reported gains in achievement without diminishing the student's feelings about or appreciation for the material of instruction.

Recognizing the value of setting an appropriate bar for mastery, and appreciating the trade-offs to student affect toward the material if the bar is too high, underscores the value of identifying mastery criteria based on the subject of instruction and the ultimate function of the course. If the course is fundamental to a variety of other subjects and sequential in nature, in which case a solid foundational understanding in early modules would affect the how well the student would grasp the later material, or if the intent is to ensure the student has deeply memorized certain facts, it may be beneficial to set the bar for mastery at 95% for some aspects of the course, or early on in the progression, and consider reducing it as appropriate. Alternatively, if the course modules could be interchangeable or are non-sequential by nature, or the course is intended to spark an interest in the students that will drive future self-directed learning, perhaps 80% criteria is sufficient. Models of mastery instruction can adopt an 80% bar as a starting point, but should continue to refine and evaluate whether that is the appropriate level given the content structure, function of the course, and the ultimate goal for what is desired of the student.

Feedback and correctives. The term "mastery" alone assumes that the only requisite is allowing for replication, meaning that a student is given the freedom to re-do the unit and repeatedly take the assessment until the mastery criterion is reached. Fundamentally missing from this commonplace depiction of mastery is arguably the most important aspect of a mastery model: the feedback that a student receives through the learning process, and the correctives that a student can refer to in order to supplement, advance, or correct limitations in understanding.

Accurately assessing what a student knows is essential for recognizing whether mastery has been attained, and providing appropriate feedback in response to an assessment is critical to furthering a student's understanding. When left unspecified, feedback means different things to different people, requiring by definition only that a reaction or response to an activity be provided. Bloom describes the need for cues, feedback, and correctives to be incorporated into the learning experience so that students can reach mastery, but while he does specify that they should be calibrated to the needs of the student, he does not describe specifics with regard to the qualities that the feedback should possess in order for it to be effective and powerful. Any model in which feedback is required should outline a systematic approach for providing it to ensure that it is timely, targeted, and actionable.

In a review of over 500 meta-analyses that included 180,000 studies, John Hattie (1999) found that of the more than 100 factors that influenced achievement, feedback in the classroom (for example, instructor-provided cues or reinforcements) was among the top five influences. Effective feedback ensures that it is timely enough that it is still relevant to the student's learning, targeted, meaning that it pinpoints areas of confusion or misunderstanding and is appropriate to the level of the student, and actionable such that the student can use it to improve understanding or advance a skill. As such, the student must be able to ascertain the goal, the extent of progress made toward the goal, and what must be done in order to make better progress through the feedback provided (Hattie & Timperley, 2007). Based on these insights, Hattie developed a framework for feedback to enhance learning that outlines the important characteristics for appropriate execution. His model asserts that the levels of task performance, process of understanding, regulatory processes, as well as the individual, must be carefully considered because they matter for the kinds of effects that result from the feedback.

Bloom describes feedback as a component of quality of instruction, distinguishing it as an important piece that involves delivering appropriate cues, encouragement, and reinforcement specific to the needs of the learner (Bloom, 1976). Although his model implies that the instructor is to calibrate the verbal and non-verbal cues to match the needs of each student in the class, he does not make explicit what features the feedback must possess to be meaningful to the student. The wrong kind of feedback, for example emphasis on knowledge the student has not yet acquired or careless presentation of the feedback, can lead to frustration and cause the student to give up rather than persist with the learning task (Deci, Koestner, & Ryan, 1999; Howie, Sy, Ford, & Vaicente, 2000). Adopting a framework for feedback that lays out how to gauge the task complexity, use feedback to promote active information processing, and ensure it is not threatening to the student, is useful in ensuring that the feedback that is provided is effective in guiding the student toward learning.

Closely linked to feedback is the kinds of correctives to which students are directed. Bloom's model, which was elaborated upon and refined by Block and Anderson (1975), calls for students to receive feedback about their misconceptions and be provided with correctives that present various forms of alternate explanations, activates, and examples that differ from, enhance, or clarify the original instruction, and that help students correct their misunderstandings (Guskey, 2007; Block & Burns, 1976). Merely redirecting students to the initial instruction that was not sufficient in the first place is inadequate. For mastery-learning to be effective, correctives must do more than simply repeat the original the explanation initially provided, but rather, incorporate any number of activities that offer alternative approaches and clarify the initial instruction in various different ways. Multiple representations are beneficial for learning when they are used for distinct purposes: to provide information that is complementary to the original instruction, when they constrain possible misinterpretations, and when they facilitate a deeper understanding of the material (Ainsworth, 1999). Offering correctives in which the various representations provide targeted support to clarify the learner's misconceptions ensures the course content is supplied in an unbiased fashion for the students in the class, allowing appropriate fit between each student's most effective approach to acquiring new information and the corrective activities.

Background knowledge. Mastery programs can be a practical reality in schools employing personalized learning models, but it is important to recognize that implementation of mastery-based learning may differ depending on what point in a student's academic life it is being introduced. Most mastery frameworks that have empirical support were designed for (and tested with) students in high school or college. Bloom stressed the profound influence that a student's background knowledge of a given subject has on achievement in that course. In traditional models of school, students move through a learning progression in lock-step. They are delivered fixed-pace instruction and administered learning assessments at the same time, after which they are provided with grades that differentiate levels of understating. They are then are all directed to the next learning task in unison (Burk, 1913; Brophy, 1982). This structure of education results in the minor achievement differences early on in learning becoming large achievement gaps that increasingly widen as students are moved through grades in a standardized progression. Students in the same classroom, receiving the same instruction from the same teacher, reach drastically different educational outcomes; those who do not acquire a solid foundation of the fundamentals like the number line (Friso-van den Bos, Kroesbergen, Van luit, Xenidou-Dervou, Jonkman, Van der Schoot, & Van Lieshout, 2015), vocabulary (Ehri, & Rosenthal, 2010; Ehri, & Rosenthal, 2007), and reading early on have a hard time catching up (Chatterji, 2006). Small initial differences in performance persist and eventually become increasingly evident achievement disparities that continually exacerbate over time.

The degree to which a student is sufficiently equipped with the background knowledge to embark on a new learning task has important consequences for whether the new material is learned. Therefore, introducing students to a mastery-learning program in a personalized learning environment after they have spent years in the standardized system that produces profound differences in knowledge and understanding requires substantial emphasis on helping students develop the relevant background knowledge needed to succeed in that course. A systematic approach to ensuring students are sufficiently equipped with the prerequisites that are assumed of (and essential for) a student to succeed in the learning tasks ahead is an often overlooked and yet incredibly important component of initiating a mastery-learning program (Arlin, 1984). To address this in the design of a learning environment, rather than necessitating an entire course be a prerequisite, which often contains additional content that is irrelevant to the upcoming learning tasks, existing online resources that are modularized by concepts and short units of instruction, can be selectively assigned to ensure that students have command of the essential background knowledge that is truly required. The prevalence of online resources and the ease with which they can be created and widely accessed in the digital space, allows the instructor to compile a variety of explanations and activities that support the acquisition of cognitive entry characteristics. Existing examples like *Khan Academy*, which contains a dashboard of instructional video repositories and practice exercises for students to progress through at their own discretion, and *Assistments*, an online tutoring platform with built-in flexible assessments and that provides immediate feedback to students while also apprising the instructor of student progress, could be utilized together as the flipped classroom approach for prerequisites, to allow instructors to systematically ensure that students enter the course with the background knowledge base required to succeed. In the absence of attention to this seemingly inconsequential detail, mastery programs may appear ineffective and fail to produce the learning outcomes desired, when in fact the issue was not the mastery model, but rather its implementation on an unstable foundation of prerequisite knowledge.

Implication 2: Individuality

Overview

Personalization is essential for an education system that assumes students are capable because it rests on the assumption that individuality matters. If students were generally the same, then standardized approaches to sorting them would be a sufficient way of identifying who should fill what kinds of positions of employment and stations in society. The underlying assumption that gave way to standardization is that an average, meaning the calculation of the mean of a group, provides meaningful information about the population (Porter, 1986; Stigler, 1986). The idea of an average person was proposed by Adolphe Quetelet as the perfect ideal of a person, which individuals should strive to resemble (Quetelet, 1842). Francis Galton argued that most people were close to the average, and being average was not ideal but rather, mediocre (Galton, 1886). He believed that the people who were above average were superior, and those people should be identified for the more prestigious work and positions in life (Thorndike, 1943; Tomilson, 1997). These views advocated that people could be understood in relation to averages – either as membership into a group based on an average type of person (i.e., personality type, or "learning disabled") or regarded by how one compared against the average person (for example, how they score on the SAT or an IQ test) (Hankins, 1925; JoBeth, 1979). This thinking even permeated early personalization efforts, where instruction was differentiated based on learning styles of groups like "gifted and talented" or "underachieving" (Landrum & McDuffie, 2010; Dunn, 1983).

Statistical precision about the average and knowing how a person deviates from average was thought to be useful because it allowed for easy sorting of individuals and assigning rank; the problem with this, however, is that no amount of statistical information about a group provides empirical knowledge about the individuals within it (Lamiell, 2013). In fact, aggregate-level analysis can lead to incorrect conclusions about individuals (von Eye & Bergman, 2003). This has been established with a proven theorem which shows that average-based insights do not provide practical insights about how to nurture, develop, or understand individuals. Ergodic theory, a mathematical-statistical theory developed by Birkhoff (1931), denotes the strict conditions under which features of a group represent the individuals that comprise that group. The two conditions that must be met in order for the group characteristics to be instructive about individual characteristics are homogeneity and stationarity. Homogeneity requires that each individual in the group obey the same dynamical laws, meaning they be on the same trajectory. Stationarity requires that each subject have constant statistical characteristics over time, meaning they evolve identically. In other words, for the group characteristics to be informative about the individuals that comprise the group, all of the students must be identical in the way learn, grow, and develop (Molenaar, 2004). Fundamental tenets of human development dictate that individuals are unique (Molenaar et al., 2013), people change over time (Gayles & Molenaar, 2013; Ram et al, 2005; Van Geert, 2006), and context matters (Mischel, 2004). Non-ergodic processes, such as human development, learning, and adaptation, require explicit analysis of individuality in order to obtain valid results (Valsiner, Molenaar, Lyra, & Chaudhary, 2009).

In other words, ergodic theory demonstrates that if the goal is to understand individuals, grouping by averages and referring to aggregate-level insights may be of limited utility.

Fortunately, a new approach to science has been emerging over the past few decades that rejects the use of group averages as a mechanism to understand individuals; rather than washing out individual variability it focuses on patterns of individuality (von Eye, 2010). This science of individuality has led to breakthrough insights about medicine and nutrition (Zeevi et al., 2015), neuroscience (Miller et al., 2012), human development (Thelen, 1986), personality (Shoda et al, 1993; Mischel, 2004), emotion (Ram et al., 2005a), and more (e.g.: Hyde, Conroy, Picus, and Ram, 2011; Markowitz, & Bertagnolli, 2009; Nevins, 2011; Russnes, Navin, Hicks, & Borresen-Dale, 2011; Wang, Xie, Molenaar, & Ulbrecht, 2015), validating that not only are individuals unique, but that this unique individuality is not an obstacle to scale the way it was once thought to be. With proper utilization of modern technology and the scientific methods and techniques for understanding individuality, we can build systems that are designed to nurture individuals and help them advance. For this reason, the science of individuality offers a strong and suitable foundation for personalized public education system.

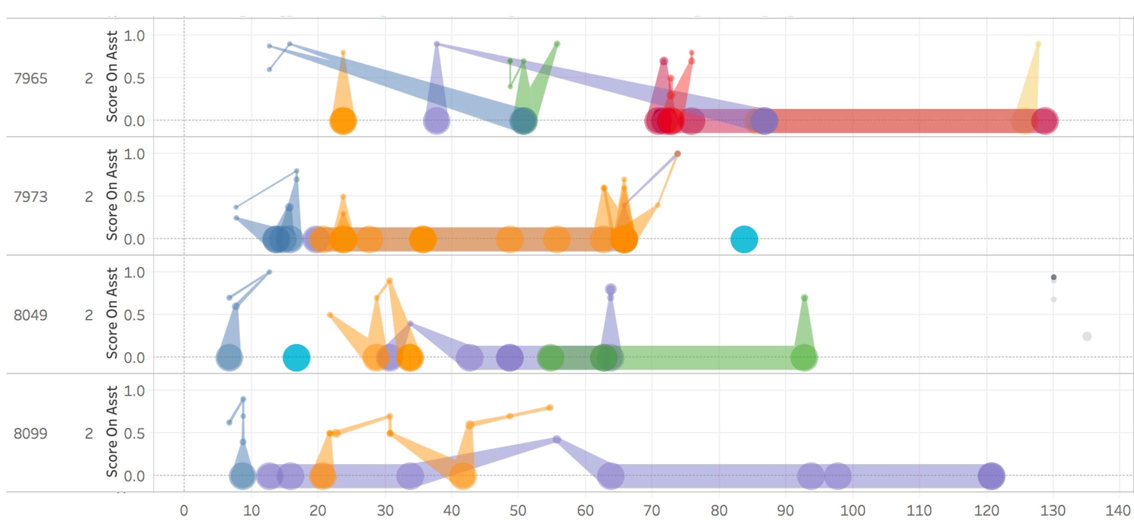
Individuality in the Data

The current study examined students in the aggregate, but when we more closely scrutinize the patterns of individual students throughout the semester, we see some of the issues with ignoring individuality. The difference in patterns of students who ultimately scored similarly in the course, but did so by progressing through the material in idiosyncratic ways, suggests that individuality also carries signal that is not captured by the group-level analysis.

Analyzing the patterns of students grouped by overall applied knowledge score in the course, we see that there is no common approach that leads to the same score. Visualizations of clusters of students who earned the same overall final applied knowledge score are provided to illustrate the differences in individual patterns. Figure 5 shows all of the students who earned an overall score of 94; Figure 6 shows all of the students who earned an overall score of 90; Figure 7 shows all of the students who earned an overall score of 84; Figure 8 shows all of the students who earned an overall score of 74; Figure 9 shows all of the students who earned an overall score of 64. In every cluster of students grouped by final overall score, we see differences in the number of assessments taken, the amount of time the student spent on each assessment, the number of times a student re-took assessments for a unit, the time gap between assessment attempts, the order in which they sequenced the various units, and how long the student spent in the semester between their first and last assessments.

Figure 5

Students who earned an overall score of 94.

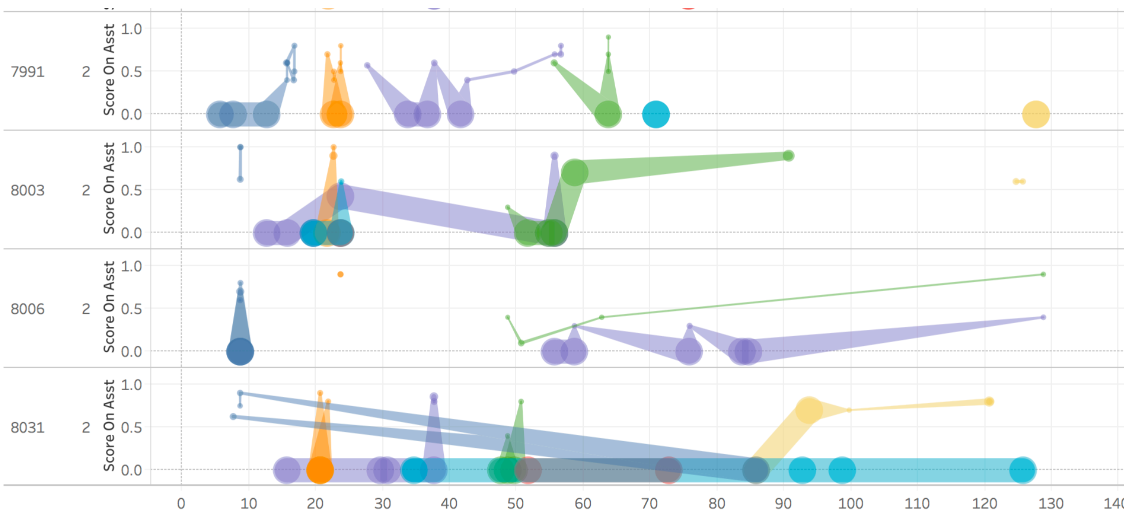


What is common about the students who scored a 94 is that every unit that was taken had at least one assessment attempt for which the student took several hours to complete and which resulted in a score of 0. In many cases, the student performed well on one take of a unit assessment, but still continued assessment attempts on the unit, which did not reflect an improvement in assessment score. This indicates that the student, despite having reached the mastery threshold on a unit, continued to engage with the unit content for purposes other than assessment scores. This behavior could mean that the student was not confident in their understanding of the material despite having mastered the assessment, and felt the need to continue practicing despite the mastery score attained. Alternatively, it could mean that the student was engaging with the unit material to deepen their own knowledge of the content or make connections between other units of content after mastering the unit.

Student 7973 and 8099 only took assessments for three of the units in the course. This could reflect a lack of engagement in the subject or disinterest in the material, or it could indicate that these students are already so well versed in the material that they do not even want to spend the time taking assessments because they are confident in their ability to demonstrate their knowledge of the material. In all of these individual cases, it's important to better understand the reasoning behind the decisions that the students made.

Figure 6

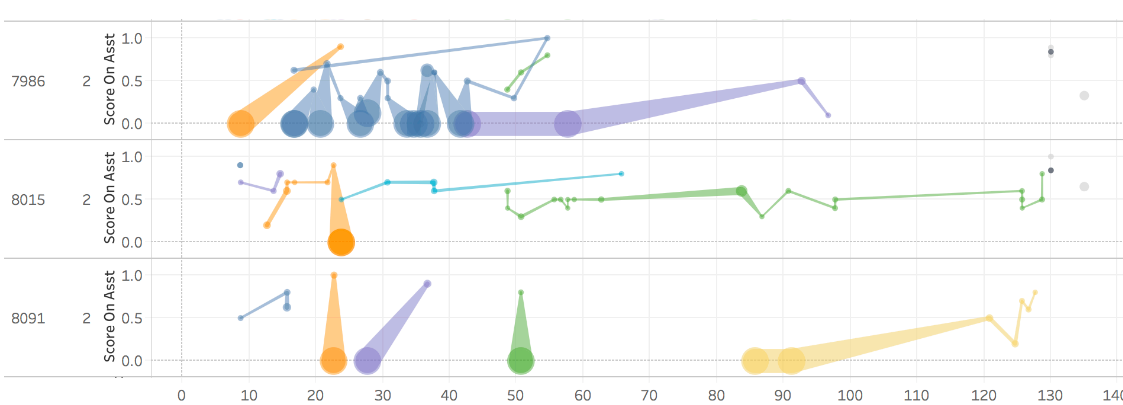
Students who earned an overall score of 90.



