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INNOVATIVE LEARNING ANALYTICS FOR EVALUATING INSTRUCTION

A Big Data Roadmap to Effective Online Learning

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Innovative Learning Analytics for Evaluating Instruction:

A Big Data Roadmap to Effective Online Learning

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ABSTRACT

If you were an investor, and you could choose between a company that is *not likely* to use effective business strategies and a company that is *three to five times more likely* to use them, where would you put your money? Likewise, if you could use methods of education that were three to five times more likely to help students succeed in their learning journeys, would you?

We document the extraordinary effectiveness of First Principles of Instruction for promoting online learning. We used these principles to design the online Indiana University Plagiarism Tutorials and Tests. Analysis of Patterns in Time was the primary research methodology for evaluating this MOOC in 2019 and 2020. We used APT to segment nearly 1.87 million temporal maps and to match learning patterns by leveraging Google Analytics tracking and reporting tools. We then created spreadsheet formulas to compute APT likelihood ratios from the GA results. We found that successful students worldwide were nearly four times as likely to select instruction designed with First Principles, when compared to unsuccessful learners.

Analysis of Patterns in Time can be used as a practical way to evaluate instructional effectiveness. Applying APT to do learning analytics means big data can be harnessed to evaluate online teaching and learning. APT is a powerful method for finding meaningful patterns in massive datasets.

KEYWORDS

Educational research methods; online learning; e-learning; learning analytics; analysis of patterns in time; big data; MOOC; instructional effectiveness; first principles of instruction; learning journeys; Google Analytics; mastery learning; how to recognize plagiarism; measuring learning achievement; landmark research; innovative research; practical research.

Preface

The Big Picture

If you were an investor, and you could choose between a company that is not likely to use effective business strategies and a company that is three to five times more likely to use them, where would you put your money? Likewise, if you could use methods of education that were three to five times more likely to help students succeed in their learning, would you?

Drawing on decades of experience as a teacher, instructional designer, and education researcher, Merrill (2002) proposed five principles common to a variety of instructional design theories, principles that he believes lead to effective, efficient, and engaging learning. Merrill named these First Principles of Instruction (FPI) and hypothesized that instruction that fails to implement one or more of these principles will result in a "decrement in learning and performance" (Merrill, 2013, p. 21). He went on to write "the support for this hypothesis can only come from evaluation studies for a given instructional product or research comparing the use and misuse of these principles" (Merrill, 2013, p. 21).

In this book, we describe our efforts to apply FPI in the redesign of an online learning resource, the Indiana University Plagiarism Tutorials and Tests (IPTAT), and how we empirically evaluated the effectiveness of FPI using Analysis of Patterns in Time (APT), a powerful method for finding meaningful patterns in massive datasets. We document the extraordinary effectiveness of First Principles of Instruction for promoting online learning. In brief, we found that students who passed an IPTAT certification test were three to four times more likely per learning journey to choose instructional activities designed with FPI, when compared with unsuccessful students. These findings were based on over 936,000 learning journeys by students who were located in 213 countries and territories worldwide, mostly between ages of 14 and 44. These findings are based on Big Data collected over two years, 2019-2020.

We provide a roadmap for educators and researchers to follow for both online and in-person instruction, and we illustrate through concrete examples how to document instructional effectiveness with Analysis of Patterns in Time. For those who teach students in-person, we provide a practical alternative for measuring effectiveness. We illustrate how we used student perceptions of Teaching and Learning Quality (TALQ) when coupled with instructor assessments of student mastery of course objectives. We used APT here as well; and what we found for face-to-face courses was similar. Students who agreed that they experienced FPI and successful engagement were between three and five times more likely to be independently rated by their instructors as high masters of course objectives.

What this Book Is About

Our main goal in this book is to show how Analysis of Patterns in Time (APT) can be used as a practical and powerful way to evaluate the effectiveness of online instruction. What is new in this book is the application of APT as an innovative way to do learning analytics of Big Data on online teaching and learning.

APT is a proven methodology that differs from traditional qualitative and quantitative approaches to measurement (Frick, 1983, 1990; Frick & Dagli, 2016; Myers & Frick, 2015). APT is a way to analyze *student learning journeys*. Student learning journeys are a new way to capture temporal maps of what students do. In APT, patterns of learning are themselves *qualitative*; whereas counting occurrences of those patterns within learning journeys is *quantitative*.

