Presentation to 4th Annual Learning Analytics Summit

Analysis of Patterns in Time for Evaluating Effectiveness of First Principles of Instruction

Ted Frick

Professor Emeritus
Indiana University

May 11, 2022

My learning analytics quest began over 50 years ago*

Time	Event
1966	*Equality of Educational Opportunity* (U.S. study published by James Coleman, et al.)
1970	Do teachers make a difference?
1976	Nonmetric Temporal Path Analysis (NTPA) invented
1983	Seminal study comparing NTPA and linear models approach: Ph.D. dissertation
1990	Name change from NTPA to Analysis of Patterns in Time (APT): AERJ publication
2016	Redesign of IU Plagiarism Tutorials and Tests (IPTAT) using First Principles of Instruction
2020	Discovery that APT can be done (in part) by using Google's Universal Analytics as a tool
2021	New book: *Innovative Learning Analytics for Evaluating Instruction* (Frick, et al.)
2022	Follow-up study of IPTAT effectiveness using Google Analytics 4 to do APT
Today (in 20 min)	Analysis of Patterns in Time for Evaluating Effectiveness of First Principles of Instruction (May 11, 2022)

*Click on underlined text for Web links to further details or sources throughout these slides.

A QUICK FLYOVER: 50 YEARS OF MY RESEARCH IN 20 MINUTES

Today's presentation is analogous to a jet flyover from New York to San Francisco.
More details are in the underlined Web links.

1966: *Equality of Educational Opportunity*

- Nationwide U.S. study by James Coleman, et al.
- Socioeconomic status (SES) of students and their peers in school was the strongest predictor of student achievement, as measured by standardized tests:

  > "… schools bring little influence to bear on a child's achievement that is independent of his [family] background and general social context" (p. 325)

- Nothing else seemed to matter very much

1970: *Do Teachers Make a Difference?*

- Government report: follow-up to U.S. study by James Coleman, et al.
- Authors wondered: was it actually true that
  - *teachers do not make a difference, or*
  - *is there something problematic with multiple regression analysis, the method of research that was used in the Coleman study?*
- My thoughts were:
  - *Of course, teachers can make a difference;*
  - *Why can't educational researchers document this?*
  - *What's wrong with this picture?*
- In 1972 I began my learning analytics quest (50 years ago):
  - *How can we make learning better?*
    - What research methods are needed to verify this empirically?
    - How can we verify dynamically what teachers and students do that leads to student learning achievement?