What is common about the students who scored a 90 is that every student scored 0 on at least one, but often more, of the unit assessment during the semester. However, beyond that there are very obvious differences in time, frequency, attempts, and number of units that were taken during the semester among these students.

Figure 7

Students who earned an overall score of 84.



The students who scored 84 had dramatically different patterns from one another. Student 7986 scored 0 on about half of the assessment attempts, and repeatedly took assessments in short windows of time while student 8015 scored progressively better on most assessment attempts, and only scored 0 once all semester. Student 8091 made very few attempts on assessments for a given unit, had no overlap of units, and had extensive spacing between units. This could appear to be a sign of low engagement, but given the final score in the course, it could be a result of the student's high degree of background knowledge entering the course, or a unique learning strategy that differs from what is normally seen in class.

Figure 8

Students who earned an overall score of 74.

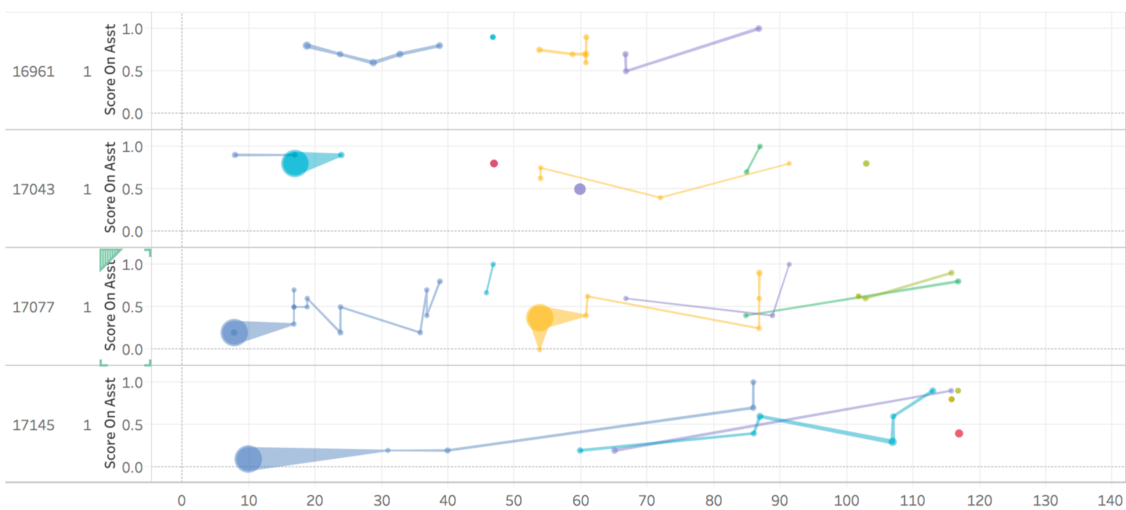
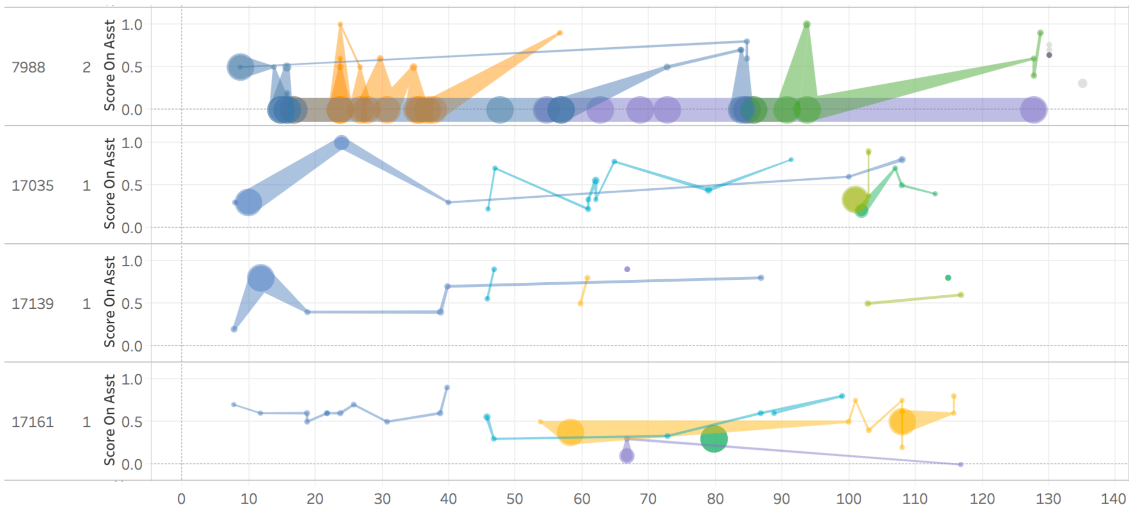


Figure 9

Students who earned an overall score of 64.



What is common about the students who scored a 64 is that they all began taking assessments within the first week of the semester, and spent over 100 days on the course material. However, beyond that there are very obvious differences in time, frequency, and attempts taking each unit.

These differences in the patterns of students with similar overall applied knowledge scores indicate that there is quite a bit of difference in such variables as prior knowledge, strategies, or other influencers that may be contributing to how the student performs in the course. In the current data, grouping students by outcome does not reveal commonalities about the students in the group that would provide actionable insights.

Grouping students by seemingly common temporal patterns of progress is similarly inadequate in understanding the aspects of individuality that matter. Figure 10, figure 11, and figure 12 show students whose patterns of performance with regard to time spent in the semester on assessments, performance on assessments, speed of assessments, and number of units taken during the semester look similar, but who had very different final applied knowledge scores.

Figure 10

Student 17067 scored 80 in the course, student 17113 scored 65.

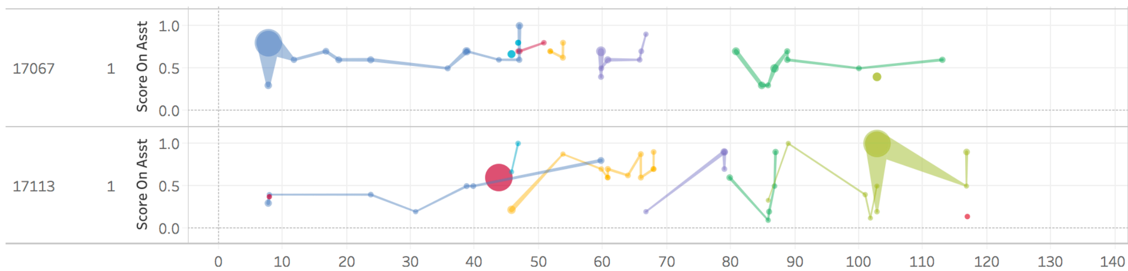


Figure 10 shows two students who seem to have spent their time similarly during the course of the semester: they both began taking assessments within a week of the start of the semester, which they worked on consistently throughout the semester, completing their last assessment at around the 110-days mark. They both engaged in six required units, and engaged in the optional additional units on more than one occasion. These students with similar patterns scored 15 points apart in their final grade in the class. Student 17067, however, scored 80 in the course, while student 17113 scored 65.

Figure 11

Student 8246 scored 96 in the course, student 7988 scored 64.

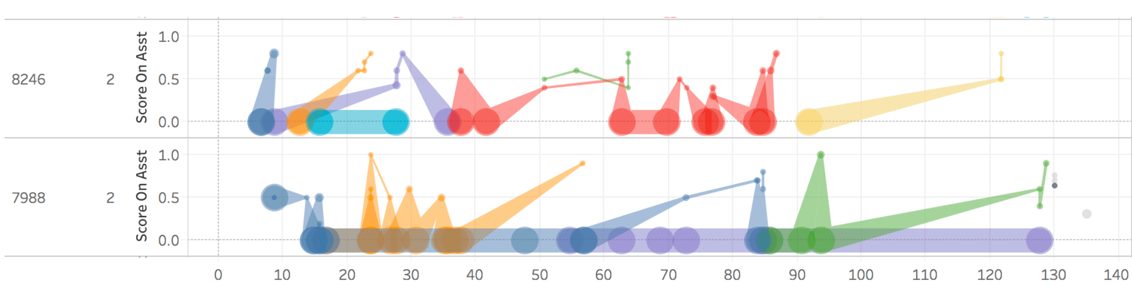


Figure 11 shows two students who both began taking assessments within a week of the start of the semester, which they worked on consistently throughout the semester, spending many hours on assessment attempts that resulted in a score of 0, completing their last assessment after 120 days in the semester. They ultimately reached mastery on most, but not all of the units. These students with similar patterns scored 16 points apart in their final grade in the class. Student 8246 scored 96 in the course, and student 7988 scored 80 in the course.

Figure 12

Student 8069 scored 88 in the course; student 17105 scored 63.

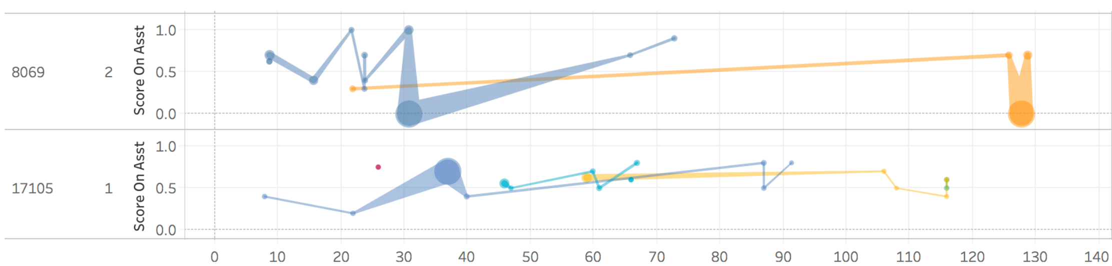


Figure 12 shows two students who both began taking assessments within a week of the start of the semester. They both worked sporadically on assessments throughout the semester, with gaps of several days between assessment attempts; their semester spanned over 115 days between first and last assessment. In both cases, they took very few units – student 8069 only took two units while 17105 took three units and tried one additional optional unit. These students, whose patterns are similar, were 25 points apart in their final score in the course. Student 8069 scored 88 in the course, and student 17105 scored 63 in the course.

The examples selected for display in this discussion are targeted to elucidate the point that by creating simple groupings by observable variables or clustering observational data that does not account for individual-level strategies, motivations, goals, or idiosyncrasies that drive behavior, the insights that we gain from the group-level analyses are of limited utility in understanding how to guide, intervene, or target support for a given student. While it is possible that individual variability in the data is random noise, and that group-level findings can be valuable at the individual level (meaning, it is possible that aggregate studies and individual-level analyses yield similar discoveries), it is unwise to assume that findings from these two different approaches would converge around similar insights, especially given this assumption has not held in any other field where individuality has been studied. A complete visualization of the patterns of progress of each student in the sample is provided in Appendix A.

Summary

What this study makes clear is that the phenomena happening at the individual level that is not captured by analyses of the aggregate. In order to develop a more robust understanding of the drivers of achievement and ways to maximize the utility of personalized learning environments for the individuals within them, we must acknowledge that research approaches that employ the methods and tools of aggregate statistics are of limited value to understanding individuality. Failing to embrace the different ideology and methodology that is at the heart of the science of individuality has long-term implications for both our understanding of individuality as well as the design choices we make that will either impede or advance the kinds of systems that are flexible, adaptive, and responsive to the needs of each and every student.

In many ways, one could argue that in our desire for personalization and recognition of the value of individuality, we have a methods problem. In other words, that we will need to develop particular methods that are finely tuned to addressing education-specific questions that provide practitioners and educators valuable, actionable, and contextually-relevant insights about individual students. However, the need for more individual-specific methods that are useful for education is not a valid excuse for maintaining the status quo. Existing research paradigms such as dynamical systems (Devaney, 1989; Kelso, 2000), and holistic-interactionistic theory (Magnusson, 1996; Bergman & Magnusson, 1997; in Bergman & Wangby, 2014) have provided a framework for thinking about person-oriented research, and scientists are continuing to develop new techniques and garner new discoveries that showcase the value and utility of this new science (Molenaar, 2004; Nesselroade & Ford, 1985). There is a great deal to be learned by borrowing methods from other fields that have already made progress in understanding individuality (van Geert, 1991; von Eye & Bergman, 2003). The study of individuality has led to distinguishing stable and labile dimensions of personality (Nesselroade, 1988), the identification of "behavioral signatures" that are fundamental to understanding personality (Shoda et al., 1994), differentiating patterns of fluid-intelligence and crystallized intelligence of an individual on a week-to-week basis (Horn 1972), identifying short-term patterns of ability of an individual that are hormonally driven (Hampson, 1990), and more (Nesselroade & Ram, 2011; Wang et al., 2013; Salthouse, Nesselroade & Berish, 2006). Ultimately, there are many questions in education that either intend to accurately understand a student, or are about change over time with regard to learning or development; therefore methods from other fields that also study the ways that individuals change over time can serve as a useful starting point. Idiographic analysis, dynamic factor analysis, Q-factor analysis, P-technique, and the currently accessible methods (see Gayles and Molenaar, 2013, for a primer) will likely prove more useful in the early stages, and serve as a better driver for continual progress, than continuing to rely on methods that are meant purely to inform aggregate understanding (Molenaar, 2013; Uher, 2011).

A focus on individuality has major implications for not only research, but for the interpretation of evidence to determine the effectiveness of interventions. Historically, insights from aggregate analyses – meaning, what works on average – have been interpreted as "the best way", thus becoming as the driver of certain "evidence-based practice" and "response to intervention" activities that are adopted in schools (Kavale & Flanagan, 2007). Believing that insights about what works on average will work for a given student assumes the existence of the "average person" (or in this case an "average student"), for which that insight is idea. The problem with this line of reasoning is that the notion of an "average person" has been falsified (Rose, 2016). Research has shown that studies yielding improved predictability at the aggregate level can have decreasing predictive accuracy at the individual level (Lamiell, 1990, 2003), ultimately providing insights about nobody (Lamiell, 2013). In order to determine whether an intervention or practice is appropriate for a given student, it is essential to abandon the idea of the average person and replace it with attention to the conditions of individuality, to consider what works for whom, and in what situations (Mischel et al, 2002; Uher, 2011). This is a very different way of thinking about what constitutes evidence and about how to determine effectiveness.

Limitations and Future Directions

The current study has contributed to the empirical evidence that shows a student's speed of learning does not reflect ability, refuting Thorndike's view that time and intelligence are coupled and supporting Bloom's position on the value of mastery. It reveals that students within a single class fluctuate in who is faster or slower at any given time, but that students across schools maintain a stable rank order of speed, which suggests speed is not a fixed quality or characteristic of an individual and is perhaps best thought of as a product of the conditions of the environment, but the conflicting results from the classroom level and the school level indicate further investigation would be beneficial. The study also reveals that predictors of time are not as obvious as those that are easily identifiable, which we often look to when trying to assess and predict whether an individual will be successful in a learning environment. While this study has provided great insights that support the argument that all students are capable and that learning environments must be personalized in order to nurture their strengths and talents, this study has a few key limitations.

The primary limitation of this study is that while it has major implications for the structure and design of learning environments, it reveals very little about what can be done at an individual level to support the needs of students. The strength of the study lies in what it tells us about how to re-think environments and what assumptions we need to break free of in order to support all students; it points us in the direction of developing a deeper understanding about individuals but it does not in itself provide individual-level insights because it did not capture the data needed to do so.

The complete sample in this study consisted of 75 students from a single personalized learning platform that supplemented a specific school model; there are, however, a variety of school models and platforms that could be utilized to study personalized learning environments. As such, it cannot be assumed that the findings from this study are generalizable across all personalized learning models, platforms, or conditions.

The personalized learning platform used in this study was designed to allow students to engage with learning content that is available outside of the platform (for example, websites that host podcasts or videos), and therefore it did not maintain records of the amount of time that a student spent engaging with the course content outside of the platform. As a result of this intentional technological design decision, I could not analyze precise measures of time that students spent engaged in learning course material.

Also, the data collected for this study overlooked the unobservable factors that may help us understand underlying mechanisms that affect speed and performance. By analyzing timestamps of different actions, I was able to measure duration, speed, and frequency of certain behaviors but I did not capture any indicators that reveal the impetus or reasoning behind those activities. It would be valuable when planning future studies, to not only think about what the technology can passively capture about student behaviors, but also to think about what the subjects themselves can offer about their subjective experiences, strategies, and what prior knowledge or skills they are drawing on to drive those decisions. Objective quantitative measures are instructive, but they require the researcher to infer a great deal about the subjects and their experiences. Utilizing the technology to also capture aspects of the student's thinking, logic, or reasoning could paint a more complete picture of the different kinds of student experiences and dramatically enhance what we learn from a study.

Finally, the flexibility in personalized learning environments necessitates a more expansive view of data collection and interpretation. In my initial conceptualization of the study, I did not appreciate the many avenues in which the flexibility of the learning environment would be utilized. By allowing students have autonomy over how they learn, when they learn, and what they learn, the standard ways of measuring variables (like time, strategy, and engagement) and which variables are instructive, are called into question. I initially conceptualized the study having had a good understanding of what happens in a traditional school environment. I knew what was recommended of the students with regard to progressions and sequence of content and therefore I envisioned students following behavior patterns similar to what is expected in a traditional classroom with only minor differences. For example, I had presumed that all students would take every required unit until they achieve mastery; in reality, however, not all of the students took every required unit, they did not reach mastery on the units they took, and they did not follow the recommended sequence of units. I did not anticipate the need to embed questions that allow me to understand the reasoning behind the decision to start taking assessments, not take certain units, move on prior to mastering a unit, digress from the recommended sequence of units, or take multiple units simultaneously. As a result, I must infer what possible motives could be without having explicitly asked them from the subjects themselves.

The limitations of this study shed light on how to think about prospective explorations and analyses of personalized environments. The limitations of this study were valuable for the field in providing useful information for future researchers about what kinds of considerations to have in mind when designing studies, what kinds of unexpected cues and signals to look for in an environment where standardized processes are not strictly imposed, and how to think about the measurement of variables in a personalized learning environment. This preliminary exploration in personalized learning serves as a valuable starting point from which to build research that can provide insights that are applicable at an individual-level.

Implications

There is substantial interest in adopting models of personalized learning in schools, and a great deal of effort and resources have gone into supporting it, but there is a lack of clarity in education about what practices, protocols constitute personalized learning. The development of a personalized learning framework, that helps schools uproot the deeply held (and outdated) assumptions that are embedded in the structure of the institution, so that the processes in place reflect the appreciation for student ability and individuality rather than reinforcing standardization, rank order, and sorting of students, is essential for progress. This research is meant to be an initial step toward developing that framework, identifying challenges that will emerge as we continue to advance educational research in flexible self-directed learning environments where students have autonomy to make decisions about their learning, and where standardized approaches to teaching, research, and assessment do not provide the kind of useful information needed to help students advance their learning.