We show through specific examples how we have used APT to answer the question: How well do First Principles of Instruction promote student learning? We primarily use the Indiana University Plagiarism Tutorials and Tests (IPTAT) as the recurring example. You can view IPTAT at: https://plagiarism.iu.edu. We encourage you to try IPTAT yourself, as you read parts of this book.

IPTAT is a type of a MOOC: massive, open, online course. IPTAT is relatively short in duration, taking about 2 hours to complete. Numerous instructors in colleges, universities, and secondary schools typically utilize IPTAT as an assignment for their students to complete on their own outside of class meetings. Students typically choose parts of IPTAT to help them pass a Certification Test. Instructors want their students to learn to recognize plagiarism, so they will not commit plagiarism in the future.

What is further innovative in this book is that we show how Google Analytics can be used to do APT. Google Analytics is a free service that that can be incorporated into your website in order to track how users interact with it pageview by pageview. Google Analytics allows you to create reports on usage of a website by applying a variation of APT methodology. You can also use Google Analytics to observe in real-time the number of current users of your website, what they are viewing, and where they are located.

We hope that this book provides a roadmap for how you and others can evaluate effectiveness of online instruction and learning. When you are finished with this book, you should have learned enough so that when you design your own instructional website, you will have at your fingertips an easy-to-understand but powerful way to determine its effectiveness. You should also be able to investigate the effectiveness of *different* design principles and instructional strategies—by following the same approach as we have illustrated in this book for First Principles of Instruction.

If you are interested in evaluating the effectiveness of in-person instruction in traditional learning settings, where teachers and students meet face-to-face in classrooms, we provide an alternative way you can use APT. We illustrate past research with the Teaching and Learning Quality

(TALQ) Scales. TALQ Scales can be used to obtain student perceptions of the quality of their instruction and learning at or near the end of a course or training workshop. When student responses to questions on the TALQ instrument are aggregated, we illustrate how teaching effectiveness can be determined through APT methods. This approach is an alternative to building websites and tracking student usage as we have done with IPTAT. Using TALQ requires no technical knowledge of website development, and can be done using a paper-and-pencil format for collecting student evaluations.

If more of us do this kind of disciplined inquiry, then, over time we will collectively advance knowledge of effective educational practices. As educators subsequently adopt these more effective practices, students will be more likely to succeed in their learning endeavors. We will improve education. More effective education should improve the quality of life for everyone.

What You Need to Know before You Start

There are many resources for learning how to make webpages and websites, including dynamic websites that require scripting in programming languages such as PHP or Python. There are numerous resources on how to store computer data collected via the Web, e.g., using database systems and query languages such as MySQL. You should use these resources if need be, since our book will not address these kinds of know-how, though we do occasionally refer to some of these elements. Most likely you will need to form a design team with members who have these different kinds of skills, much as we have for IPTAT. And have everyone on your team read this book, of course!

You and your team members do not need a degree in statistics or research methodology to understand our major approach to analysis of Big Data: *Analysis of Patterns in Time* (APT). Since APT is currently not taught in typical research courses and is not discussed in other books at this time, this book will help you understand APT and how you can use it. You do not need a Ph.D. to understand APT, or any degree at all. If you can count, add, subtract, multiply, and divide numbers, if you understand percentages and how to form proportions, and if you can compute simple averages (arithmetic means), then you should be able to understand APT. In its most basic form, APT is no more complicated than computing a baseball player's batting average by counting the number of times at bat and how many times that player got a base hit. For example, if a player went to bat 100 times and got 40 base hits, then they have a batting average of 0.400 (40 divided by 100). This means that 40 percent of the time when *that batter* faced a pitcher in a baseball game, they made a base hit.