1976: I invented *Nonmetric Temporal Path Analysis (NTPA)*

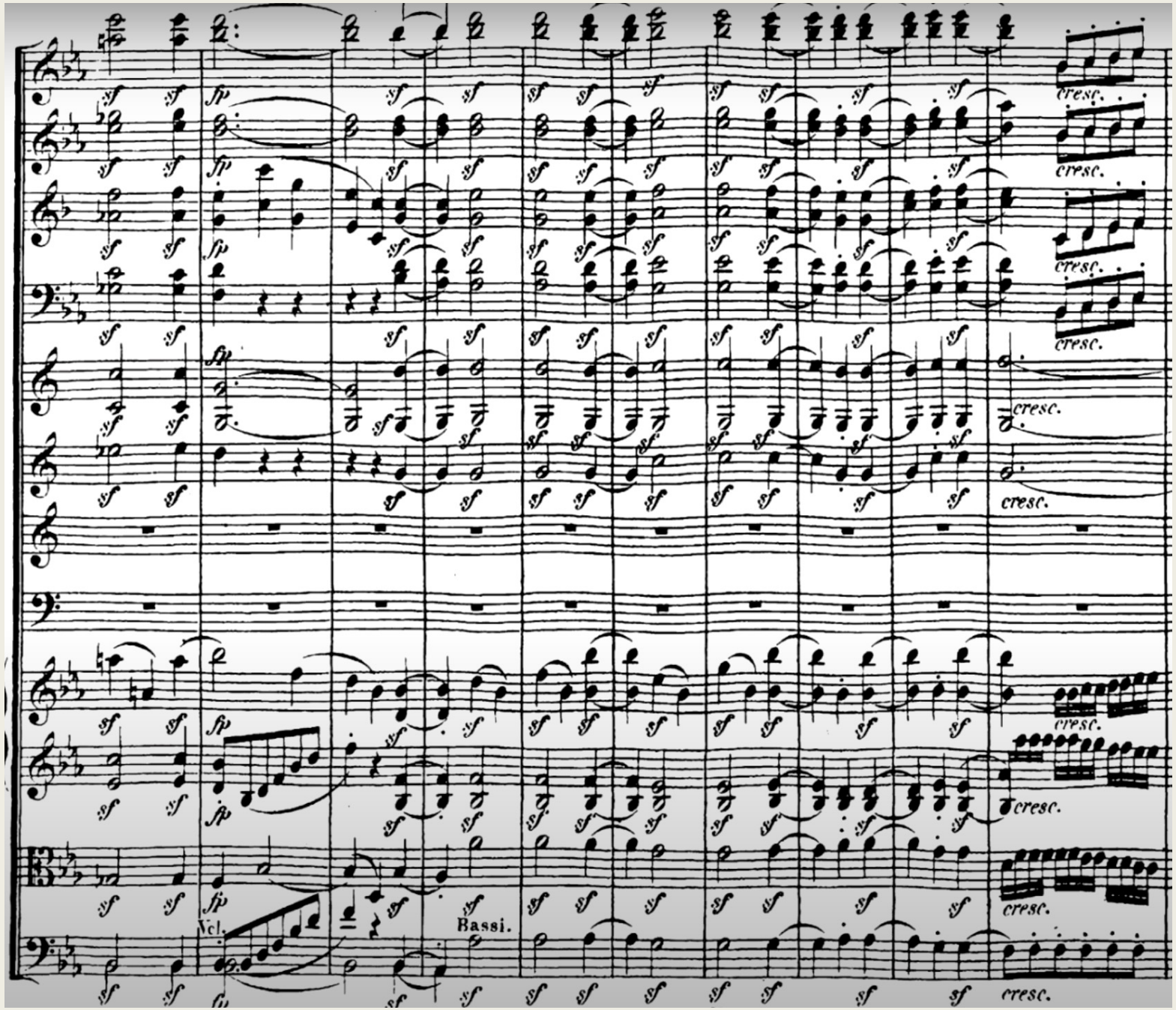
- How can we capture dynamics of teaching and learning processes that lead to student success?
- The fundamental idea of a temporal map emerged
- We needed something analogous to orchestral scores, EEG's and EKG's
  - *Parallel timelines*
  - *Ways to characterize change*

Temporal Map Example:

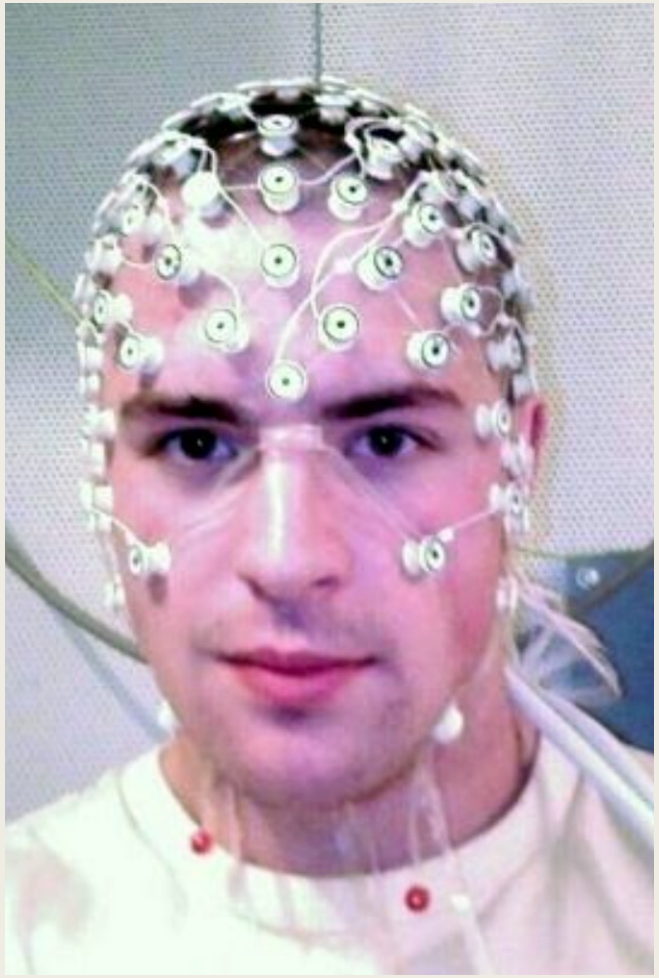
Orchestral score:

Excerpt from Beethoven's 3rd Symphony

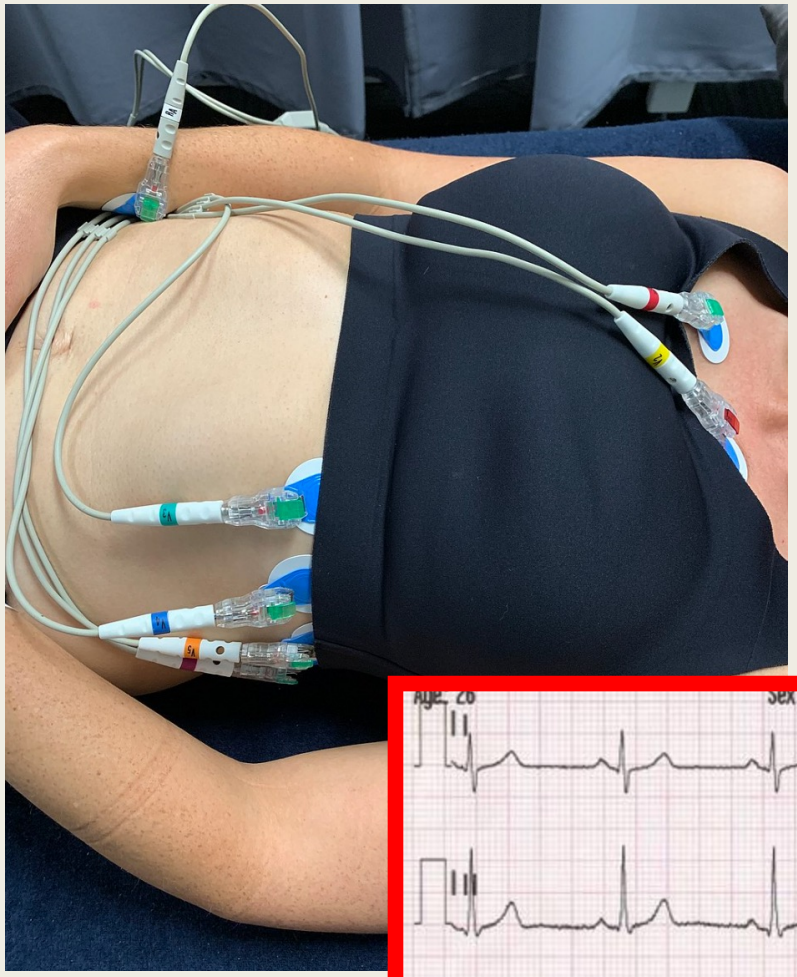
[source: YouTube]