The assumptions we carry about students, their ability, how to reach them, and what to look for when assessing their progress, have tremendous implications for the way we think about the practice of teaching, the process of learning, and the structure of the educational system. In order to continue to advance personalized learning, we must be mindful of the challenges that we face in understanding how to address these lingering questions, and be intentional about how to design spaces, craft policies, and utilize technologies that are focused on our goal of nurturing and developing the potential of all students.

Conclusion

The purpose of my dissertation was to study the role of speed as it relates to learning in a personalized environment. I chose to study speed in the context of a personalized learning environment because of how different it is from a traditional, standardized environment where students are guided through the learning process in lockstep. Personalized learning environments offer flexibility in time and allow students to be self-directed in their process of learning, which looks vastly different in practice than traditional learning in schools, and requires us to look at both the students and their data in very different ways.

The main takeaway from my research was that the relationship between time and ability that our current educational system assumes does not actually hold. My study found that speed and performance were not coupled, that faster students are not always faster, and that the predictors of speed of learning are not the usual suspects. What really mattered for performance in a course was not how much time it took for the student to learn, but rather, how much of the material was mastered, irrespective of time. Students varied in how long they spent learning material and taking assessments, but the variation did not affect performance. Mastery was the variable the mattered. This insight speaks to the need for an education system that does not assume faster is smarter and that the goal is to rank and sort students for positions in life, and instead sees all students as capable, and that is designed to develop students in their learning and help them learn the skill and knowledge necessary to accomplish their goals. That, fundamentally, requires a different kind of education system than the traditional, standardized one that has lasted over a century and continues to persist. In order to better understand how to help students, we need to better understand their individuality, and how to design for personalized systems that can nurture and develop that.

My study yielded interesting insights that matter for future work, paramount among which is the need to account for individuality in the data. My data revealed incredible individual variation that defied explanation when using the aggregate models of analysis. By visualizing the various patterns of progression, it seemed that there was an underlying strategy at the individual level in the way that students used their time. In order to better understand the patterns and complexities of student behaviors, future studies will need to consider using idiographic models or other more person-centered approaches to analysis.

Perhaps the most salient takeaway from the entire dissertation is that when it comes to ability, we don't know what we think we know – there is still uncharted territory to understand and presumed knowledge to reconsider. For over a century we have enjoyed the comfort of believing that speed tells us about ability, and we have accepted educational institutions that were designed around that, but that turns out that may simply be an artifact of the context we created. In standardized environments where strict time constraints dictate much of the learning activities, faster speed manifests itself as smarter – but in a learning environment with different constraints, that relationship doesn't hold. It would be a mistake to continue to carry this assumption into personalized systems because it distracts us from the real work we need to do to understand and develop students in real self-directed learning environments. The challenge lies in how to design effective personalized learning environments when there is ambiguity around what helps and what hinders learning. To advance the field and provide useful scientific research that is relevant to the real problems in education, and understand what is actually working for students, we need to supplant the old assumptions, draw on new methods, and consider new designs that challenge longstanding practices. The stakes are high – young students engage with these learning environments on a daily basis, and these environments shape their impressions of themselves and what they believe they can accomplish. Our ability to understand what helps and hinders them ultimately depends on an appreciation for and understanding of individuality.

APPENDIX A

Tables and figures related to the data and analysis

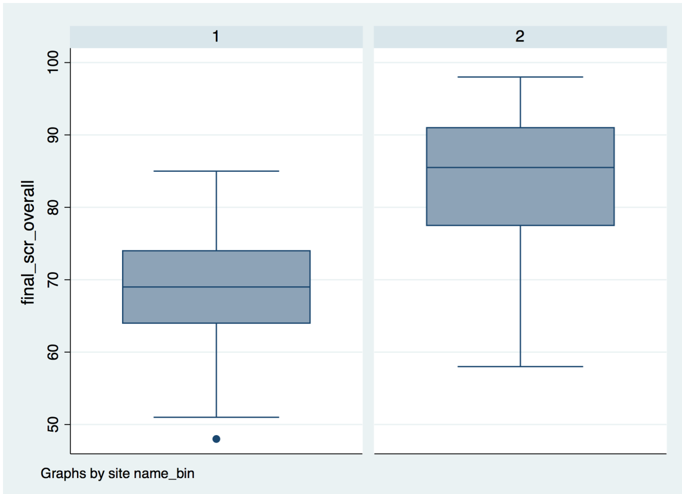
Table A1

Data captured and calculated from the personalized learning platform

Variable	Description
Course name	Name of the course
Student ID	Student's unique identification number
Focus area unit ID	Unique identification number of the focus area unit
Focus area type	The type of focus area (required or optional)
Score on assessment	Score on the assessment attempt
Site name	Name of the school/site
Minutes on assessment	Number of minutes spent on the assessment attempt
Day of assessment	What day of the semester the assessment was taken
Days between assessments	Number of days between the assessment and one preceding it
Number of unit attempts	Number of times a student attempted a given focus area unit
Minutes on unit	Number of minutes spent on a focus area unit
Average minutes per unit	Average number of minutes spent on a focus area unit
Lowest score of unit attempts	Lowest score received on the focus area unit
Mean score of unit attempts	Mean score received on the focus area unit
Median score of unit attempts	Median score received on the focus area unit
Highest score of unit attempts	Highest score received on the focus area unit
Gap score	Difference between the lowest and highest scores received on the assessment attempts s for that focus area unit
Number of unit attempts	Number of unique focus area units that the student attempted
Number of required unit attempts	Number of unique required focus area units attempted
Number of optional unit attempts	Number of unique optional focus area units attempted
Optional units attempted (yes/no)	Whether or not the student attempted any additional focus area units (binary: yes or no)
Total minutes on all units	Total number of minutes spent on all of the focus area units (combining required and optional)
Total minutes on required units	Total number of minutes spent on all required focus area units
Total minutes on optional units	Total number of minutes spent on all optional focus area units
Average minutes per assessment	Average number of minutes spent on each assessment
Average minutes on required assessment	Average number of minutes spent on each required assessment
Average minutes on optional assessment	Average number of minutes spent on optional assessments
Average attempts on units	Average number of attempts on the focus area units, combining required and optional
Average attempts on required unit	Average number of attempts on required focus area units
Days: semester to first assessment	Number of days between the start of the semester and the date the first assessment was taken
Days: first assessment to last assessment	Number of days between when the first assessment was taken and when the last assessment was taken
Days: semester to last assessment	Number of days from the start of the semester to the day that the last assessment was taken
Average days between assessments (assessment)	Average number of days between assessments, starting from when the first assessment was taken
Average days between assessments (semester)	Average number of days between assessments, starting from first day of the semester
Final score	Final score in the course
Project score	Score that the student received on the project in the course

Figure A1

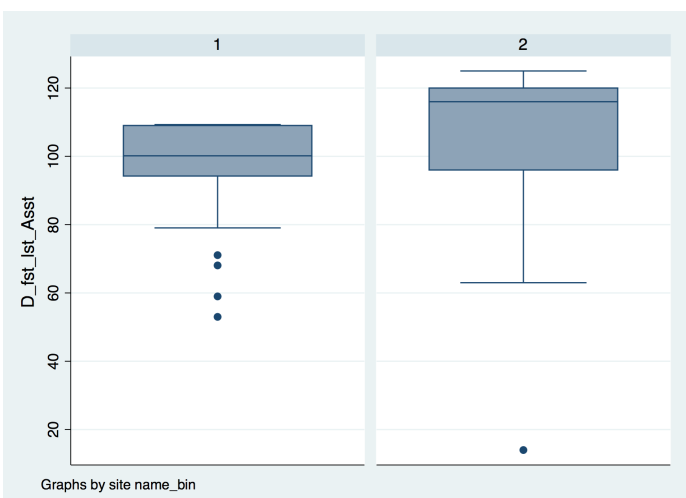
The distribution of differences in final scores between students in school 1 and school 2



Note. A paired sample t-test showed that there was a significant difference in final scores for students between school 1 (M = 69.17, SD = 8.69) and school 2 (M = 83.55, SD = 10.16); t(73) = -6.54, $p < 0.000$.

Figure A2

The distribution of differences in time between students in school 1 and school 2



Note. A paired sample t-test showed that there was not a significant difference in the amount of time for students between class 1 (M=96.75, SD=0.14.93) and class 2 (M=105.41, SD=23.12); t(73)=-1.896, p=0.062.

Figure A3

The size distinctions of the diameters in the visualization that represent number of minutes spent on the assessment

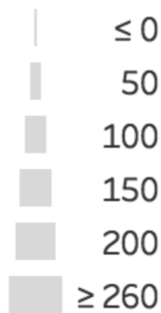


Figure A4

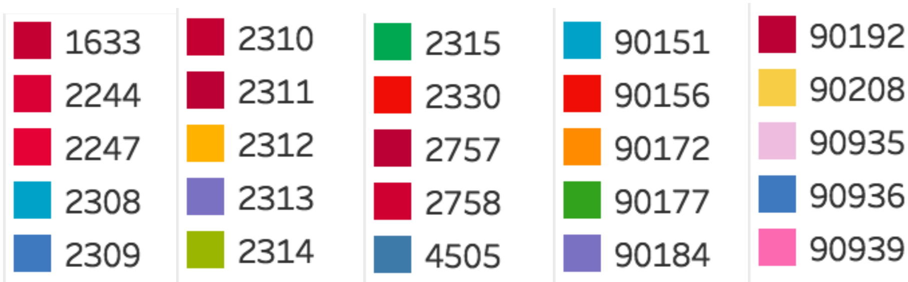
Topic of each focus area unit assessment

Unit #	Unit Name (Description)
2309	Ratios and Unit Rates
2308	Solving Equations
2312	Domain and Range
2313	Functions
2315	Linear Equation Forms
2314	Interpreting Linear Functions
4505	Solving Linear Equations
90172	Functions
90184	Linear Equations
90177	Domain and Range
90208	Univariate Data
90151	Systems of Equations
90939	Rational Roots of Quadratics
2310	Proportionality
2311	Graphing Proportions
1633	Unit Conversions
2244	Lines of Best Fit
2247	Compound Inequalities
2330	Categorical Data
2757	Problem Set
2758	Problem Set
90156	Linear Equations in Two Variables 2
90192	Linear Inequalities in Two Variables

Note. Unit numbers correspond to unit colors denoted in the color key in Figure A5.

Figure A5

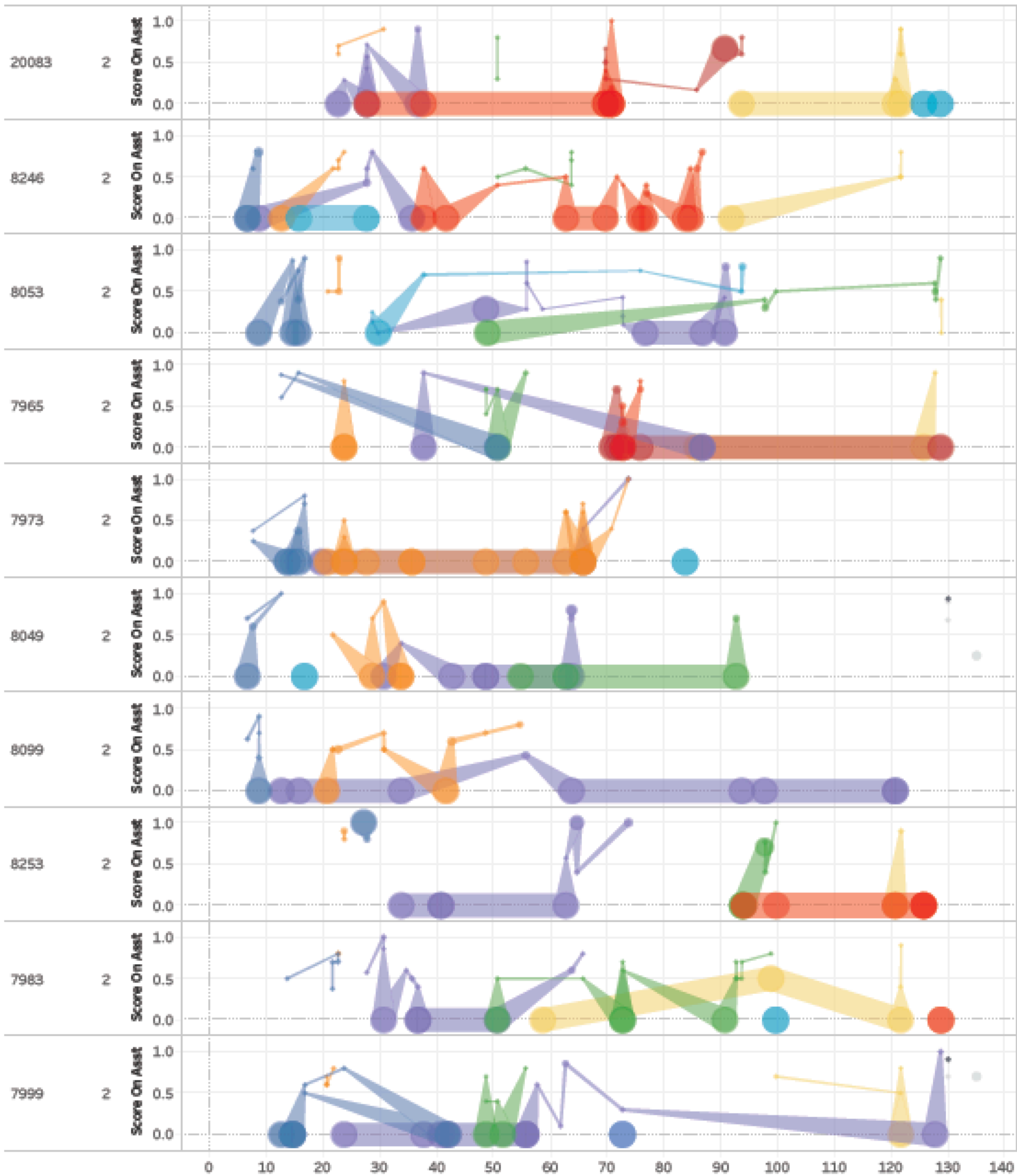
Color key corresponding to the topics for each unit available in the Algebra 1 course.



Note. Unit numbers correspond to the topics denoted in Figure A4.

Table A6a

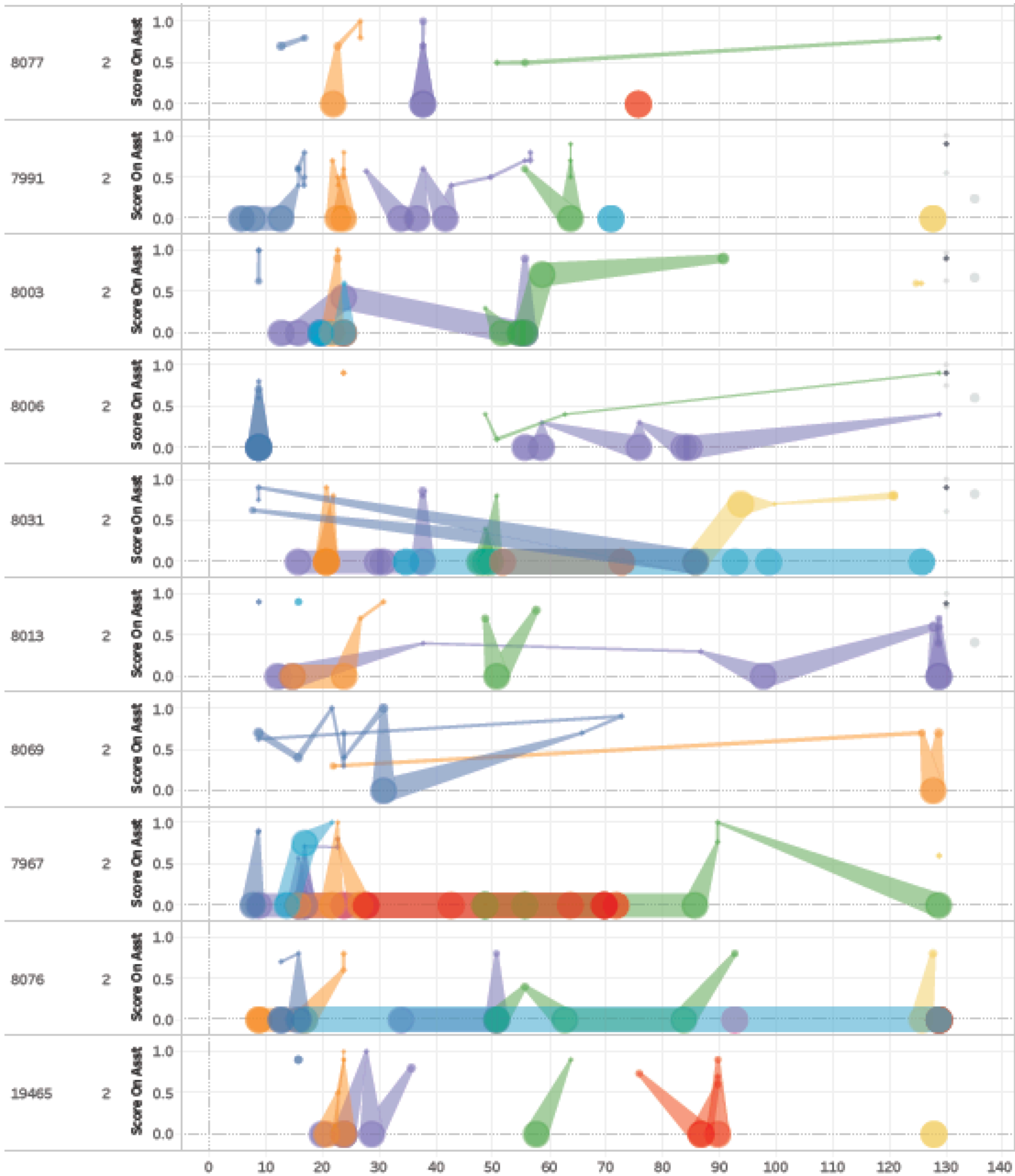
Students in Algebra 1 who received overall final scores in the course between 98 to 91



Note. The students are presented in descending order by final score.