Or suppose you and your friend went on a diet to lose weight. You each weigh yourself once a week on your scales over a period of 52 weeks, so you can determine how many pounds per week you lost. You each just add up the pounds you lost that year, and then divide the result by 52 weeks in order to determine how many *pounds per week* you lost. Suppose that you lost 2 pounds per week, and your friend lost one-half pound per week. You could claim that you lost 4 times as much weight per week as did your friend (by dividing 2 by 0.5). Or you could count kilograms and make a similar comparison, as long as you are counting the same units for both of you (or other measures such as inches or centimeters of reduced waist size).

You also need a sense of time when observing one event that follows another. For example, if you observe that clouds in the sky normally form *before* it rains or snows, then you are noting a temporal sequence of events. But it does not rain or snow every time clouds form, just some of the time. For example, it might be the case that, in your location, when clouds are present, then it rains or snows 15 percent of the time. You could also say that when clouds are overhead, the likelihood of rain or snow is 0.15 in your location. You might also observe that it *never snows* when clouds are present *and* the outside air temperature is above 40 degrees Fahrenheit (or 4 degrees Celsius). In its most basic form, APT is no more complicated than this: what are the chances that an event occurs when certain conditions are true? In our book, we want to determine that when students pass a test, what conditions are true when compared with students who have not passed a test?

Finally, if you can use a calculator, such as an app on your smartphone or computer, then you can more quickly carry out the arithmetic required for APT. And you'll need a computer with an Internet connection that runs a Web browser such as Firefox, Chrome, Safari, Edge, or Opera. We assume that you already know how to browse the Web and can use a Web browser.

For Whom Is this Book Intended?

Our main target audiences are those who do:

- Instructional design and development,
- Online and in-person instruction,
- Educational research and evaluation.

We further anticipate a worldwide target audience. Effectiveness of online and in-person learning is relevant to education everywhere, not just limited to the U.S. Due to the novel coronavirus pandemic, many schools and universities have been recently offering more online and hybrid instruction.

We believe that this book will be further useful in many other disciplines where effective means to achieve ends are valued.

Ways to Read this Book

If you are a teacher or instructional designer, Chapters 1, 2, 3, and 7 should be of most interest. These four chapters introduce the concept of learning journeys, the main findings of our Big Study, how we designed our online instruction with First Principles, and how we have previously evaluated in-person instruction using the Teaching and Learning Quality scales.

If you do educational research and evaluation, you should read the whole book. The first chapter and the last five chapters emphasize the major differences between Analysis of Patterns in Time (APT) and traditional quantitative and qualitative research methods. In the last half of the book, we provide further examples of how APT was used in other research studies, in addition to the Big Study described in the first four chapters.

We have kept this book as short as possible, in order to help readers quickly grasp the main ideas—trying to balance breadth and depth. In addition to bibliographic references, we provide hyperlinks to supplementary information that is particularly relevant and which should be available on the Web for years to come. If you are reading the digital version, you can just click on or tap the links as needed, and then return to the book to continue.

We have avoided specific step-by-step directions about how to use software tools such as Google Analytics and Microsoft Excel because they are likely to change over time, and because we ourselves have adapted to changing digital technologies over the past six decades. Instead, we describe our overall strategies and how we adapted those tools to do Analysis of Patterns in Time. Nonetheless, you should be able to follow the examples in order to replicate what we did. When APT was invented and conceived in the 1970s, there were no microcomputers or smartphones, and there was no Worldwide Web. When we started this book, we were using Google's Universal Analytics. By October 2020 Google had supplemented UA with Google Analytics 4, which we discuss and further illustrate near the end of Chapter 4.

Finally, we provide brief summaries at the beginnings of each chapter to highlight the main points. We further provide transitional information and cross-referencing in many places for those who read chapters out of order. With decades of Web design experience among the authors, this book is designed as a hybrid of both print and digital resources that can be accessed in a variety of ways. We provide a number of different routes in our roadmap for your own learning journeys.

Chapter Summaries

CHAPTER 1: Learning Journeys in Education

Chapter 1 introduces the concept of a *learning journey*. We use the Oregon Trail as a metaphor to explain why traditional quantitative and qualitative research methods are inadequate for capturing learning journeys. On the other hand, temporal maps do capture learning journeys, and Analysis of Patterns in Time (APT) can be used to count occurrences of qualitative patterns in temporal maps. We discuss the fundamental limitations of traditional qualitative and quantitative research approaches for determining effectiveness of instructional methods.