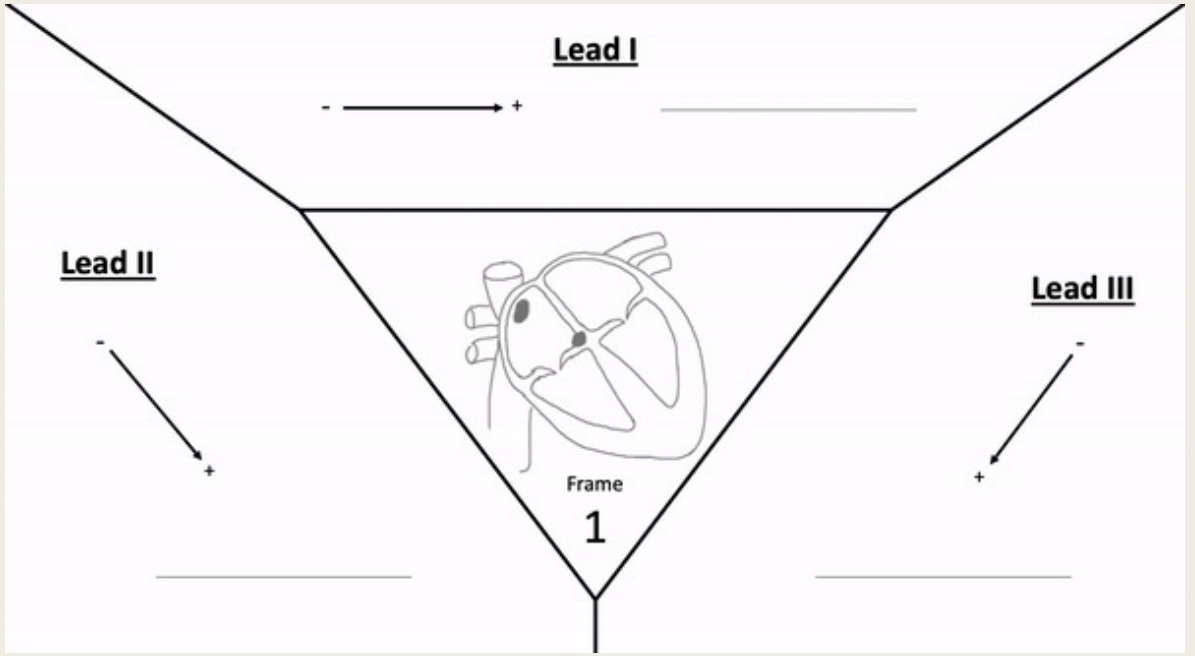


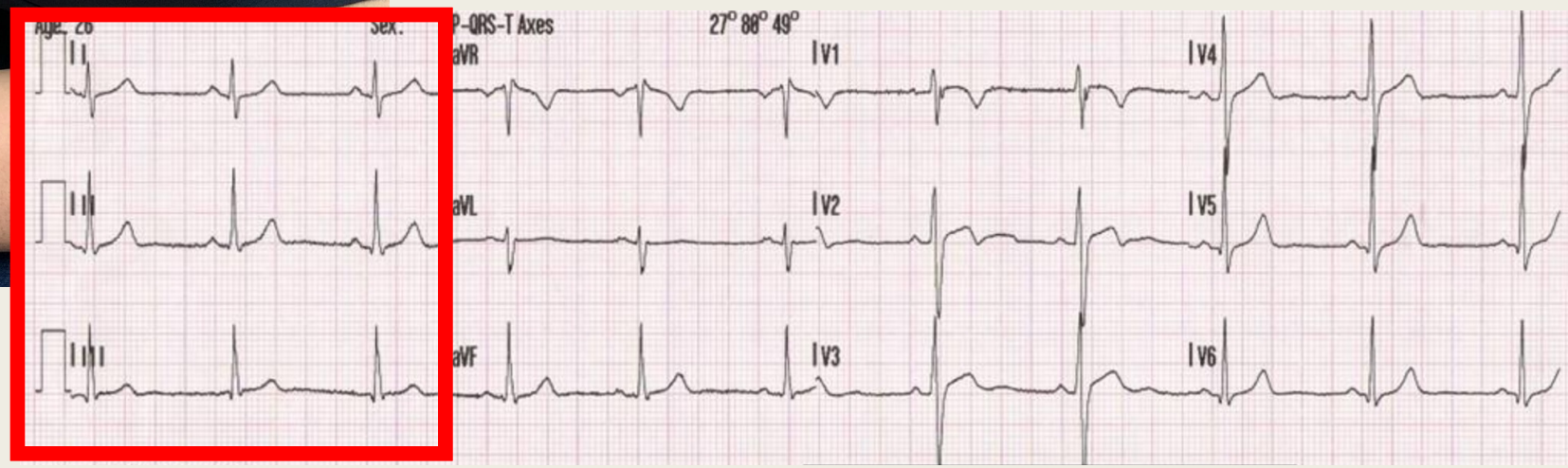
Temporal Map Example: EEG: Electroencephalograph (brain waves) [source Wikipedia]