Table A6b

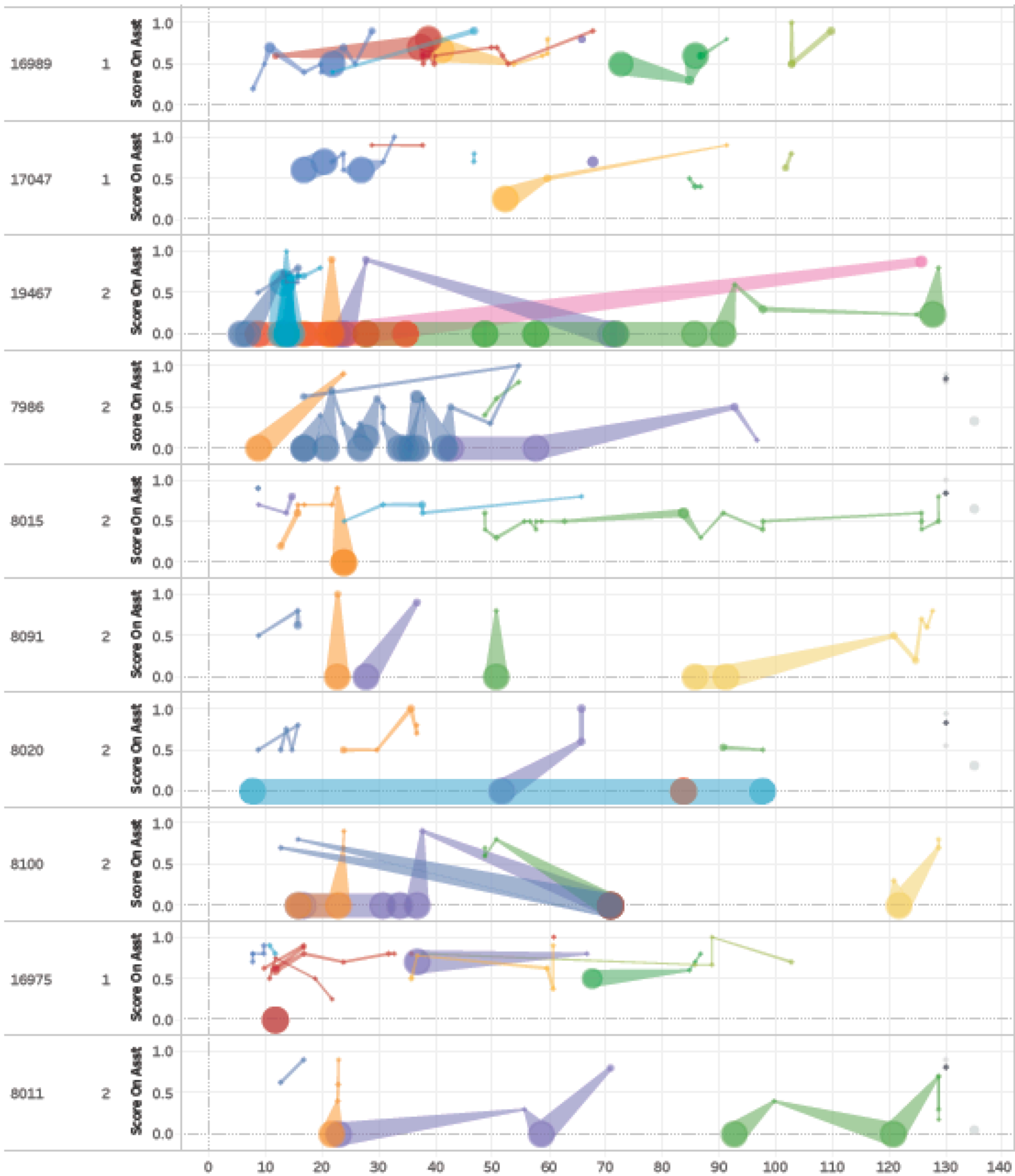
Students in Algebra 1 who received overall final scores in the course between 91 to 86.



Note. The students are presented in descending order by final score.

Table A6c

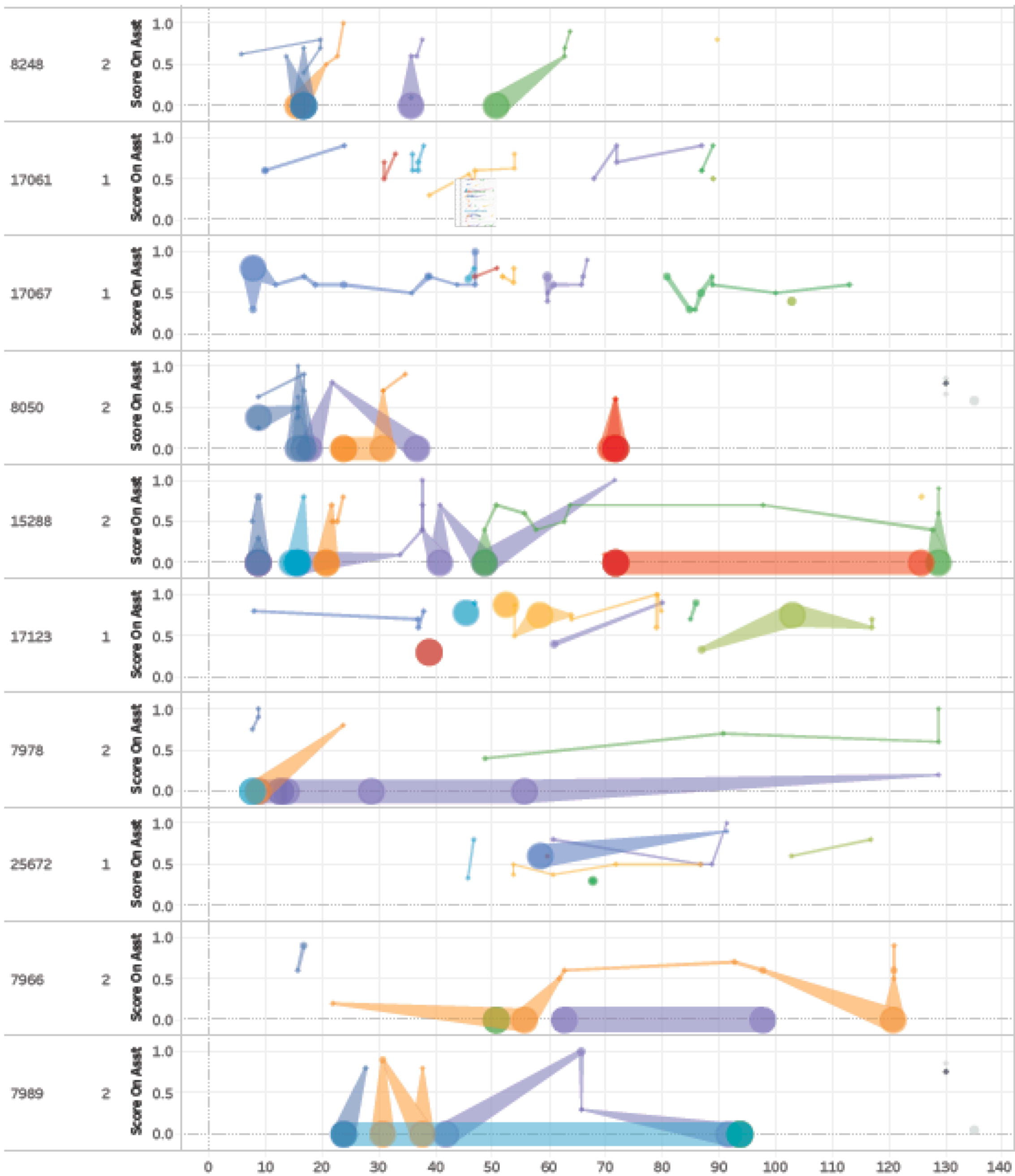
Students in Algebra 1 who received overall final scores in the course between 85 to 81.



Note. The students are presented in descending order by final score.

Table A6d

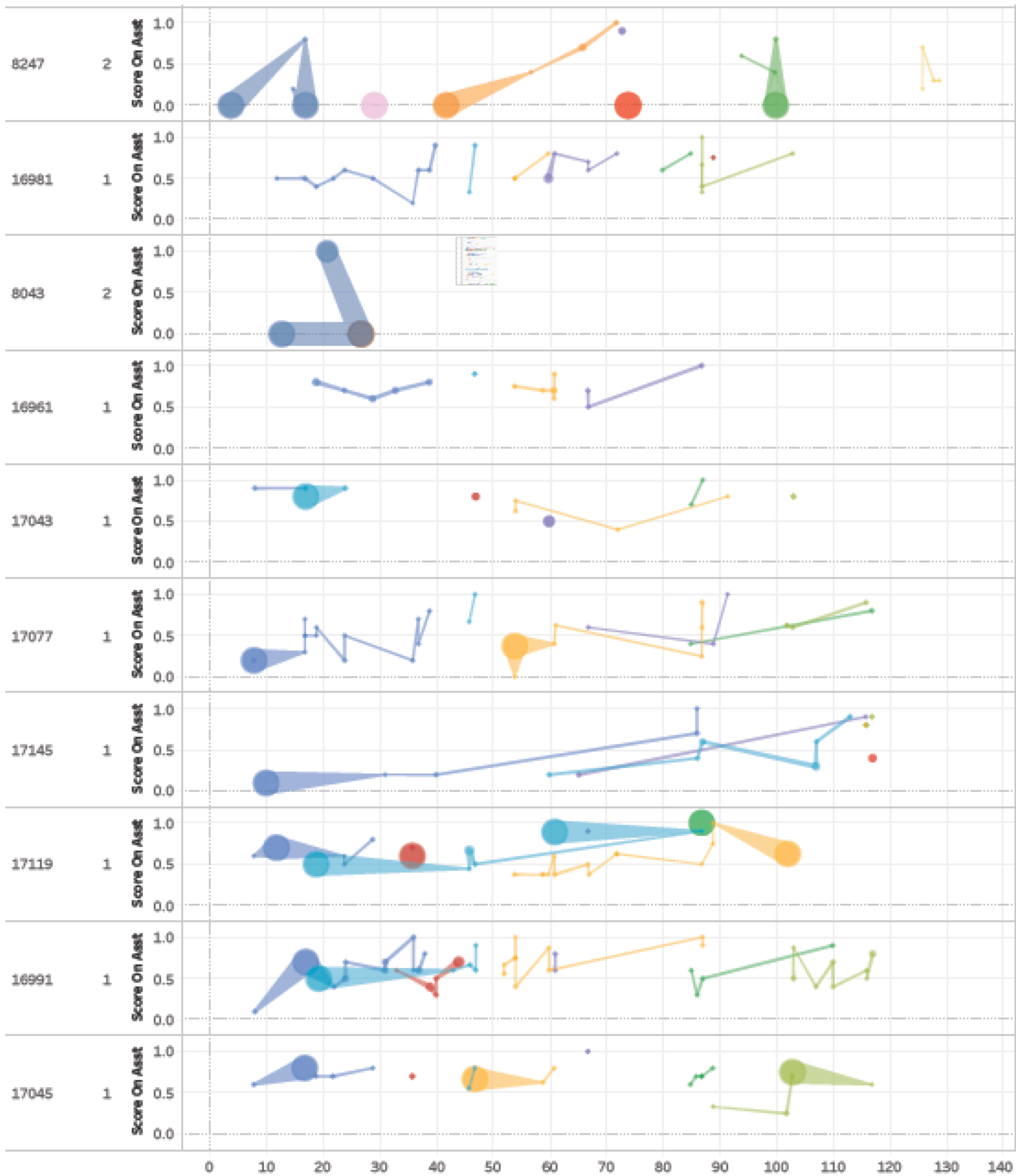
Students in Algebra 1 who received overall final scores in the course between 81 to 76.



Note. The students are presented in descending order by final score.

Table A6e

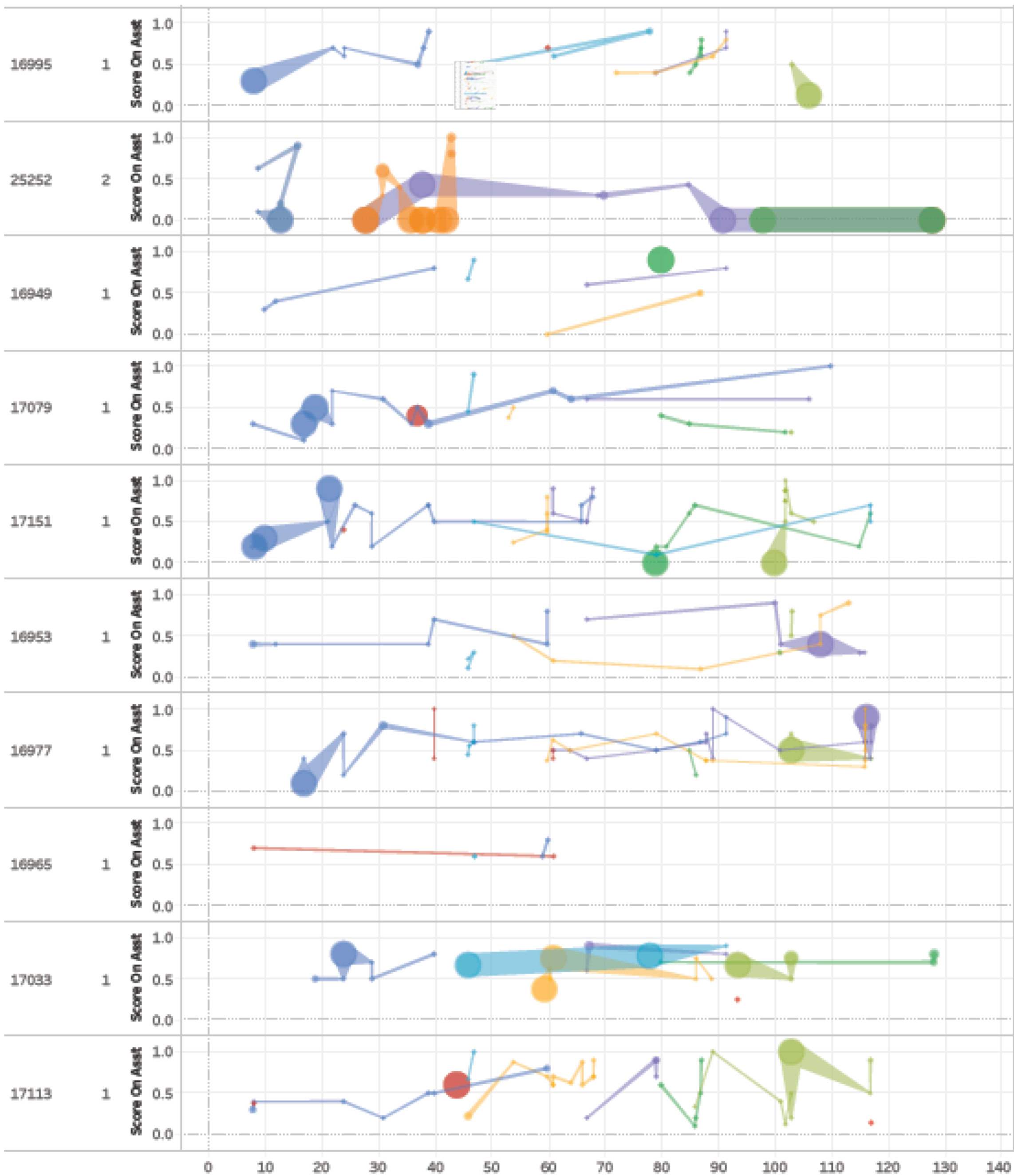
Students in Algebra 1 who received overall final scores in the course between 76 to 72.



Note. The students are presented in descending order by final score.

Table A6f

Students in Algebra 1 who received overall final scores in the course between 71 to 65.



Note. The students are presented in descending order by final score.

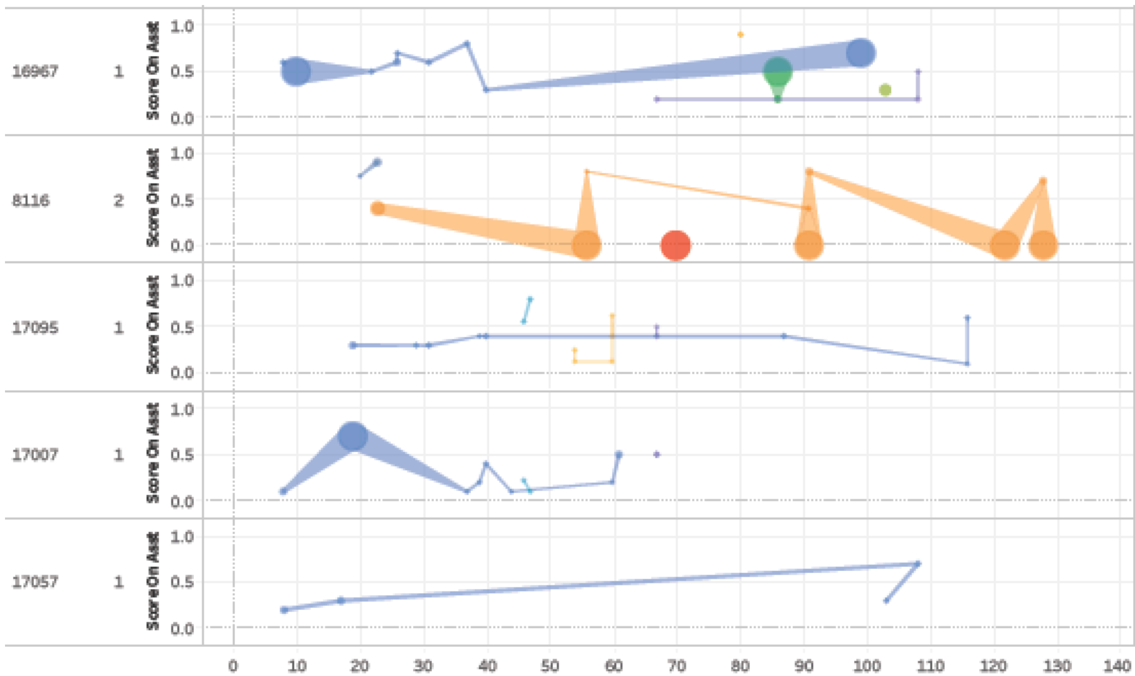
Table A6g

Students in Algebra 1 who received overall final scores in the course between 65 to 60.

Note. The students are presented in descending order by final score.

Table A6h

Students in Algebra 1 who received overall final scores in the course between 59 to 48.