CHAPTER 2: Overview of the Big Study

In Chapter 2 we apply APT to a large-scale study of the effectiveness of First Principles of Instruction within the online Indiana University Plagiarism Tutorials and Tests (IPTAT). We begin by illustrating two typical cases of learning journeys: Sam and Melinda. We next summarize the results from our Big Study of over 936,000 learning journeys during 2019 and 2020. We demonstrate how we found that, on average in each learning journey, successful students were nearly four times more likely to utilize unique parts of IPTAT which were designed with First Principles of Instruction, when compared with unsuccessful students.

CHAPTER 3: The Indiana University Plagiarism Tutorials and Tests: 2002 through 2020

Chapter 3 describes how we redesigned the IPTAT in 2015 using First Principles of Instruction. We provide examples of IPTAT web pages and learning activities that illustrate FPI: sequencing tasks from simple to complex; activation of prior knowledge; demonstration of skills to be learned; application of newly acquired skills to solve problems; and integration of new skills in one's everyday life. We also describe how we created trillions of Certification Tests to measure student success in classifying word-for-word, paraphrasing, and non-plagiarism when viewing original source materials and samples of student writing. We conclude by describing two years of IPTAT usage, where there were nearly 36.5 million pageviews. We note three general kinds of usage patterns: minimalists, traditionalists, and dabblers.

CHAPTER 4: More Details of the Big Study

In Chapter 4 we report on our Big Study in greater detail, which was previewed in the second chapter. We demonstrate how we arrived at our findings over a two-year interval, by illustrating APT for one quarter, and then we describe how we combined quarters using a spreadsheet. The Big Study involved students from 213 countries and territories worldwide, mostly between 14 and 44 years old. We describe how Google Analytics was used to track IPTAT usage. Then we illustrate how segmenting of temporal maps and logical conditions were applied via Google Analytics in order to carry out parts of APT queries. We further illustrate how we used a spreadsheet with cell formulas to complete the APT calculations. We provide further details on how Google Analytics identifies users. We conclude by summarizing demographic characteristics of students who registered to take IPTAT Certification Tests.

CHAPTER 5: Analysis of Patterns in Time (APT) as a Research Methodology

Chapter 5 discusses APT in greater detail. We provide several historical examples of use of APT as a research method. We then describe use of APT concepts outside of educational research. One example is *Moneyball*, which is the story of how the Oakland Athletics professional baseball team used sabermetrics in evaluating players. This helped the Oakland A's field winning teams at a fraction of the cost of player salaries paid by other successful Major League Baseball teams. The second example is Google Analytics, which provides a Web tracking service to help their business clients determine advertising strategies and patterns of usage that lead to increased sales of the clients' products and services.

CHAPTER 6: Using APT for Formative Evaluation of a Learning Design

Chapter 6 provides a further example of how APT has been used for improving an online simulation game. We used APT to improve the fidelity of the online Diffusion Simulation Game (DSG) by evaluating the congruence of DSG gameplay processes and outcomes with empirical research on adoption of innovations. We illustrate how APT was used to identify several inconsistencies of DSG gameplay outcomes with outcomes expected from theory and empirical research on diffusion of innovations. This then allowed us to correct several mistakes in DSG algorithms, and then to further use APT to verify that the changed algorithms did indeed improve DSG fidelity. The DSG has been played hundreds of thousands of times by more than 18,000 registrants from 2014 through 2020.

CHAPTER 7: APT with Teaching and Learning Quality (TALQ) Surveys

Chapter 7 describes an alternative way to determine instructional effectiveness that can be used in a wide range of learning environments—for both online and in-person instruction. The alternative is to have students complete an evaluation instrument called the Teaching and Learning Quality (TALQ) Scales. Students rate their instruction and learning experiences without knowing what First Principles of Instruction are. They rate their experiences by responding to a random mix of Likert-type items. They also rate their own academic learning time (ALT, which is successful engagement), learning progress, satisfaction with the course and instructor, and overall quality of their experience. We provide examples from several studies of how TALQ was used with APT methods to determine effectiveness of FPI and ALT. The advantage of TALQ is that if it is used appropriately, teachers and researchers can determine instructional effectiveness without the technical knowledge and skills required for building websites such as IPTAT.