Temporal Map Example: ECG: Electrocardiogram (heart) [source Wikipedia]

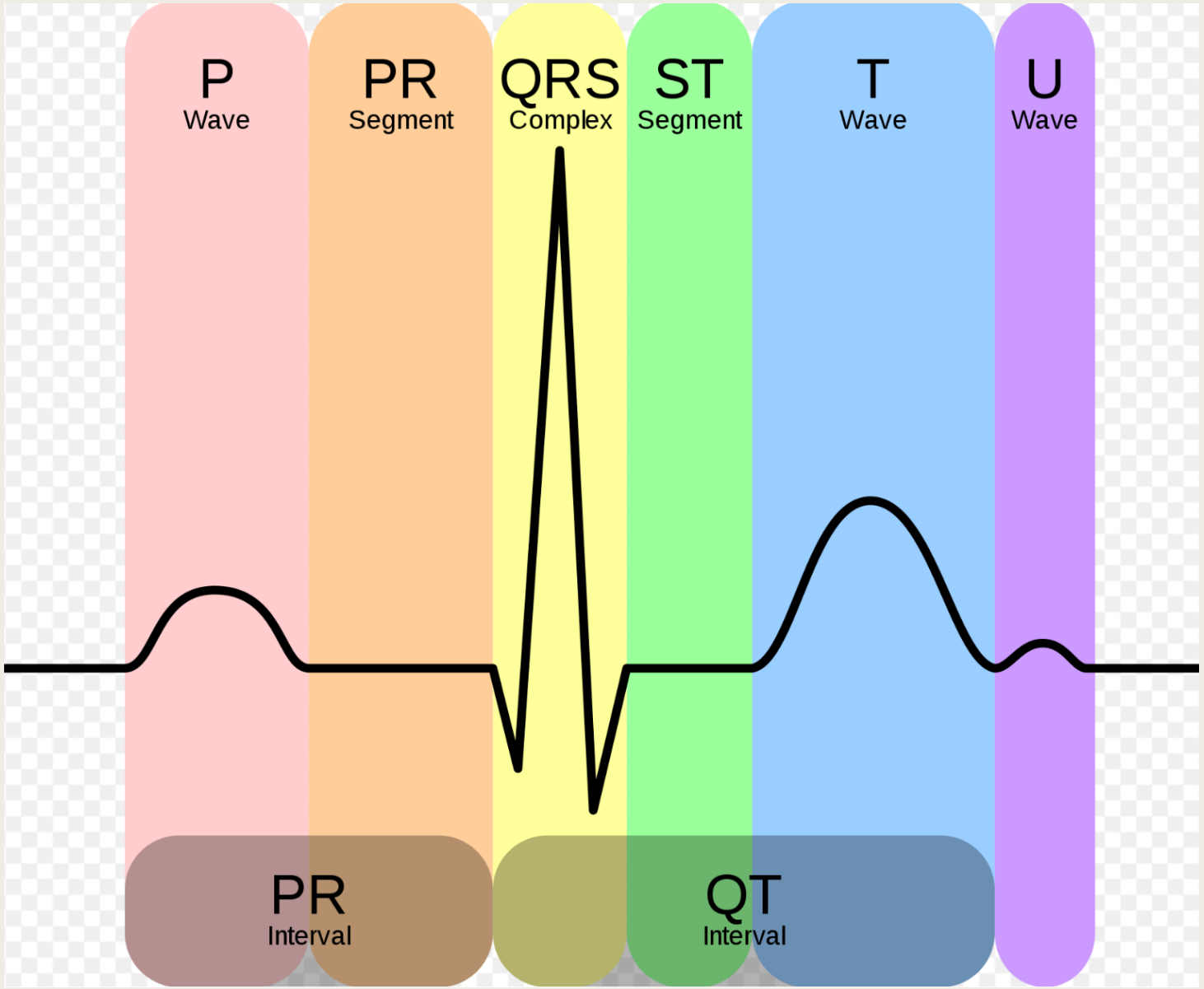




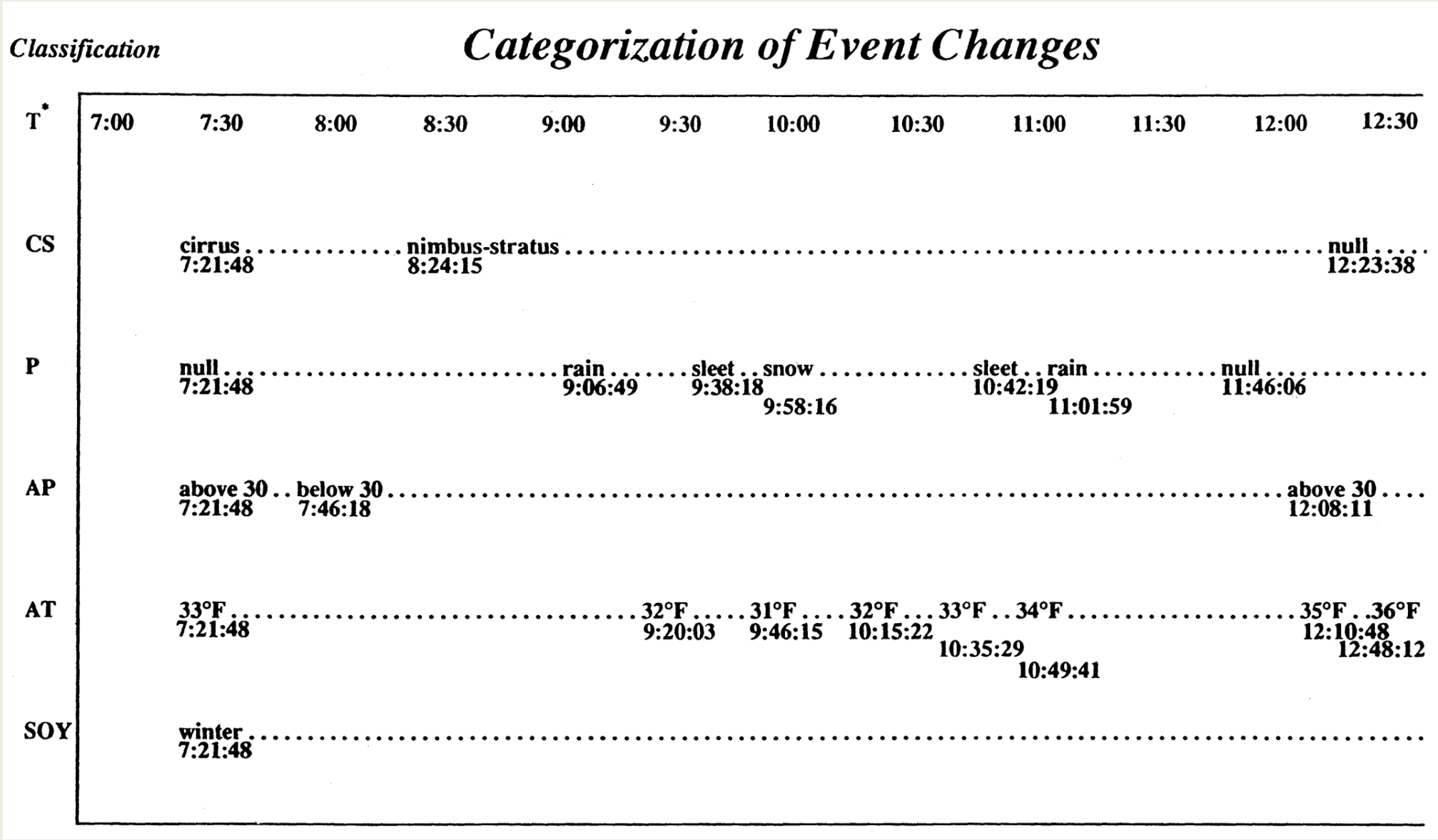