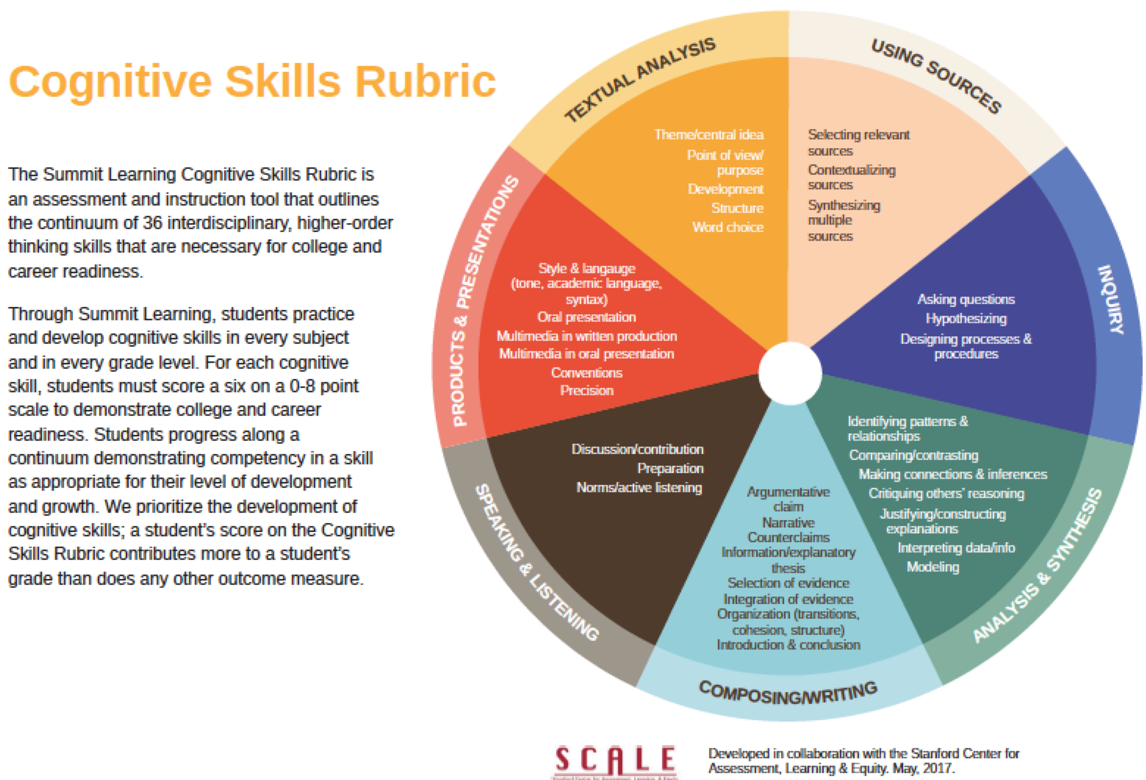
Note. The students are presented in descending order by final score.

APPENDIX B

Rubric and documents related to the personalized learning platform

Figure B1

Rubric that is used to assess how the student has applied cognitive skills to the demonstration of the course content.



Cognitive Skills Standards Alignment

The Summit Cognitive Skills Rubric—developed in partnership with the Stanford Center for Assessment, Learning & Equity (SCALE)—is aligned to the Common Core State Standards (CCSS), Next Generation Science Standards (NGSS), and C3 Social Studies Framework.

Skill Domain	Skill Dimension	High-Level Description	References to Standards
Textual Analysis (Close Reading)	Theme/Central Idea	Determining theme(s)/central idea(s) with details that convey the central idea(s)	CCSS.ELA-LITERACY.CCRA.R.2
	Point of View/Purpose	Analyzing the point of view or purpose of a character, narrator, and/or author/speaker and how that point of view influences the message or meaning of the text	CCSS.ELA-LITERARY.CCRA.R.6 C3 D2.His.4 C3 D2.His.5 C3 D2.His.6
	Development	Explaining the connection between events, ideas or concepts in a text using specific details.	CCSS.ELA-LITERACY.RL.x.3 CCSS.ELA-LITERACY.RI.x.3
	Structure	Analyzing an author's structural writing choices how they (3-5): contribute to the overall structure of the text; (6-12): affect the clarity and effectiveness of arguments, explanations, or narratives	CCSS.ELA-LITERACY.CCRA.RI.5
	Word Choice	Analyzing the effect of language, specifically word choice, on the meaning, tone, or mood of a text, and explaining how word choice relates to context or medium.	CCSS.ELA-LITERACY.CCRA.RI.4 CCSS.ELA-LITERACY.CCRA.RL.4
Using Sources	Selecting Relevant Sources	Selecting sources that support answering a particular research question with relevant, credible information that distinguishes between fact and opinion	C3 Framework for Social Studies (D2. His.4-13 C3 D3.His.3.1-2 CCSS.ELA-LITERACY.RI.7 CCSS.ELA-LITERACY.CCRA.W.1 CCSS.ELA-LITERACY.CCRA.W.7 CCSS.ELA-LITERACY.CCRA.W.8 CCSS.ELA-LITERACY.CCRA.W.9 NGSS Science Practice 8: Obtaining, Evaluating, and Communicating Information
	Contexutalizing Sources	Identifying how a source is situated within the world of its origin (time period, location, socio-political climate, cultural conditions, etc.) and explaining how the perspectives within the source shape and/or are shaped by those conditions	C3 Framework for Social Studies (D2. His.4-9) NGSS Science Practice 8: Obtaining, Evaluating, and Communicating Information
	Synthesizing Multiple Sources	Integrating information across multiple sources to support an argument or explanation	CCSS.ELA-LITERACY.CCRA.W.8 CCSS.ELA-LITERACY.RI.x.7 CCSS.ELA-LITERACY.RI.x.9 C3 D2.His.16 NGSS Science Practice 8: Obtaining, Evaluating, and Communicating Information
Inquiry	Asking Questions	Developing focused, answerable inquiry and research questions	NGSS Science Practice 1: Asking Questions and Defining Problems; CCSS.ELA-LITERACY.CCRA.W.7; C3 D1: Constructing Compelling Questions
	Predicting/Hypothesizing	Developing hypotheses and predictions	NGSS Science Practice 1: Asking Questions and 3: Planning and Carrying Out Investigations
	Designing Processes & Procedures	Following and/or developing step-by-step processes to use in the course of answering problems/prompts or conducting inquiries/investigations	NGSS Science Practice 3: Planning and Carrying Out Investigations

Analysis & Synthesis	**Identifying Patterns & Relationships**	Analyzing and organizing information (including numerical and visual) to identify patterns and/or relationships to answer a question or solve a problem	NGSS Science Practice 4: Analyzing and Interpreting Data NGSS Science Practice 5: Using Mathematics and Computational Thinking C3 D2.His.14 C3 D2.His.15 CCSS.MATH.PRACTICE.MP7 Look for and make use of structure. CCSS.MATH.PRACTICE.MP8 Look for and express regularity in repeated reasoning.
	Comparing/Contrasting	Identifying and describing similarities and differences and use them to support an argument or explanation	C3 D2.His.9 and 10 CCSS.ELA-LITERACY.RL.x.7 CCSS.ELA-LITERACY.RL.x.9 NGSS Science Practice 4: Analyzing and Interpreting Data NGSS Science Practice 7: Engaging in Argument from Evidence
	Modeling	Representing concepts** with models, visual representations or symbols AND/OR Using appropriate tools to understand and analyze situations **"Concepts," in this dimension, refers to abstract situations/information, processes, and systems	NGSS Science Practices 2: Developing and Using Models CCSS.MATH.PRACTICE.MP2: Reason abstractly and quantitatively CCSS.MATH.PRACTICE.MP4: Model with Mathematics.
	Interpreting Data/ Information	Interpret data and/or information from sources and draw justifiable conclusions from data	NGSS Science Practice 4: Analyzing and Interpreting Data CCSS.MATH.PRACTICE.MP3 Construct Viable Arguments and Critique the Reasoning of Others CCSS.MATH.PRACTICE.MP7 Look for and make use of structure. CCSS.ELA-LITERACY.CCRA.R.1
Analysis & Synthesis	**Making Connections and Inferences**	Connecting ideas and making inferences based on evidence or reasoning	CCSS.ELA-LITERACY.CCRA.R.1 NGSS Science Practice 4: Analyzing and Interpreting Data CCSS.MATH.PRACTICE.MP7 Look for and make use of structure.
	Critiquing the Reasoning of Others	Evaluating arguments, explanations, and solutions, including identifying logical fallacies and missteps	CCSS.ELA-LITERACY.RI.x.8 CCSS.ELA-LITERACY.W.x.9.B CCSS Math Practice 3: Construct Viable Arguments and Critique the Reasoning of Others C3 D2.His.17 C3 D4.4 C3 D4.5 NGSS Science Practice 7: Engaging in Argument from Evidence
	Justifying/Constructing an Explanation	Using logic and reasoning to justify a response or explain a phenomenon	NGSS Science Practice 6. Construction Explanations and Designing Solutions CCSS Math Practice 3: Construct Viable Arguments and Critique the Reasoning of Others
Composing/ Writing	**Argumentative Claim**	Developing a strong opinion/argument through clear, well-sequenced claims	CCSS.ELA-LITERACY.CCRA.W.1 C3 D2.His.16 C3 D3.4 C3 D4.1 NGSS Science Practice 7: Engaging in Argument from Evidence CCSS.MATH.PRACTICE.MP3: Construct viable arguments and critique the reasoning of others.
	Informational/Explanatory Thesis	Constructing explanations or conveying ideas and information through clear, well-organized, relevant ideas	CCSS.ELA-LITERACY.CCRA.W.2 C3 D4.2 CCSS.MATH.PRACTICE.MP3: Construct viable arguments and critique the reasoning of others.

Composing/ Writing	**Narrative**	Developing an oral or written narrative that relates connected experiences, events, procedural steps, or the like (whether they are real or imagined)	CCSS.ELA-LITERACY.CCRA.W.3 CCSS English Language Arts Appendix A
	Counterclaims	Acknowledging and developing alternate or opposing positions	CCSS.ELA-LITERACY.CCRA.W.1 C3 D3.4
	Selection of Evidence	Using relevant and sufficient evidence to support claims	CCSS.ELA-LITERACY.CCRA.W.1 CCSS.ELA-LITERACY.CCRA.W.2 C3 D3.3
	Explanation of Evidence	Analyzing how the selected evidence support the writer's statements (e.g., claims, controlling ideas)	CCCSS.ELA-LITERACY.W.x.1.B CCSS.ELA-LITERACY.W.x.2.B CCSS English Language Arts Appendix A, Definitions of the Standards' Three Text Types CCSS.MATH.PRACTICE.MP3: Construct viable arguments and critique the reasoning of others. NGSS Science Practice 6: Constructing Explanations and Designing Solutions
	Integration of Evidence	Representing evidence accurately (via notes, summary, and/or paraphrase) and including evidence in text	CCSS.ELA-LITERACY.CCRA.W.8
	Organization (Transitions, Cohesion, Structure)	Using text structure and transitions to communicate with clarity and coherence.	CCSS.ELA-LITERACY.CCRA.W.4
	Introduction and Conclusion	Framing a composition with a relevant introduction and conclusion	CCSS.ELA-LITERACY.CCRA.W.1 and 2
Speaking & Listening	**Discussion/Contribution**	Communicating ideas and contributing to discussion through questioning, connecting, and probing	CCSS.ELA-LITERACY.CCRA.SL.1; CCSS.ELA-LITERACY.SL.x.1.C
	Preparation	Entering a discussion or presentation with appropriate evidence and relevant details	CCSS.ELA-LITERACY.CCRA.SL.1; CCSS.ELA-LITERACY.SL.x.1.A
	Norms/Active Listening	Using roles and norms to support collegial discussions and completion of group work	CCSS.ELA-LITERACY.CCRA.SL.1; CCSS.ELA-LITERACY.SL.x.1.B CCSS. ELA-LITERACY.SL.x.1.D

Products & Presentations	**Style and Language (Tone, Academic Language, Syntax)**	Using appropriate style in a written product, including academic language, tone, and syntax	CCSS.ELA-LITERACY.CCRA.L.3, CCSS.ELA-LITERACY.CCRA.L.6
	Oral Presentation	Using appropriate public speaking strategies, including interaction with presentation mediums, to engage the audience and communicate points	CCSS.ELA-LITERACY.CCRA.SL.4 CCSS.ELA-LITERACY.CCRA.SL.6
	Multimedia in Written Production	Integrating technology to create high-quality written products	CCSS.ELA-LITERACY.CCRA.W.6
	Multimedia in Oral Presentation	Integrating multiple mediums, including technology, to create high-quality spoken presentations	CCSS.ELA-LITERACY.CCRA.SL.5
	Conventions	Using discipline-appropriate conventions to support clear expression of ideas and information	CCSS.ELA-LITERACY.CCRA.L.1, CCSS.ELA-LITERACY.CCRA.L.2
	Precision	Expressing ideas and information with exactness, specificity, correct use of terminology, and refinement	CCSS Math Practice 6: Attend to Precision

Domain: Textual Analysis (Close Reading)								
Dimension: Theme/Central Idea								
High-Level Description: Determining theme(s)/central idea(s) with details that convey the central idea(s)								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of identifying a theme/main idea in a text. OR Identifies a topic and details loosely related to a theme/main idea.	Identifies a theme/main idea in a text and provides a few key details.	Identifies a theme/main idea in a text and uses key details to explain the theme/main idea.	Identifies a theme/main idea in a text using key details and Elaborates on how key details support the main idea OR Uses key details to describe how characters/ speakers view events/topics.	Identifies a theme/central idea in a text and provides a limited explanation of how that theme/ central idea is developed through specific details.	Identifies a major theme/central idea in a text and provides an accurate explanation of how that theme/ central idea is developed through specific details. Provides some explanation of how the theme/ central idea interacts with supporting ideas or other elements in the text (e.g., setting, plot, character).	Identifies multiple themes/central ideas in a text and provides an accurate analysis of their development and interaction with each other and with supporting ideas or other elements in the text (e.g., setting, plot, character).	Identifies multiple themes/central ideas in a text and provides a thorough, accurate analysis of their development and interaction with each other and with supporting ideas or other elements in the text (e.g., setting, plot, character). Where applicable, interprets theme/central idea through a critical lens or framework.	Identifies multiple themes/central ideas in a text and provides a sophisticated analysis of their development and interaction with each other and with supporting ideas or other elements in the text, including an evaluation of which theme/ central idea is the most significant and why. Where applicable, persuasively interprets theme/central idea through a critical lens or framework.

Domain: Textual Analysis (Close Reading)								
Dimension: Point of View/Purpose								
High-Level Description: Analyzing the point of view or purpose of a character, narrator, and/or author/speaker and how that point of view influences the message or meaning of the text								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of identifying the point of view of an author/narrator/ speaker.	Identifies the author/narrator/ speaker's point of view, and distinguishes it from own point of view.	Describes author/narrator/ speaker's points of view. Compares and contrasts firsthand and secondhand accounts of the same event or topic OR Compares and contrasts the perspectives in first and third person narratives.	Describes how an author/ narrator/ speaker's point of view influences how events are described. Compares and contrasts the points of view represented in multiple accounts of the same event or topic.	Describes author's/ speaker's point of view or purpose and clearly explains how that point of view or purpose is conveyed and developed through the use of relevant details in the text. Explains how author's point of view differs from others and, where applicable, how the author acknowledges and responds to conflicting evidence or viewpoints.	Accurately describes author's/ speaker's point of view or purpose and analyzes how that point of view or purpose is conveyed and developed through the use of relevant details in the text. Explains how author's point of view differs from others, including the limitations or biases of the author's/ speaker's point of view. Where applicable, explains how the author acknowledges and responds to conflicting evidence or viewpoints.	Analyzes author's/ speaker's point of view, including its development, limitations, biases, and differences from and responses to other points of view. Explains how author/speaker uses rhetoric or differences in point of view to create specific effects.	Analyzes author's/ speaker's point of view, including its development, limitations, biases, and differences from and responses to other points of view. Analyzes author's/ speaker's use of rhetoric or differences in point of view to create specific effects. Analyzes the effect of cultural experience on author's/ speaker's point of view.	All of Level 7 PLUS: Identifies cases where the rhetoric or the development of point of view is particularly effective and analyzes how the point of view and/or rhetoric contributes to the power, persuasiveness, or beauty of the text.

Domain: Textual Analysis (Close Reading)								
Dimension: Development								
High-Level Description: Explaining the connection between events, ideas or concepts in a text using specific details.								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of describing how individual actions, events, ideas/concepts, or steps in a procedure are connected to a sequence of events.	Describes characters in a story and explains how their actions contribute to the sequence of events. OR Describes the relationship between a series of events, ideas/ concepts, or steps in a procedure using language that pertains to time sequence or cause/effect.	Uses specific details in a text to... Describe in depth a character, setting, or event in a story. OR Explain events, ideas/concepts, or steps in a procedure in informational text, including what happened and why.	Uses specific details in a text to explain the relationship or interactions between two or more... Characters, settings, or events in a story. OR Events, ideas/ concepts, or steps in a procedure in informational text.	Explains how events, individuals, and/or ideas/ concepts interact within a text and contribute to the development of the storyline or theme/ central idea. Analyzes how the text makes connections and distinctions between or among key events, individuals, and/or ideas/ concepts.	Analyzes clearly and accurately the development of a complex event, individual (e.g., someone with conflicting motivations) and/or idea/ concept within a text. Analysis includes how the complex event, individual, and/ or idea/concept is introduced, explained, and developed, and how it connects, is distinguished from, and interacts with other elements in the text.	Analyzes clearly and accurately how a series of events or ideas/concepts unfolds in a text, including when and how they are introduced and developed, the connections between/ among them, and how they contribute to the development of the storyline or theme/central idea of the text.	Analyzes clearly and accurately how a complex series of events or ideas/concepts unfolds in a text, including when and how they are introduced and developed, the connections between/ among them, and how they contribute to the development of the storyline or theme/central idea of the text.	Analyzes clearly and accurately the development (e.g., introduction, unfolding, connections, interactions) of a complex event, individual, and/or idea/ concept or a series of complex events and/or ideas/concepts within a text. Analysis includes an evaluation of the effectiveness of the development.

Domain: Textual Analysis (Close Reading)								
Dimension: Structure								
High-Level Description: Analyzing an author's structural writing choices how they (3-5): contribute to the overall structure of the text; (6-12): affect the clarity and effectiveness of arguments, explanations, or narratives								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of structural analysis.	Identifies the key organizing features of a text. Describes how parts of text relate to or build on earlier sections of the text.	Describes the key organizing features in a text and the overall structure of the text.	Describes the key organizing features and sections in a text. Explains how those organizing features contribute to the overall structure of the text.	Accurately and thoroughly describes the key organizing features of a text. Analyzes how a particular sentence, paragraph, or section contributes to the development of the central idea/ theme of a text.	Accurately and thoroughly describes the key organizing features and sections in a text. Evaluates the effectiveness of a particular sentence, paragraph, or section in developing the central idea/ theme.	Accurately and thoroughly describes the key organizing features and sections in a text. Evaluates the effectiveness of particular sections in developing the central idea/ theme of a text, as well as other key ideas/claims or elements (e.g., tone, meaning) of a text.	Efficiently describes the key organizing features and sections in a text. Evaluates the effectiveness of the overall structure of the text in developing the argument, explanation, or narrative.	Efficiently describes the key organizing features and sections in a text. Evaluates the effectiveness of the overall structure of the text in developing the argument, explanation, or narrative, including whether the structure helps makes points clear and/or convincing, and the text engaging. When applicable, proposes structural changes that could improve the development of the argument, explanation, or narrative.