CHAPTER 8: Analysis of Patterns in Time as an Alternative to Traditional Approaches

Chapter 8 reviews the change in perspective which we have provided in this book. When we focus on temporal patterns, we can predict what leads to successful learning outcomes. By making inductive inferences from APT results, predictable patterns of instructional effectiveness can be identified. We further contrast APT with other existing approaches to learning analytics. We conclude by discussing the value of theory for APT and its further extension to MAPSAT: Map and Analyze Patterns and Structures Across Time.

EPILOGUE: The 50-Year Journey to Writing this Book

The Epilogue tells the story of the serendipitous discovery of Google Analytics as a way to do Analysis of Patterns in Time. It concludes by describing the 50-year journey that has culminated in this book. Acknowledgments follow.

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Chapter 1

Summary: We introduce the concept of a *learning journey*. We use the Oregon Trail as a metaphor to explain why traditional quantitative and qualitative research methods are inadequate for capturing learning journeys. On the other hand, temporal maps do capture learning journeys, and Analysis of Patterns in Time (APT) can be used to count occurrences of qualitative patterns in temporal maps. We discuss the fundamental limitations of traditional qualitative and quantitative research approaches for determining effectiveness of instructional methods.

Learning Journeys in Education

Metaphor of a Journey: The Oregon Trail

Education is a temporal process. Teaching and learning occur through intervals of time. Education is analogous to a journey, such as following the Oregon Trail. The destination we often want to reach in education is successful student learning achievement. Teachers provide the guidance to help students reach the destination. From a practical perspective, we want to document what makes some trips more successful than others. If other educators who come along later follow routes that have previously been successful, then *their* students would be expected to benefit also.

The Oregon Trail was a major route that early U.S. settlers traveled in the mid-1800s from what is now Independence, Missouri, near Kansas City, to the Columbia River Valley, near what is now Portland, Oregon (see https://en.wikipedia.org/wiki/Oregon_Trail). Lewis and Clark were pioneers who successfully made the trip in the early 1800s largely by horseback, canoes and rafts, and on foot, mostly by following the Missouri and Columbia Rivers. Later, settlers traveled by covered wagons pulled by oxen, on horseback, and most walked. The winding 2,200-mile trip took many months and was perilous. Some travelers died on the trip; and others never made it to Oregon, settling in places along the route. Those who did make it often arrived with very little food and belongings. Many travelers lost weight or died due to malnutrition and disease during the trip. Diseases took more lives than anything else, including cholera, dysentery, typhoid fever, and diphtheria. In that sense, those who were fortunate succeeded, but survivors often were somewhat poorer and weighed less when they arrived at their destination.

Fast-forward to May, 2020.

Many people now can get to Portland from Kansas City by driving an automobile and by taking interstate highways. According to Google Maps, the trip should take about 27 hours of driving time. If stopping overnight to rest, then the trip might take 3 driving days, travelling about 600 miles each day. A mini-van could be rented to transport 5 passengers and their luggage for about $500, plus the additional cost of fuel, 2 motel rooms for 2 nights of lodging, food purchased for

meals along the way, etc. A conservative estimate of the cost of the 1800-mile trip would be approximately $300 per person, assuming expenses and motel rooms are shared.

Another way to make that trip is to fly on commercial passenger airlines. For example, Southwest Airlines offers one-way fares for about $400 for an adult that will typically take 7 to 10 hours, depending on stops and plane changes. Two bags, 50 pounds or less, can be taken as luggage with no extra charge.

Finally, for the more wealthy, private jets can be chartered. A web search in May, 2020, indicated that the one of the least expensive flights would cost approximately $18,000 for 3 hours of flight time in a small jet for 6 passengers, or approximately $3,000 per person. Flights can often be scheduled to depart and arrive when convenient for passengers. These jets typically have more comfortable seating and more amenities.