Domain: Textual Analysis (Close Reading)

Dimension: Word Choice

High-Level Description: Analyzing the effect of language, specifically word choice, on the meaning, tone, or mood of a text, and explaining how word choice relates to context or medium.or narratives

0	1	2	3	4	5	6	7	8
No evidence of analysis of author's word choice.	Identifies and defines academic, domain-specific words and phrases in the text relevant to understanding the topic or meaning of the text. (e.g., literal or nonliteral language).	Identifies and explains the meaning of academic, domain-specific words and phrases and/or literary allusions that impact the meaning or tone of the text.	Identifies and accurately explains the meaning of academic, domain-specific words and phrases and/or literary allusions that impact the meaning or tone of the text (e.g., figurative language such as metaphors and similes).	Identifies words and phrases that impact the meaning and/ or tone of the text; clearly and accurately explains the meaning of those words and phrases as they are used in the text (including figurative, connotative, and technical meanings); explains the impact of those word choices on meaning and/or tone in the text.	Identifies words and phrases that impact the meaning and tone of the text; clearly and accurately explains the meaning of those words and phrases as they are used in the text (including figurative, connotative, and technical meanings). Clearly explains the impact of those specific word choices on the meaning and/or tone of the text. Generally explains how specific word choices relate to context or medium.	Identifies words and phrases that impact the meaning and tone of the text; clearly and accurately explains the meaning of those words and phrases as they are used in the text (including figurative, connotative, and technical meanings). Explains the cumulative impact of those specific word choices on the meaning and/ or tone of the entire text. Clearly explains how specific word choices relate to context or medium.	Identifies words and phrases that impact the meaning and tone of the text; clearly and accurately explains the meaning of those words and phrases as they are used in the text (including figurative, connotative, and technical meanings). Explains the impact of a pattern of word choices on meaning and/or tone, including how patterns of word choice relate to context or medium. Where applicable, generally explains how an author uses or refines the meaning of a key term/ concept over the course of a text.	Identifies words and phrases that impact the meaning and tone of the text; clearly and accurately explains the meaning of those words and phrases as they are used in the text (figurative, connotative, and technical meanings). Analyzes the impact of a pattern of word choices on meaning and tone and the relationship between word choice and context or medium. Where applicable, clearly analyzes how an author uses or refines the meaning of a key term/ concept over the course of a text.

Domain: Using Sources

Dimension: Selecting Relevant Sources

High-Level Description: Selecting sources that support answering a particular research question with relevant, credible information that distinguishes between fact and opinion

0	1	2	3	4	5	6	7	8
Selects information from provided sources with little to no relevance to a research question or understanding of the text(s).	Selects information from provided sources, including illustrations (e.g., maps, photographs) and the words in a text that are relevant to an understanding of the text (e.g., where, when, why, and how key events occur), but may not be relevant to a research question.	Selects information relevant to the research question from provided sources of varied format (e.g., charts, graphs, diagrams, time lines, animations, or interactive elements on Web pages).	Selects multiple sources that provide key evidence relevant to the research question. Where applicable, sources vary in format.	Selects sources that provide sufficient, credible information relevant to the research question. Where applicable, sources vary in perspective and/or format.	Selects sources that provide detailed, credible information relevant to the research question. Where applicable, sources vary in perspective and/ or format.	Selects sources that provide detailed, comprehensive, credible information relevant to the research question. Where applicable, sources vary in perspective and/or format.	Selects sources that provide nuanced, comprehensive, credible information relevant to the research question. Where applicable, sources vary in perspective and/or format. Any gaps or limitations in sources are noted.	Selects sources that provide nuanced, comprehensive, credible information relevant to the research question at a level of detail and complexity appropriate to the audience and purpose of the research. Where applicable, sources vary in perspective and/ or format. Any gaps or limitations in sources are noted and the impact of those gaps and limitations is discussed.

Domain: Using Sources								
Dimension: Contextualizing Sources								
High-Level Description: Identifying how a source is situated within the world of its origin (time period, location, socio-political climate, cultural conditions, etc.) and explaining how the perspectives within the source shape and/or are shaped by those conditions								
0	1	2	3	4	5	6	7	8
No evidence of contextualizing sources.	Identifies a source's time and place of origin.	Provides information about a source's time or place of origin. Includes basic information about the maker.	Provides information about a source's time and place of origin. Includes information about the maker, the maker's perspective, and intended audience or purpose.	Provides accurate information about a source's time and place of origin. Includes some information about the historical, scientific, political, economic, social, and/or cultural conditions of the source's origin.	Provides accurate information about the historical, scientific, political, economic, social, and/or cultural conditions of the source's origin. Makes connections between these conditions and the contents of the source.	Provides accurate, relevant information about the historical, scientific, political, economic, social, and/or cultural conditions of the source's origin, including (where relevant) events and conditions leading up to or immediately following the source's creation. Generally explains how these conditions shape the meaning or significance of the source.	Provides accurate, relevant information about the historical, scientific, political, economic, social, and/or cultural conditions of the source's origin, including (where relevant) events and conditions leading up to or immediately following the source's creation. Clearly explains how these conditions shape the meaning or significance of the source.	Provides thorough, relevant information about the historical, scientific, political, economic, social, and/or cultural conditions of the source's origin, including (where relevant) events and conditions leading up to or immediately following the source's creation. Uses analysis of these conditions to strengthen and refine an argument or explanation.

Domain: Using Sources								
Dimension: Synthesizing Multiple Sources								
High-Level Description: Integrating information across multiple sources to support an argument or explanation								
0	1	2	3	4	5	6	7	8
No evidence of synthesizing information from multiple sources. One source dominates the work.	Makes note of key points or details from two sources on the same topic.	Integrates information from two sources on the same topic by comparing information.	Integrates information from several sources on the same topic by sorting and comparing information.	Connections among sources are made by comparing information from multiple sources and/or comparing the type of sources (e.g., format, genre, time period, etc.).	Connections among sources are made by grouping similar information/ positions from multiple sources or identifying significant differences between sources (in content and/ or type).	Information from multiple sources is compared and grouped to deepen or extend an argument or explanation.	Information from multiple sources is compared, grouped, and synthesized with the student's own claims or ideas to form a cohesive, supported argument or explanation.	Significant and nuanced connections are made among the sources and synthesized with the student's own claims or ideas to form a cohesive, supported, compelling argument or explanation.

Domain: Inquiry								
Dimension: Asking Questions								
High-Level Description: Developing focused, answerable inquiry and research questions								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Questions do not support understanding of a given topic.	Questions are relevant to a specific topic.	Questions are relevant to a specific topic and are based on the described problem or situation.	Questions are relevant to a specific topic, are testable or researchable, and build on prior knowledge about the topic.	Questions are relevant to a specific topic, are testable or researchable, and build on existing disciplinary knowledge about the topic.	Questions are valid, testable or researchable, and based on patterns or observations.	Questions are valid, focused, testable or researchable, based on patterns/ observations, current research, and/ or a specific model or theory.	Questions are valid, precise, testable or researchable, and based on patterns/ observations, specific evidence from current research, and/ or a specific model or theory.	Questions are valid, precise, testable or researchable, based on patterns/ observations, specific evidence from current research and/ or a specific model or theory, and push standard thinking on a given topic or in a particular discipline.

Domain: Inquiry								
Dimension: Predicting/Hypothesizing								
High-Level Description: Developing hypotheses and predictions								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of hypothesis or prediction.	Makes a prediction that is partially relevant to the inquiry question with little or no reasoning.	Makes a prediction related to the inquiry question. Supports reasoning for prediction with prior observations or experiences.	Makes a reasonable prediction related to the inquiry question that involves changing a variable. Begins to explain reasoning for prediction by relating it to prior knowledge such as cause and effect relationships.	Makes a reasonable prediction related to the inquiry question that involves changing a variable. Hypothesis relates to prior research about the topic.	Constructs a testable hypothesis about the investigated question, with a basic description of the variables ("if... then..."). Hypothesis relates to observation, research, or scientific principle.	Constructs a clear, testable hypothesis about the investigated question, with an accurate description of the variables ("if... then..."). Hypothesis is based on observation, research, scientific principle, model, or theory.	Constructs a precise, testable hypothesis about the investigated question, with an accurate explanation of the relationship between variables ("if... then... because...)". Hypothesis is based on observation, research, scientific principle, model, or theory.	Constructs a precise, testable, and insightful hypothesis about the investigated question, with accurate and thorough explanation of the relationship between variables ("if... then... because"). Hypothesis is based on observation, research, scientific principle, model, or theory.

Domain: Inquiry								
Dimension: Designing Processes & Procedures								
High-Level Description: Following and/or developing step-by-step processes to use in the course of answering problems/prompts or conducting inquiries/investigations								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of an action plan to address the problem/ prompt.	Identifies a general approach to investigate a question or solve a problem. OR Follows a recommended set of procedures for investigating a question or solving a problem.	Identifies the first few steps in a specific approach to investigate a question or solve a problem. Identifies specific tools or methods.	Creates a step-by-step plan to investigate a question or solve a problem. Identifies appropriate methods, tools, and/or approaches.	Creates an orderly action plan and addresses most aspects of the problem/ prompt. Includes a description of appropriate methods, tools, and/or approaches.	Creates an orderly action plan that addresses all aspects of a problem/prompt with some inefficiencies.	Creates a clear and orderly action plan that is mostly replicable and addresses all aspects of a problem/prompt in an efficient way. Includes a rationale for some steps or aspects of the plan.	Creates a clear, detailed action plan that is fully replicable and addresses all aspects of a problem/prompt in an efficient way. Includes a rationale for several steps or aspects of the plan. Where applicable, includes some alternate or contingency plans.	Creates a clear, detailed, fully replicable action plan to address a problem/ prompt as efficiently as possible. Includes a rationale for the complete plan. Where applicable, acknowledges potential weaknesses or limitations of the plan and includes thorough alternate or contingency plans.

Domain: Analysis & Synthesis								
Dimension: Identifying Patterns & Relationships								
High-Level Description: Analyzing and organizing information (including numerical and visual) to identify patterns and/or relationships to answer a question or solve a problem								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of organizing information or identifying patterns.	Makes note of simple connections or patterns from information displayed in structures.	Organizes information into mostly useful structures (tables, concept maps, or other graphical displays), and identifies patterns with some inaccuracies.	Organizes information into useful structures (tables, concept maps, or other graphical displays), and accurately identifies patterns.	Organizes information into useful structures. Accurately identifies patterns and a general relationship among patterns.	Organizes information into useful structures. Accurately identifies patterns and some relationships among patterns.	Organizes information into useful structures. Accurately identifies significant/ relevant patterns and relationships among patterns.	Organizes information into useful structures. Identifies and explains significant/ relevant patterns and the relationships among patterns. Makes note of examples and data that do not fit the pattern(s) or relationship(s).	Organizes information into useful structures. Identifies and explains significant/ relevant patterns and relationships among patterns. Identifies and explains examples and data that do not fit the pattern(s) or relationship(s).

Domain: Analysis & Synthesis

Dimension: Comparing/Contrasting

High-Level Description: Identifying and describing similarities and differences and use them to support an argument or explanation

0	1	2	3	4	5	6	7	8
No evidence of comparing/ contrasting.	Identifies a similarity or difference relevant to a claim/main idea.	Identifies similarities and differences relevant to a specific claim/ main idea.	Identifies significant similarities and differences relevant to a specific claim/ main idea.	Describes significant similarities and differences relevant to a specific claim/ main idea/ thesis.	Identifies significant similarities and differences relevant to a specific claim/ main idea/thesis. Explains in a limited way why the similarities/ differences are meaningful within the frame of reference (i.e., the claim/main idea/thesis).	Analyzes or evaluates significant similarities and differences relevant to a specific claim/main idea/thesis. Thoroughly explains why the similarities/ differences are meaningful within the frame of reference. Organizes points of comparison in a logical way.	Analyzes or evaluates significant similarities and differences relevant to a specific claim/ main idea/ thesis, including an explanation of how the similarities/ differences support a specific claim/ main idea/ thesis. Organizes points of comparison in a way that supports understanding and analysis.	Analyzes or evaluates significant similarities and differences relevant to a specific claim/main idea/thesis, including an explanation of how the similarities/ differences refine or sharpen a specific claim/ main idea/ thesis. Organizes points of comparison in a way that best highlights and frames similarities and differences for analysis and understanding.

Domain: Analysis & Synthesis

Dimension: Modeling

High-Level Description: Representing concepts** with models, visual representations or symbols. AND/OR: Using appropriate tools to understand and analyze situations. **"Concepts," in this dimension, refers to abstract situations/information, processes, and systems

0	1	2	3	4	5	6	7	8
No evidence of using models, visuals, or symbols to represent concepts.	Begins to identify general components of a concept and develops an oversimplified and/or incomplete physical, visual and/or abstract model.	Identifies specific components of a concept and develops a simple and partially accurate physical, visual and/or abstract model to represent key features.	Identifies specific components of a concept and develops a simple but accurate physical, visual and/or abstract model to represent key features.	Identifies significant components of a concept and develops an accurate physical, visual, and/or abstract model to represent key features.	Identifies significant components of a concept and develops an accurate visual and/or model to represent key features. Visual or model begins to make visible the relationship of the components to the whole.	Identifies significant components of a concept and develops accurate visual(s) and/ or model(s) to represent key features. Visual(s) or model(s) highlight the relationship of the components to the whole and makes visible the relationships among components.	Identifies significant components of a complex concept and develops accurate visual(s) and/ or model(s) to represent key features. Visual(s) or model(s) highlight the relationships of the components to the whole and the relationships among components. Model allows for manipulation and/or testing of a proposed idea, process, or system.	Develops and/or uses multiple types of models to accurately represent and manipulate complex concepts. Visuals or models highlight the relationships of the components to the whole and the relationships among the components. Evaluates the merits and limitations of each model and moves flexibly between model types as appropriate to the purpose.

Domain: Analysis & Synthesis								
Dimension: Interpreting Data/Information								
High-Level Description: Interpret data and/or information from sources and draw justifiable conclusions from data								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of interpreting data/ information.	Description or summary of data/information is incomplete or unsupported.	Provides a reasonable interpretation of data/ information. Uses a relevant analytic strategy (e.g., sorting, compare/ contrast) to characterize the data/information in a general way.	Provides a reasonable interpretation of data/ information. Uses a relevant analytic strategy (e.g., sorting, compare/ contrast) or concept (e.g., mean, mode) to characterize the data/ information.	Provides an accurate interpretation of data/ information. Uses a relevant analytic strategy (e.g., sorting, compare/ contrast) or concept (e.g., mean, mode) to characterize the data/ information.	Provides an accurate interpretation of data/information. Applies some analytic strategies (e.g., sorting, compare/ contrast) or concepts (e.g., mean, mode) to characterize the data/information.	Provides an accurate interpretation of data/ information. Applies appropriate analytic strategies or concepts to characterize the data/ information. Considers the context from which the data/ information arose.	Provides a thorough, accurate interpretation of data/ information. Applies multiple analytic strategies or concepts to characterize the data/ information. Considers the context from which the data/ information arose. Recognizes gaps or outliers in the data/ information.	Provides a thorough, accurate interpretation of data/ information. Applies multiple analytic strategies/ concepts and determines which strategy/ concept is best for the purpose of the analysis. Considers the context from which the data/ information arose. Explains gaps or outliers in the data/ information.

Domain: Analysis & Synthesis								
Dimension: Making Connections & Inferences								
High-Level Description: Connecting ideas and making inferences based on evidence or reasoning								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Reasoning is not evident. Focuses on explicit details, with no reference to implicit or inferred meanings.	Demonstrates a basic understanding of a text based on explicit details in the text. Refers to a specific example relevant to that understanding.	Makes an inference based on evidence. Refers to a specific example relevant the inference.	Makes relevant inferences based on evidence. Makes clear connections between two or more specific examples relevant to the inferences.	Makes relevant inferences based on evidence and identifies the larger significance of the inference. Connections between a specific example and the larger idea are clear and appropriate.	Makes clear and relevant inferences based on evidence and partially explains the larger significance of the inference. Connections to the larger idea are made through multiple examples but may have some gaps in explanation or may not be fully developed.	Makes clear, relevant, thoughtful inferences and explains their larger significance. Where applicable, identifies limitations of inferences based on gaps in evidence. Connections to the larger idea are clearly made through multiple examples.	Makes clear, highly relevant and thoughtful inferences and thoroughly explains their larger significance. Where applicable, identifies limitations of inferences based on gaps in evidence. Uses inferences as the basis for predictions or broader generalizations. Connections to the larger idea are clearly made through multiple examples, including attempts at non- or counter-examples.	Makes clear, highly relevant, insightful inferences and thoroughly explains their larger significance with sophisticated insight or originality of interpretation. Where applicable, identifies limitations of inferences based on gaps in evidence. Uses inferences as the basis for predictions or broader generalizations. Connections to the larger idea are clearly made through multiple examples, including non- or counter-examples.

Domain: Analysis & Synthesis								
Dimension: Critiquing the Reasoning of Others								
High-Level Description: Evaluating arguments, explanations, and solutions, including identifying logical fallacies and missteps								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Accepts or rejects argument/ explanation with no evaluation of reasons or evidence.	Restates the argument/ explanation. Provides an opinion about the argument/ explanation, referring to at least one reason or piece of evidence.	Summarizes the argument/ explanation or specific claim, and determines whether the reasons/ evidence are relevant.	Accurately summarizes the argument/ explanation or specific claims, and determines whether the reasoning is logical and evidence is relevant.	Traces and evaluates the argument/ explanation and specific claims, assessing whether the reasoning is logical and/or the evidence is relevant.	Delineates and evaluates the argument/ explanation and specific claims, assessing whether the reasoning is valid and/or the evidence is relevant and sufficient. Where applicable, identifies some false statements and fallacious reasoning (logical fallacies).	Clearly delineates and evaluates the argument/ explanation and specific claims, thoroughly assessing in detail whether the reasoning is valid and/or the evidence is relevant and sufficient. Where applicable, identifies false statements and fallacious reasoning (logical fallacies) and considers alternate claims or evidence that would improve the logic of the argument/ explanation.	Clearly delineates and evaluates the argument/ explanation and specific claims, thoroughly assessing in detail whether the reasoning is valid and the evidence is relevant and sufficient. Identifies false statements and fallacious reasoning and thoroughly explains alternate claims or evidence to improve the logic of the argument/ explanation.	All of Level 7 PLUS Identfies and evaluates the appro-priateness of the premise(s) or principle(s) on which the argument is constructed, and, where applicable, suggests alternate premise(s) or principle(s).

Domain: Analysis & Synthesis								
Dimension: Justifying/Constructing an Explanation								
High-Level Description: Using logic and reasoning to justify a response or explain a phenomenon								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of justifying or explaining.	Provides a brief description of steps, procedures, or a phenomenon. Explanation or justification is missing or very limited. Explanation of reasoning is limited or incomplete.	Provides some detail in explaining steps, procedures, or a phenomenon. Uses concrete details/ examples to explain reasoning.	Provides a logical chain of reasoning to justify steps or procedures, or to explain a phenomenon. Uses concrete details/ examples and/ or disciplinary ideas to justify reasoning.	Provides a logical chain of reasoning to explain or justify specific steps, procedures, or phenomena. Develops explanation/ justification with some detail/ examples.	Provides a logical chain of reasoning to explain or justify steps, procedures, or phenomena in support of an overall solution strategy/ procedure or a holistic explanation of the phenomenon. Develops explanation/ justification with relevant detail/ examples.	Applies a specific premise (such as a disciplinary principle, axiom, or theory) to explain or justify a solution, strategy, response, or phenomenon. Fully develops explanation/ justification through relevant detail and examples. Acknowledges limitations, tradeoffs, and/ or alternate explanations/ approaches.	Applies one or more specific premises (such as disciplinary principles, axioms, or theories) to insightfully explain or justify a solution, strategy, response, or phenomenon. Fully develops explanation/ justification through detail and examples. Responds to limitations, tradeoffs, and/ or alternate explanations/ approaches.	Uses a variety of logical strategies and relevant, sufficient detail and examples to develop a sophisticated, persuasive explanation or justification that fully takes into account limitations, tradeoffs, and/ or alternate explanations/ approaches.

Domain: Composing/Writing								
Dimension: Argumentative Claim								
High-Level Description: Developing a strong opinion/ argument through clear, well-sequenced claims								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Opinion/claim is missing or unclear.	Introduces an opinion/claim and provides reasons that support student's point of view.	Introduces a clear opinion/ claim and provides reasons that support student's point of view.	Introduces a clear opinion/ claim and provides logically ordered reasons that support student's point of view.	Claims and subclaims are clearly introduced throughout writing and organized so that relationships between claims and subclaims are evident.	Claims and subclaims are clearly introduced and organized in a way that makes relationships among claims and subclaims clear and supports the reader's understanding. Some attention is given to the significance of claims.	Claims and subclaims are clear, focused, and consistent throughout the writing; the sequencing of the claims and subclaims builds the reader's understanding throughout the writing. The significance of the claims is clearly established.	Claims and subclaims are clear, precise, and consistent throughout the writing with some nuance; the sequencing of the claims and subclaims creates a coherent structure that builds the reader's understanding throughout the writing. The significance of the claims is clearly established and developed.	Claims and subclaims are clear, precise, and nuanced throughout the writing; the sequencing of the claims and subclaims creates a complex and coherent structure that builds the reader's understanding throughout the writing. The significance of the claims is clear and persuasive.

Domain: Composing/Writing								
Dimension: Informational/Explanatory Thesis								
High-Level Description: Constructing explanations or conveying ideas and information through clear, well-organized, relevant ideas								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Topic or main idea is unclear.	Topic is evident with an unclear main idea.	Main idea is clear, on-topic, and focused. Some supporting ideas are provided.	Main idea is clear, on-topic, and focused; supporting ideas are relevant to main idea.	Main idea/ thesis is clear and focused; supporting ideas are relevant and organized so that relationships between main idea and supporting ideas are evident.	Main idea/thesis is clear, focused, and consistent throughout the writing; supporting ideas are relevant, organized in a way that makes relationships among ideas clear and that supports the reader's understanding.	Main idea/ thesis is clear and complex; relevant, sufficient supporting ideas are explicitly connected to main idea and organized logically to create a coherent structure that builds the reader's understanding throughout the writing.	Main idea/thesis is complex, focused, and consistent; highly relevant supporting ideas are tightly connected to the main idea and with each other to create a complex and coherent structure that builds the reader's understanding throughout the writing.	Main idea/ thesis is complex, precise, and consistent; significant, highly relevant supporting ideas build on the main idea and on one another in an elegant progression to create a complex and coherent structure that builds the reader's understanding throughout the writing.

Domain: Composing/Writing								
Dimension: Narrative								
High-Level Description: Developing an oral or written narrative that relates connected experiences, events, procedural steps, or the like (whether they are real or imagined)								
0	1	2	3	4	5	6	7	8
Describes loosely related events. Does not introduce narrator or characters. Does not provide a sense of closure. Does not include details or does not use narrative technique to develop characters and plot.	Establishes a situation and organizes a sequence of events using temporal words and phrases. Introduces a narrator and/ or characters and provides a sense of closure. Uses limited details and a narrow set of narrative techniques such as description of actions, thoughts, and feelings or dialogue to develop characters and plot, but they are unevenly developed.	Establishes a situation and organizes a sequence of events using some transitional words and phrases. Introduces a narrator and/ or characters and provides a logical conclusion. Uses concrete words and phrases, sensory details, and some narrative techniques, such as description of actions, thoughts, and feelings and dialogue, to develop characters and plot.	Establishes a situation and organizes a sequence of events using a variety of transitional words, phrases, and clauses. Introduces a narrator and/ or characters and provides a logical conclusion. Uses concrete words and phrases, sensory details, and the full range of narrative technique, such as description of actions, thoughts, and feelings, dialogue, and pacing, to develop characters and plot.	Orientation (including point of view), storyline, and/ or organization of experiences, events, and/or steps are clearly established; organizational sequence is logical, coherent, and/ or unfolds naturally; where appropriate, multiple narrative techniques are used (e.g., description, dialogue, pacing, or reflection); description includes some precise vocabulary and some details and/or sensory language; conclusion generally follows from the narrated experiences/ events/steps.	Orientation (including point of view), storyline, and/ or organization of experiences, events, and/or steps are clearly established; organizational sequence is logical, coherent, and/or unfolds naturally and smoothly; where appropriate, multiple narrative techniques are used effectively (e.g., description, dialogue, pacing, or reflection); description includes precise vocabulary and, where appropriate, vivid details and sensory language; conclusion clearly follows from the narrated experiences/ events/steps.	All of Level 5, PLUS: Uses a variety of techniques to sequence experiences/ events/steps so that they build on one another to create a coherent whole, a particular tone and/or mood, and/ or a specific outcome.	All of Level 6, PLUS: Uses narrative techniques to provide deep insight into the content (personalities and motivations, significance of events, etc.) Develops multiple plots, storylines, or sequences of events/steps.	All of Level 7, PLUS: Manipulates pace and other narrative elements to highlight the significance of experience/ events/steps or create specific effects.

Domain: Composing/Writing								
Dimension: Counterclaims								
High-Level Description: Acknowledging and developing alternate or opposing positions								
0	1	2	3	4	5	6	7	8
Counterclaims are not acknowledged.	Acknowledges that there is disagreement without identifying a specific counterclaim.	Makes note of a specific counterclaim.	Describes a specific counterclaim.	Describes specific counterclaims and clearly distinguishes them from claims.	Develops counterclaims with some evidence or detail and points out their limitations.	Develops counterclaims fairly with sufficient evidence or detail, pointing out their strengths and limitations in a way that anticipates the audience's knowledge level and concerns.	Develops counterclaims fairly and thoroughly with sufficient evidence or detail, pointing out their strengths and limitations in a way that anticipates the audience's knowledge level, concerns, values, and possible biases.	Develops counterclaims fairly and thoroughly with highly relevant evidence or detail; refutes counterclaims thoroughly and strategically, conceding points where appropriate to strengthen the writer's own argument.

Domain: Composing/Writing								
Dimension: Selection of Evidence								
High-Level Description: Using relevant and sufficient evidence to support claims								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence or evidence is completely unrelated to statements.	Selects evidence with minimal relevance to main claim(s).	Selects evidence relevant to main claim(s).	Selects relevant evidence that supports main claim(s). Evidence for subclaims is limited or weakly related.	Selects relevant evidence that supports both main claim(s) and subclaims.	Selects a variety of relevant evidence that is sufficient to support main claim(s); evidence still only generally supports subclaims.	Selects a variety of detailed, relevant evidence that is sufficient to support both main claim(s) and subclaims.	Selects a variety of detailed, significant evidence that is sufficient to support and develop both main claim(s) and subclaims.	Selects the most significant evidence that is highly appropriate to the audience's knowledge of the topic or other concerns to persuasively support and develop both claim(s) and subclaims.

Domain: Composing/Writing								
Dimension: Explanation of Evidence								
High-Level Description: Analyzing how the selected evidence support the writer's statements (e.g., claims, controlling ideas)								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Includes unrelated facts, definitions, and details.	Includes relevant facts, definitions, and/or details (and relevant illustrations when appropriate).	Includes relevant facts, definitions, concrete details, and quotations, and/ or examples (as well as illustrations or multimedia when appropriate) that support the main idea.	Explains relevant facts, definitions, concrete details, and/or quotations, and/ or examples (as well as illustrations or multimedia when appropriate) that support the opinion/main idea.	Provides relevant analysis that explains how the selected evidence supports claims or statements; analysis stays rooted in the evidence but at times may be vague, illogical, or overly general.	Provides clear analysis that accurately explains how the selected evidence supports claims or statements.	Provides insightful and clear analysis that thoroughly and accurately explains how the evidence supports claims or statements; where applicable, analysis acknowledges some weakness(es) or gaps in the evidence.	Provides insightful, clear, compelling analysis that thoroughly and accurately explains how the evidence supports claims or statements; where applicable, analysis addresses weakness(es) or gaps the evidence.	Provides insightful, compelling analysis that thoroughly, accurately, and concisely explains how the evidence supports claims or statements; where applicable, analysis clearly addresses weakness(es) or gaps in the evidence; analysis is elegant in its precision and/or sophistication and originality.

Domain: Composing/Writing								
Dimension: Integration of Evidence								
High-Level Description: Representing evidence accurately (via notes, summary, and/or paraphrase) and including evidence in text								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of including evidence from sources, or evidence is presented inaccurately.	Presents information from experiences or sources in brief notes taken in a provided organizer.	Presents relevant evidence from experiences or sources in notes organized by categories OR at appropriate places in the text.	Presents relevant evidence from experiences or sources through accurate summary or paraphrase at appropriate places within the text.	Evidence from sources is presented objectively and accurately and inserted at appropriate points in the text to support an argument, explanation, or analysis.	Evidence is presented objectively and accurately, positioned appropriately in the text, and contextualized with introductory and/or explanatory phrases or statements.	Evidence is presented objectively and accurately, positioned and contextualized appropriately, and purposefully excerpted, paraphrased, or summarized to highlight the aspects that are most relevant or important to the argument, explanation, or analysis.	Evidence is presented objectively and accurately, positioned and contextualized appropriately, and excerpted, paraphrased, or summarized strategically. Evidence is integrated into the text in a variety of ways (e.g., breakout quotes, combination of summary and direct quote) that support the argument, explanation, or analysis and develop a consistent tone appropriate to the purpose.	Evidence is presented objectively and accurately and integrated seamlessly and strategically into the text in a variety of ways that support the argument, explanation, or analysis and develop a consistent and sophisticated tone appropriate to the purpose.

Domain: Composing/Writing								
Dimension: Organization (Transitions, Cohesion, Structure)								
High-Level Description: Using text structure and transitions to communicate with clarity and coherence								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Lists information about claim or main idea. Uses no linking words.	Groups related information together related to claim/main idea. Uses linking words to connect ideas/ claims.	Organizes paragraphs or sections around claim/ideas. Uses words and phrases to link ideas within categories of information/ claims	Organizes paragraphs or sections logically to support the main idea or claim. Uses words, phrases, and clauses to link ideas within and across categories/ claims.	Paragraphs and/or sections are connected and sequenced to support understanding of ideas. Transitions are varied and are mostly appropriate and effectively used.	Paragraphs and/or sections are connected and logically build upon one another to deepen understanding of ideas and clarify relationships among ideas. Transitions are varied and appropriately and effectively used.	Paragraphs and/or sections are connected and clearly and logically build upon one another to deepen understanding of complex ideas and to clarify relationships among those ideas. Transitions are varied and appropriately and effectively used. Sequencing of paragraphs and use of transitions help build cohesion.	Sequencing of paragraphs and/or sections creates a coherent whole that deepens understanding of the content and builds toward a particular outcome. Transitions are appropriate, effective, and varied in their structure and location.	Sequencing of paragraphs or sections creates a coherent whole that deepens understanding of the content and clearly guides the reader toward a particular outcome. Transitions are appropriate, effective, and varied in their structure and location. Sequencing of ideas and transitions is seamless and fluid, and enhances the purpose of the writing.

Domain: Composing/Writing								
Dimension: Introduction & Conclusion								
High-Level Description: Framing a composition with a relevant introduction and conclusion								
0	1	2	3	4	5	6	7	8
Includes introduction but main idea or claim is unclear or missing. Provides no concluding statement or conclusion.	Introduces the topic and includes main idea or claim. Provides a concluding statement or section.	Introduces the topic and a clear main idea or claim; focus on the main idea or claim is mostly maintained. Provides a concluding statement or conclusion that relates to the main idea or claim.	Introduces the topic and a clear main idea or claim; maintains a consistent focus on the main idea or claim. Provides a concluding statement or conclusion that relates to the main idea or claim.	Introduction includes related background or context information about the topic and introduces the main idea(s) or claim(s); conclusion logically follows from the content presented and ties back to main idea(s) or claim(s).	Introduction includes relevant background or context information about the topic, introduces main idea(s) or claim(s), and establishes purpose for writing. Conclusion summarizes the content presented and pulls multiple ideas together in relation to the main idea(s) or claim(s).	Introduction includes relevant and sufficient background or context information about the topic, introduces main idea(s) or claim(s), and establishes purpose for writing; introduction is engaging. Conclusion summarizes, pulls ideas together, and highlights important points of the content presented; when appropriate, conclusion considers some implication(s) of the content presented.	Introduction clearly contextualizes the topic, and clearly establishes the main idea(s) or claim(s) and purpose for writing; introduction is engaging. Conclusion summarizes, highlights, and/ or extends ideas as appropriate; when appropriate, conclusion addresses implications or significance of the content presented.	Introduction clearly and concisely contextualizes the topic and establishes the main ideas(s) or claims(s); introduction clearly establishes the purpose and outlines the structure of the content that follows; introduction is engaging and inviting. Conclusion strongly supports the content presented by clearly summarizing, highlighting, and/ or extending ideas as appropriate; when appropriate, conclusion clearly addresses implications/ significance of and/or acknowledges questions that arise from the content presented.

Domain: Speaking & Listening								
Dimension: Discussion/Contribution								
High-Level Description: Communicating ideas and contributing to discussion through questioning, connecting, and probing								
0	1	2	3	4	5	6	7	8
Does not participate in discussions. Asks questions or provides comments unrelated to discussion or text.	Provides comments that connect to the ideas of others and stay on topic. Asks questions for clarification.	Provides original comments that contribute to the discussion and connect to the ideas of others. Asks and responds to specific questions for clarification.	Provides original comments and/or draw conclusions that contribute to the discussion and elaborate on the ideas of others. Asks and responds to specific questions for clarification.	Expresses original ideas clearly and connects to the ideas of others. Questions and responses are mostly high level. Attempts to move discussion forward by asking and responding to questions.	Expresses original ideas clearly and persuasively; connects to the ideas of others and builds new pathways of discussion. Attempts to deepen discussion by asking connecting questions or building on the responses of others.	Expresses original ideas clearly and persuasively. Builds new pathways of discussion that are clearly connected to the ideas of others. Propels conversations by relating to broader themes.	Expresses original ideas clearly and persuasively. Builds new pathways of discussion that are clearly connected to the ideas of others. Uses questions and summarization to preserve focus. Propels conversations by relating to broader themes.	Expresses original ideas clearly and persuasively. Builds new pathways of discussion that are clearly connected to the ideas of others. Uses questions and summarization to preserve focus. Propels conversations by relating to broader themes, probing reasoning and evidence and/ or promoting divergent and creative perspectives.

Domain: Speaking & Listening								
Dimension: Preparation								
High-Level Description: Entering a discussion or presentation with appropriate evidence and relevant details								
0	1	2	3	4	5	6	7	8
No evidence of preparation for discussion.	Comes to discussions prepared with ideas related to assigned reading.	Comes to discussions prepared and explicitly draws on ideas from assigned reading and other relevant information.	Comes to discussions prepared and explicitly draws on highly relevant ideas or details from the assigned reading and other relevant information.	Comes to discussions prepared and draws on specific evidence from the assigned reading and other relevant information.	Comes to discussions having read and researched material for teacher-provided questions; explicitly draws on texts and research to stimulate a thoughtful, well-reasoned exchange of ideas.	Come to discussions with responses and evidence generated with peers through studying, research, or inquiry; explicitly draws on texts and research to stimulate a thoughtful, well-reasoned exchange of ideas.	Come to discussions with self-generated questions from studying, research, and/ or inquiry. Attempts to move discussion along by using those questions at appropriate moments.	Comes to dis-cussions with self-generated, sequenced, specific questions and evidence to move the dis-cussion along purposefully (i.e., toward an intended outcome or desired under-standing).

Domain: Speaking & Listening								
Dimension: Norms/Active Listening								
High-Level Description: Using roles and norms to support collegial discussions and completion of group work								
0	1	2	3	4	5	6	7	8
Participates in discussions by disrupting others and speaking out of turn or off-topic.	Participates in discussions and follows agreed-upon norms.	Participates in discussions and follows agreed-upon rules. Carries out assigned roles.	Participates in discussions and follows agreed-upon rules and deadlines. Carries out assigned roles.	Mostly adheres to established norms for collegial discussions. Tracks progress toward specific goals and deadlines. Enacts individual roles independently.	Adheres to teacher-enforced collegial discussion norms. Facilitates progress toward specific goals and deadlines. Attempts to establish individual roles within the group as needed.	Adheres to teacher- and group-enforced collegial discussion norms. Effectively facilitates progress toward specific goals and deadlines. Establishes appropriate individual roles within the group as needed.	Adheres to and helps enforce collegial discussion norms. Sets clear goals and deadline and facilitates conversation and interaction to meet them. Manages individual roles within the group as needed.	Applies collegial discussion norms to promote civil, democratic discussions and decision-making. Sets clear and detailed goals and deadlines and effectively facilitates conversation/ interaction to meet them. Efficiently manages individual roles and partnerships within the group as needed.