The State-Trait Approach to Measurement: Quantitative Methods

In this approach to research, we measure states or properties of individual persons, things and conditions at various points in time. Using quantitative research methods, we might conduct an Oregon Trail Study by assessing personal wealth, a person's weight at the start and end of the trip, duration of the trip, and overall cost. In effect, the above description characterized states and traits of those individuals at various points in time for different classes of people and different eras. Separate measures would be taken: cost per person in US dollars, weights of each person and their luggage, trip duration in hours, whether or not the destination was reached, and the personal wealth of each individual when the trip begins and ends.

A quantitative study using a linear models approach (LMA) would most likely find an inverse linear relationship between cost of trip and its duration. Trips that take less time cost more. For wealthy individuals, a charter jet rental would not appreciably change their personal wealth. For someone with only $1,000 in personal savings, a charter flight would leave them in several thousand dollars of debt. For most individuals in 2020, their weight would not appreciably change when measured at the start and end of the trip, while that would not be true for many early settlers in the 1800s, who arrived at their destination emaciated and starving.

Suppose we did take independent measures such as these on a sample of 500 individuals who took trips from Kansas City to Portland, Oregon in the mid-1800s and early 2020.

Here is what we would likely find. Richer people complete the trip in less time than poorer travelers. There would be a negative linear relationship between personal wealth and trip duration. Greater wealth would be associated with shorter trips. If we look at the relationship between individuals' weight lost during the trips, early settlers would have lost more weight on average, whereas travelers in 2020 would not appreciably change their weight. Overall, there would be a positive linear relationship. Trips of longer duration would be associated with more weight lost. More deaths also occurred during the longer trips, also a positive linear relationship—statistically speaking.

Without information about what happened *during* the trip, it would be difficult to explain the weight loss. Moreover, why is it that richer people make the trip in less time? Without additional information about modes of travel, speed along the way, routes taken, relative costs, and causes of deaths and not finishing the trip (i.e., dropouts), it would be unclear why.

For educational research using quantitative methods, this approach is descriptive of thousands of studies from the 1960s to present. Quantitative research studies typically use a state-trait method of measurement, and statistical linear models are used to relate those measures (Kirk, 1999, 2013; Tabachnick & Fidell, 2018). In effect, snapshots are taken at each point in time, but there is often lack of information about what happened between the snapshots.

Individual Episodic Stories: Qualitative Methods

When using qualitative research methods that are narratives, we essentially tell episodic stories (e.g., Creswell & Creswell, 2018; Creswell & Poth, 2018). For example, consider the trip made by Lewis and Clark in the early 1800s. Then compare it with a trip taken by Bill Gates in 2020, who is a multi-billionaire and who could easily afford his own private jet. Telling unique stories about their contrasting trips might be quite interesting and illuminating, but it would be unwise to make any generalizations about all Oregon Trail travelers from this non-random sample of two trips.

In qualitative research, we may discover some interesting common patterns in the unique stories, but generalizability of findings is on shaky grounds. For example, Lewis, Clark, and Gates became famous men, who were willing to take risks when younger. Samples are typically very small. Sampling error and lack of generalizability to larger populations is a paramount criticism. Rich, detailed descriptions of a few cases may provide insight into what is happening in education, but it makes it difficult to generalize about what educational methods are more effective than others. It makes it difficult to predict educational outcomes in general—about what is likely to make a difference in *successful* learning.

Qualitative Temporal Mapping that is Quantifiable and Generalizable: A Third Alternative for Educational Research Methods

There is another way to approach this, referred to as Analysis of Patterns in Time (APT). The state-trait approach does not capture event-by-event temporal details, even so-called time-series analysis methods. The state-trait approach is analogous to taking still photographs. What happens *between* those snapshots is often unknown. As a further example, use of box scores to characterize baseball games exemplifies the state-trait approach.

On the other hand, APT temporal maps are analogous to "documentary movies" about what happens at various times to students and teachers *during* their educational journeys. APT temporal maps can describe learning journeys as well as other temporal processes. Temporal maps consist of coded episodic events, as are coded stories in qualitative methods. A temporal map of a baseball game describes what happened *during* the game, not just the total runs scored and which team won.

However, unlike qualitative methods, APT *queries* can subsequently identify *patterns of events within* temporal maps. This can help identify activities that are more or less successful in helping students reach their learning destinations. When temporal maps are representative of large populations, results of APT queries are generalizable to those populations (Frick, 1990). Analyzing temporal maps of professional baseball games can help identify patterns and strategies that lead to a team's winning season, year in and year out.

APT has been around for several decades, and the benefits of such an approach have been demonstrated in a number of educational research studies (An, 2003; Barrett, 2015; Dagli, 2017; Frick, 1983, 1990, 1992; Frick et al., 2008; Frick et al., 2009; Frick et al., 2010; Koh, 2008; Koh & Frick, 2009; Howard et al., 2010; Lara, 2013; Luk, 1994; Myers, 2012; Myers & Frick, 2015; Plew, 1989; Yin, 1998). A major obstacle to adoption by educational researchers has been the time and effort required to create temporal maps, as well as lack of adequate software for subsequently querying collections of such maps (see https://aptfrick.sitehost.iu.edu/).

It's relatively much easier to measure a few things independently and apply linear models, or to observe a few cases and write detailed descriptions. Nonetheless, APT techniques have been used *outside* of education with well-documented success (e.g., *Moneyball*; Lewis, 2004), especially now with big data and large arrays of computers doing parallel processing. Perhaps the most successful application of APT is *Google Analytics* (2005: https://en.wikipedia.org/wiki/Google_Analytics, https://analytics.google.com/analytics/academy/course/6). It is further likely that APT is used in *proprietary* extant artificial intelligence systems which use pattern matching for making predictions (see Segaran, 2008; Segaran & Hammerbacher, 2009).

With increasing use of the World Wide Web by billions of people, websites which are used for research purposes can now provide rich data sets that consist of temporal maps. Google has been doing this tracking since 2005. Google Analytics is the current hardware/software platform that allows vast amounts of temporal data to be collected through large computer data centers which utilize state-of-the art parallel processing systems (so-called "cloud computing", e.g., https://en.wikipedia.org/wiki/Cloud_computing; https://computing.llnl.gov/tutorials/parallel_comp/). While Google typically sells these services to business clients whose goal is to make a profit, these Google services can also be used by educational researchers who know how to leverage them, even for free.

While APT can be done locally on laptop computers and tablets, or basically on any computing devices including smartphones, this is on a very miniscule scale when compared to Google cloud computing. The real computing power is in the cloud, and computers we touch with our hands are the clients, e.g., running web browsers, which access the cloud computers via the Internet.

The Larger Problem in Educational Research

It is therefore not surprising that educational research has largely failed to provide widely *generalizable* empirical results supporting educational methods that are more effective than others. Since the Coleman et al. (1966) study we have known, for example, that there is a positive relationship between socioeconomic status and student learning achievement as

measured by standardized tests. Little else makes a significant difference in learning achievement after statistically controlling for SES, which accounts for a large proportion of the variance in student achievement, when taking a state-trait approach to measurement and using linear models for investigating relationships among variables. Linear models include multiple and logistical regression, factor analysis, canonical analysis, path analysis, discriminant analysis, ANOVA, MANOVA, ANCOVA, hierarchical linear models, time-series analysis, and the like (Kirk, 1999, 2013; Tabachnick & Fidell, 2018). When using traditional quantitative research methods, we measure things *separately*, and then we try to verify relationships among those measures.

What we need is strong, empirical, and generalizable evidence to document methods of education that are more effective than others, widely accessible to educators, more cost-effective, and more efficient (Fischer et al., 2020). To do this, we also need research *methods* that can document what happens during such educational journeys.

APT is clearly one such method. We illustrate the power and practicality of APT by example in this book. Perhaps, as did Lewis and Clark for the Oregon Trail, we will establish a trail for other researchers to follow in the future who are attempting to add to praxiological knowledge of education.

Next, in Chapter 2 we present an overview of what we call the Big Study. We illustrate by example a way to address limitations of traditional qualitative and quantitative research methods. In this Big Study we demonstrate the creation of temporal maps for tracking student interaction with the online Indiana University Plagiarism Tutorials and Tests (IPTAT). We then illustrate how we used APT to analyze learning journeys characterized by those maps. We show how we segmented nearly 1.87 million temporal maps (i.e., Big Data) in order to evaluate the effectiveness of First Principles of Instruction.

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