Domain: Products & Presentations								
Dimension: Style & Language (Tone, Academic Language, Syntax)								
High-Level Description: Using appropriate style in a written product, including academic language, tone, and syntax								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Uses general academic or specialized language incorrectly; frequently uses language that is informal or unsuitable for purpose.	Uses general academic or specialized language with minor inaccuracies and recognizes differences between written (formal) and spoken language. Word choice supports purpose.	Uses general academic or specialized language appropriately, and uses formal language when appropriate to purpose. Word choice is precise and supports the purpose.	Uses general academic or specialized language precisely and uses formal language when appropriate to the purpose. Sentences vary in structure; word choice is precise and supports the purpose and reader/listener interest.	Consistently uses a formal style with some academic or specialized language. Sentence structure is functional; writing may demonstrate strong control over basic sentence structures but limited control over more complex structures.	Consistently uses a formal style with consistently appropriate academic or specialized language. Sentence patterns are somewhat varied, with strong control over basic sentence structures and variable control over more complex structures.	Consistently uses a formal style and academic/ specialized language when most appropriate but also varies style and language effectively given the purpose, audience & conventions of the writing. Sentence structures are varied and effective.	Consistently uses a formal style and academic/ specialized language when most appropriate but also varies style, language, tone, and voice effectively given the purpose, audience & conventions of the writing. Sentence structures are varied and used strategically to enhance meaning by drawing attention to key ideas or reinforcing relationships among ideas.	Style, language, tone, and voice build ethos and high reader engagement. The style, language, tone, and voice are perfectly appropriate to the audience, and effectively accomplish the author's purpose. Sentence structures are varied, used strategically to enhance meaning, and are often powerful or beautiful.

Domain: Products & Presentations								
Dimension: Oral Presentation								
High-Level Description: Using appropriate public speaking strategies, including interaction with presentation mediums, to engage the audience and communicate points								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Makes no eye contact. Speaks in low volume or at a pace that makes the content of the presentation difficult to discern.	Makes irregular eye contact with audience. Speaks in a low volume and/ or at a pace that makes the presentation difficult to understand.	Makes eye contact with audience. Shows variable body posture and speaks at a volume and pace that does not interfere with audience understanding of the presentation	Makes regular eye contact with audience. Shows appropriate body posture and speaks at a volume and pace that does not interfere with audience understanding of the presentation.	Makes regular eye contact with audience. Shows confident body posture and speaks at an adequate volume and pace with clear pronunciation.	Uses consistently appropriate eye contact, adequate volume, clear pronunciation, and appropriate body posture (e.g., calm, confident).	Demonstrates consistent control of eye contact, volume, pronunciation, and body posture. Uses some variation in volume and inflection to emphasize key points. Uses some body movements to enhance articulation.	Demonstrates strong control of eye contact, pronunciation, and body posture. Varies volume and inflection to maintain audience interest and emphasize key points. Uses fluid body movements to help audience visualize ideas. May use additional engagement techniques such as humor, anecdotes, rhetorical questions, etc. as appropriate to the context.	Demonstrates strong control of eye contact, pronunciation, and body posture. Varies volume and inflection to maintain audience interest and emphasize key points. Uses fluid body movements to help audience visualize ideas. May use additional engagement techniques such as humor, anecdotes, rhetorical questions, etc. as appropriate to the context.

Domain: Products & Presentations								
Dimension: Style & Language (Tone, Academic Language, Syntax)								
High-Level Description: Using appropriate style in a written product, including academic language, tone, and syntax								
0	1	2	3	4	5	6	7	8
Uses general academic or specialized language incorrectly; frequently uses language that is informal or unsuitable for purpose.	Uses general academic or specialized language with minor inaccuracies and recognizes differences between written (formal) and spoken language. Word choice supports purpose.	Uses general academic or specialized language appropriately, and uses formal language when appropriate to purpose. Word choice is precise and supports the purpose.	Uses general academic or specialized language precisely and uses formal language when appropriate to the purpose. Sentences vary in structure; word choice is precise and supports the purpose and reader/listener interest.	Consistently uses a formal style with some academic or specialized language. Sentence structure is functional; writing may demonstrate strong control over basic sentence structures but limited control over more complex structures.	Consistently uses a formal style with consistently appropriate academic or specialized language. Sentence patterns are somewhat varied, with strong control over basic sentence structures and variable control over more complex structures.	Consistently uses a formal style and academic/ specialized language when most appropriate but also varies style and language effectively given the purpose, audience & conventions of the writing. Sentence structures are varied and effective.	Consistently uses a formal style and academic/ specialized language when most appropriate but also varies style, language, tone, and voice effectively given the purpose, audience & conventions of the writing. Sentence structures are varied and used strategically to enhance meaning by drawing attention to key ideas or reinforcing relationships among ideas.	Style, language, tone, and voice build ethos and high reader engagement. The style, language, tone, and voice are perfectly appropriate to the audience, and effectively accomplish the author's purpose. Sentence structures are varied, used strategically to enhance meaning, and are often powerful or beautiful.

Domain: Products & Presentations								
Dimension: Oral Presentation								
High-Level Description: Using appropriate public speaking strategies, including interaction with presentation mediums, to engage the audience and communicate points								
0	1	2	3	4	5	6	7	8
Makes no eye contact. Speaks in low volume or at a pace that makes the content of the presentation difficult to discern.	Makes irregular eye contact with audience. Speaks in a low volume and/ or at a pace that makes the presentation difficult to understand.	Makes eye contact with audience. Shows variable body posture and speaks at a volume and pace that does not interfere with audience understanding of the presentation	Makes regular eye contact with audience. Shows appropriate body posture and speaks at a volume and pace that does not interfere with audience understanding of the presentation.	Makes regular eye contact with audience. Shows confident body posture and speaks at an adequate volume and pace with clear pronunciation.	Uses consistently appropriate eye contact, adequate volume, clear pronunciation, and appropriate body posture (e.g., calm, confident).	Demonstrates consistent control of eye contact, volume, pronunciation, and body posture. Uses some variation in volume and inflection to emphasize key points. Uses some body movements to enhance articulation.	Demonstrates strong control of eye contact, pronunciation, and body posture. Varies volume and inflection to maintain audience interest and emphasize key points. Uses fluid body movements to help audience visualize ideas. May use additional engagement techniques such as humor, anecdotes, rhetorical questions, etc. as appropriate to the context.	Demonstrates strong control of eye contact, pronunciation, and body posture. Varies volume and inflection to maintain audience interest and emphasize key points. Uses fluid body movements to help audience visualize ideas. May use additional engagement techniques such as humor, anecdotes, rhetorical questions, etc. as appropriate to the context.

Domain: Products & Presentations								
Dimension: Multimedia in Written Production								
High-Level Description: Integrating technology to create high-quality written products								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of integrating technology into writing products.	Uses technology, to produce and publish writing products, as well as interact and collaborate with others.	Uses technology, including the internet, to produce and publish writing products, as well as interact and collaborate with others.	Uses technology, including the internet, to produce and publish writing products, as well as interact and collaborate with others effectively.	Uses technology, including the internet, to produce/publish writing, link/cite sources, and interact/collaborate with others effectively and efficiently. Uses technology/media tools to illustrate ideas or show relationships between information/ideas.	Uses technology, including the internet, to effectively and efficiently produce, publish, and update individual or shared writing products. Uses appropriate technology/media tools to illustrate ideas or show relationships among information/ideas effectively.	Uses technology, including the internet, to produce, publish, and update individual or shared writing products. Uses appropriate technology/media tools to illustrate ideas or show relationships among information/ideas by taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.	Uses technology, including the internet, to produce, publish, and update individual or shared writing products. Uses carefully selected technology/media tools creatively to illustrate ideas or show relationships among information/ideas by taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.	Uses technology beyond commonly used tools to explore novel and effective ways of producing writing products.

Domain: Products & Presentations								
Dimension: Multimedia in Oral Presentation								
High-Level Description: Integrating multiple mediums, including technology, to create high-quality spoken presentations								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Uses technology beyond commonly used tools to explore novel and effective ways of producing writing products.	Multimedia components and/or visual displays emphasize or enhance facts and details relevant to the focus of the presentation.	Multimedia components and/or visual displays illustrate ideas relevant to the focus of the presentation.	Multimedia components and visual displays illustrate relevant information and develop ideas	Multimedia components and visual displays clarify and illustrate information and ideas.	Most multimedia components and visual displays clarify or illustrate information and ideas and strengthen arguments, explanations, and/or narratives by highlighting significant points.	All multimedia components and visual displays are purposeful and effective (i.e., clarify, illustrate, and strengthen arguments, explanations, and/or narratives) and add interest to the presentation.	Multimedia components and visual displays are purposeful, engaging, effective, and strategically/efficiently used to enhance understanding of arguments, explanations, and narratives.	Multimedia components and visual displays are purposeful, engaging, effective, and strategically/efficiently used to enhance understanding of arguments, explanations, and narratives. Integration of multimedia into presentation is seamless, engaging, and sophisticated.

Domain: Products & Presentations								
Dimension: Multimedia in Written Production								
High-Level Description: Integrating technology to create high-quality written products								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of integrating technology into writing products.	Uses technology, to produce and publish writing products, as well as interact and collaborate with others.	Uses technology, including the internet, to produce and publish writing products, as well as interact and collaborate with others.	Uses technology, including the internet, to produce and publish writing products, as well as interact and collaborate with others effectively.	Uses technology, including the internet, to produce/publish writing, link/cite sources, and interact/collaborate with others effectively and efficiently. Uses technology/media tools to illustrate ideas or show relationships between information/ideas.	Uses technology, including the internet, to effectively and efficiently produce, publish, and update individual or shared writing products. Uses appropriate technology/media tools to illustrate ideas or show relationships among information/ideas effectively.	Uses technology, including the internet, to produce, publish, and update individual or shared writing products. Uses appropriate technology/media tools to illustrate ideas or show relationships among information/ideas by taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.	Uses technology, including the internet, to produce, publish, and update individual or shared writing products. Uses carefully selected technology/media tools creatively to illustrate ideas or show relationships among information/ideas by taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.	Uses technology beyond commonly used tools to explore novel and effective ways of producing writing products.

Domain: Products & Presentations								
Dimension: Oral Presentation								
High-Level Description: Using appropriate public speaking strategies, including interaction with presentation mediums, to engage the audience and communicate points								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Makes no eye contact. Speaks in low volume or at a pace that makes the content of the presentation difficult to discern.	Makes irregular eye contact with audience. Speaks in a low volume and/or at a pace that makes the presentation difficult to understand.	Makes eye contact with audience. Shows variable body posture and speaks at a volume and pace that does not interfere with audience understanding of the presentation	Makes regular eye contact with audience. Shows appropriate body posture and speaks at a volume and pace that does not interfere with audience understanding of the presentation.	Makes regular eye contact with audience. Shows confident body posture and speaks at an adequate volume and pace with clear pronunciation.	Uses consistently appropriate eye contact, adequate volume, clear pronunciation, and appropriate body posture (e.g., calm, confident).	Demonstrates consistent control of eye contact, volume, pronunciation, and body posture. Uses some variation in volume and inflection to emphasize key points. Uses some body movements to enhance articulation.	Demonstrates strong control of eye contact, pronunciation, and body posture. Varies volume and inflection to maintain audience interest and emphasize key points. Uses fluid body movements to help audience visualize ideas. May use additional engagement techniques such as humor, anecdotes, rhetorical questions, etc. as appropriate to the context.	Demonstrates strong control of eye contact, pronunciation, and body posture. Varies volume and inflection to maintain audience interest and emphasize key points. Uses fluid body movements to help audience visualize ideas. May use additional engagement techniques such as humor, anecdotes, rhetorical questions, etc. as appropriate to the context.

Domain: Products & Presentations								
Dimension: Multimedia in Written Production								
High-Level Description: Integrating technology to create high-quality written products								
0	1	2	3	4	5	6	7	8
No evidence of integrating technology into writing products.	Uses technology, to produce and publish writing products, as well as interact and collaborate with others.	Uses technology, including the internet, to produce and publish writing products, as well as interact and collaborate with others.	Uses technology, including the internet, to produce and publish writing products, as well as interact and collaborate with others effectively.	Uses technology, including the internet, to produce/publish writing, link/ cite sources, and interact/ collaborate with others effectively and efficiently. Uses technology/ media tools to illustrate ideas or show relationships between information/ ideas.	Uses technology, including the internet, to effectively and efficiently produce, publish, and update individual or shared writing products. Uses appropriate technology/ media tools to illustrate ideas or show relationships among information/ideas effectively.	Uses technology, including the internet, to produce, publish, and update individual or shared writing products. Uses appropriate technology/ media tools to illustrate ideas or show relationships among information/ ideas by taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.	Uses technology, including the internet, to produce, publish, and update individual or shared writing products. Uses carefully selected technology/ media tools creatively to illustrate ideas or show relationships among information/ ideas by taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.	Uses technology beyond commonly used tools to explore novel and effective ways of producing writing products.

Domain: Products & Presentations								
Dimension: Multimedia in Oral Presentation								
High-Level Description: Integrating multiple mediums, including technology, to create high-quality spoken presentations								
0	1	2	3	4	5	6	7	8
Uses technology beyond commonly used tools to explore novel and effective ways of producing writing products.	Multimedia components and/or visual displays emphasize or enhance facts and details relevant to the focus of the presentation.	Multimedia components and/or visual displays illustrate ideas relevant to the focus of the presentation.	Multimedia components and visual displays illustrate relevant information and develop ideas	Multimedia components and visual displays clarify and illustrate information and ideas.	Most multimedia components and visual displays clarify or illustrate information and ideas and strengthen arguments, explanations, and/or narratives by highlighting significant points.	All multimedia components and visual displays are purposeful and effective (i.e., clarify, illustrate, and strengthen arguments, explanations, and/or narratives) and add interest to the presentation.	Multimedia components and visual displays are purposeful, engaging, effective, and strategically/ efficiently used to enhance understanding of arguments, explanations, and narratives.	Multimedia components and visual displays are purposeful, engaging, effective, and strategically/ efficiently used to enhance understanding of arguments, explanations, and narratives. Integration of multimedia into presentation is seamless, engaging, and sophisticated.

Domain: Products & Presentations								
Dimension: Multimedia in Written Production								
High-Level Description: Integrating technology to create high-quality written products								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No evidence of integrating technology into writing products.	Uses technology, to produce and publish writing products, as well as interact and collaborate with others.	Uses technology, including the internet, to produce and publish writing products, as well as interact and collaborate with others.	Uses technology, including the internet, to produce and publish writing products, as well as interact and collaborate with others effectively.	Uses technology, including the internet, to produce/publish writing, link/ cite sources, and interact/ collaborate with others effectively and efficiently. Uses technology/ media tools to illustrate ideas or show relationships between information/ ideas.	Uses technology, including the internet, to effectively and efficiently produce, publish, and update individual or shared writing products. Uses appropriate technology/ media tools to illustrate ideas or show relationships among information/ideas effectively.	Uses technology, including the internet, to produce, publish, and update individual or shared writing products. Uses appropriate technology/ media tools to illustrate ideas or show relationships among information/ ideas by taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.	Uses technology, including the internet, to produce, publish, and update individual or shared writing products. Uses carefully selected technology/ media tools creatively to illustrate ideas or show relationships among information/ ideas by taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.	Uses technology beyond commonly used tools to explore novel and effective ways of producing writing products.

Domain: Products & Presentations								
Dimension: Multimedia in Oral Presentation								
High-Level Description: Integrating multiple mediums, including technology, to create high-quality spoken presentations								
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Uses technology beyond commonly used tools to explore novel and effective ways of producing writing products.	Multimedia components and/or visual displays emphasize or enhance facts and details relevant to the focus of the presentation.	Multimedia components and/or visual displays illustrate ideas relevant to the focus of the presentation.	Multimedia components and visual displays illustrate relevant information and develop ideas	Multimedia components and visual displays clarify and illustrate information and ideas.	Most multimedia components and visual displays clarify or illustrate information and ideas and strengthen arguments, explanations, and/or narratives by highlighting significant points.	All multimedia components and visual displays are purposeful and effective (i.e., clarify, illustrate, and strengthen arguments, explanations, and/or narratives) and add interest to the presentation.	Multimedia components and visual displays are purposeful, engaging, effective, and strategically/ efficiently used to enhance understanding of arguments, explanations, and narratives.	Multimedia components and visual displays are purposeful, engaging, effective, and strategically/ efficiently used to enhance understanding of arguments, explanations, and narratives. Integration of multimedia into presentation is seamless, engaging, and sophisticated.

Domain: Products & Presentations								
Dimension: Conventions								
High-Level Description: Using discipline-appropriate conventions to support clear expression of ideas and information								
0	1	2	3	4	5	6	7	8
Uses the conventions of the discipline inconsistently with a pattern of errors that impede understanding Uses the conventions of the discipline inconsistently with a pattern of errors that impede understanding.	Generally uses the conventions of the discipline. Minor errors sometimes impede understanding.	Uses the conventions of the discipline. Errors are few/ minor, and do not impede understanding.	Uses the conventions of the discipline with some consistency. Minor errors, while noticeable, do not impede understanding.	Uses the conventions of the discipline with consistency. Minor errors do not impede understanding.	Uses the conventions of the discipline appropriately; some minor errors, while noticeable, do not impede understanding.	Uses the conventions of the discipline appropriately with almost no noticeable errors.	Applies the conventions of the discipline consistently to support clear expression of ideas and information. Errors are so few and so minor that the reader would be unlikely to notice them unless specifically looking for them.	Applies the conventions of the discipline consistently and precisely to support clear, sophisticated expression of ideas and information.

Domain: Products & Presentations								
Dimension: Precision								
High-Level Description: Expressing ideas and information with exactness, specificity, correct use of terminology, and refinement								
0	1	2	3	4	5	6	7	8
No evidence of precision.	Expresses ideas in broad or general terms. Uses relevant terms, symbols, etc. with minor errors or misconceptions. OR Does not use relevant terms, symbols.	Expresses some ideas with specificity appropriate for the given purpose. Correctly uses relevant terms, symbols, etc.	Expresses ideas with specificity appropriate for the given purpose. Defines key terms, symbols, etc.	Consistently expresses ideas with adequate specificity for the given purpose. Defines terms, symbols, etc.	Consistently expresses ideas with clarity and specificity. Consistently defines terms, symbols, etc.	Consistently expresses ideas with clarity and specific, highly relevant detail. Consistently defines terms, symbols, etc.	Expresses ideas with clarity and efficiency, using no more detail than is needed for the given purpose. Consistently defines terms, symbols, etc.	Expresses ideas and information with near-perfect clarity and efficiency, using no more detail than is needed for the given purpose. Consistently defines terms, symbols, etc. Expression is refined and sophisticated.

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