ECG event categories

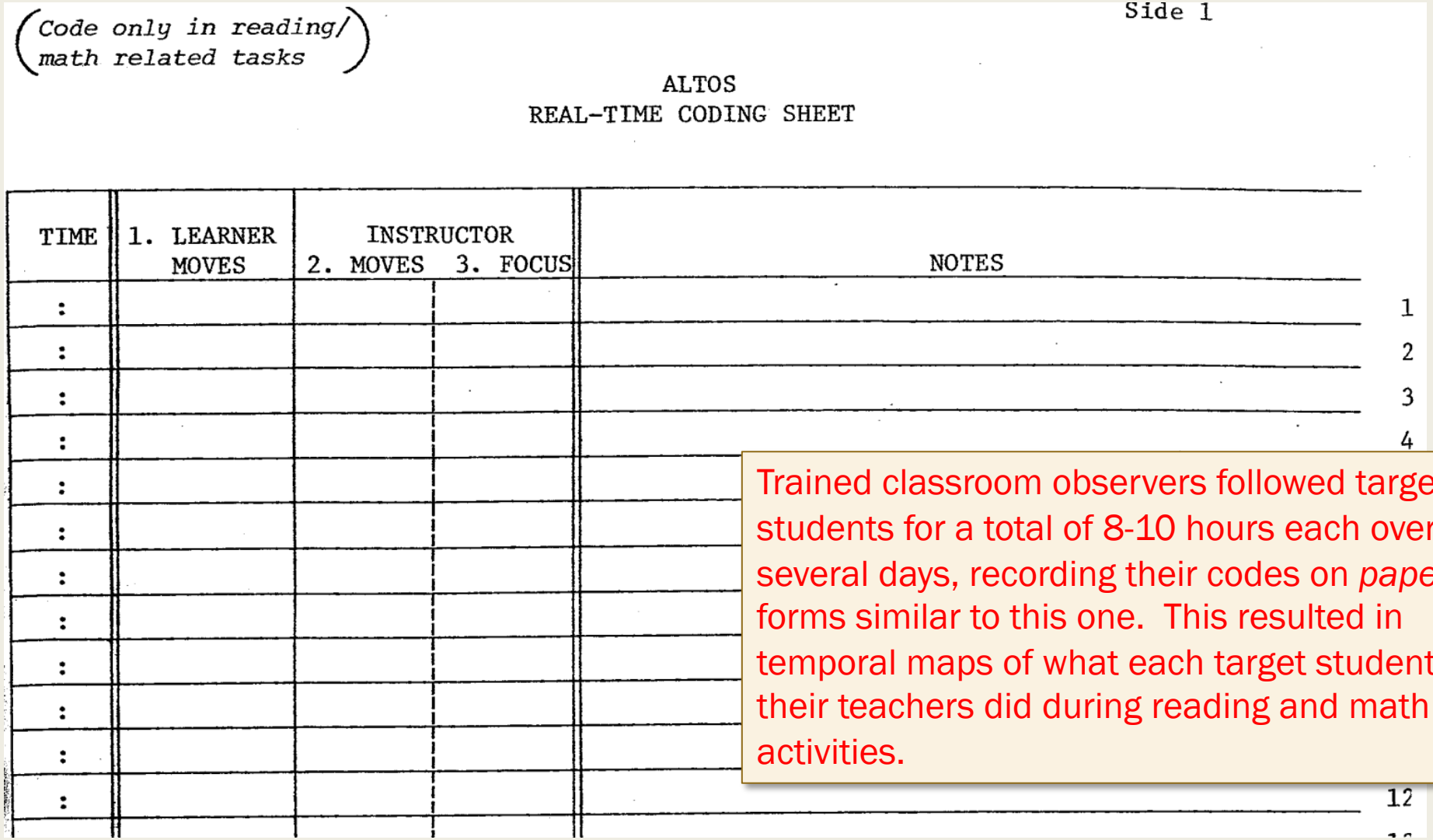
[source: Wikipedia]



Temporal Map Example: Weather [source: Frick, 1990]



Temporal Map Example: ALTOS: Academic Learning Time Observation System [source: Frick & Rieth, 1981]



(Code only in reading/ math related tasks)

Side 1

ALTOS
REAL-TIME CODING SHEET

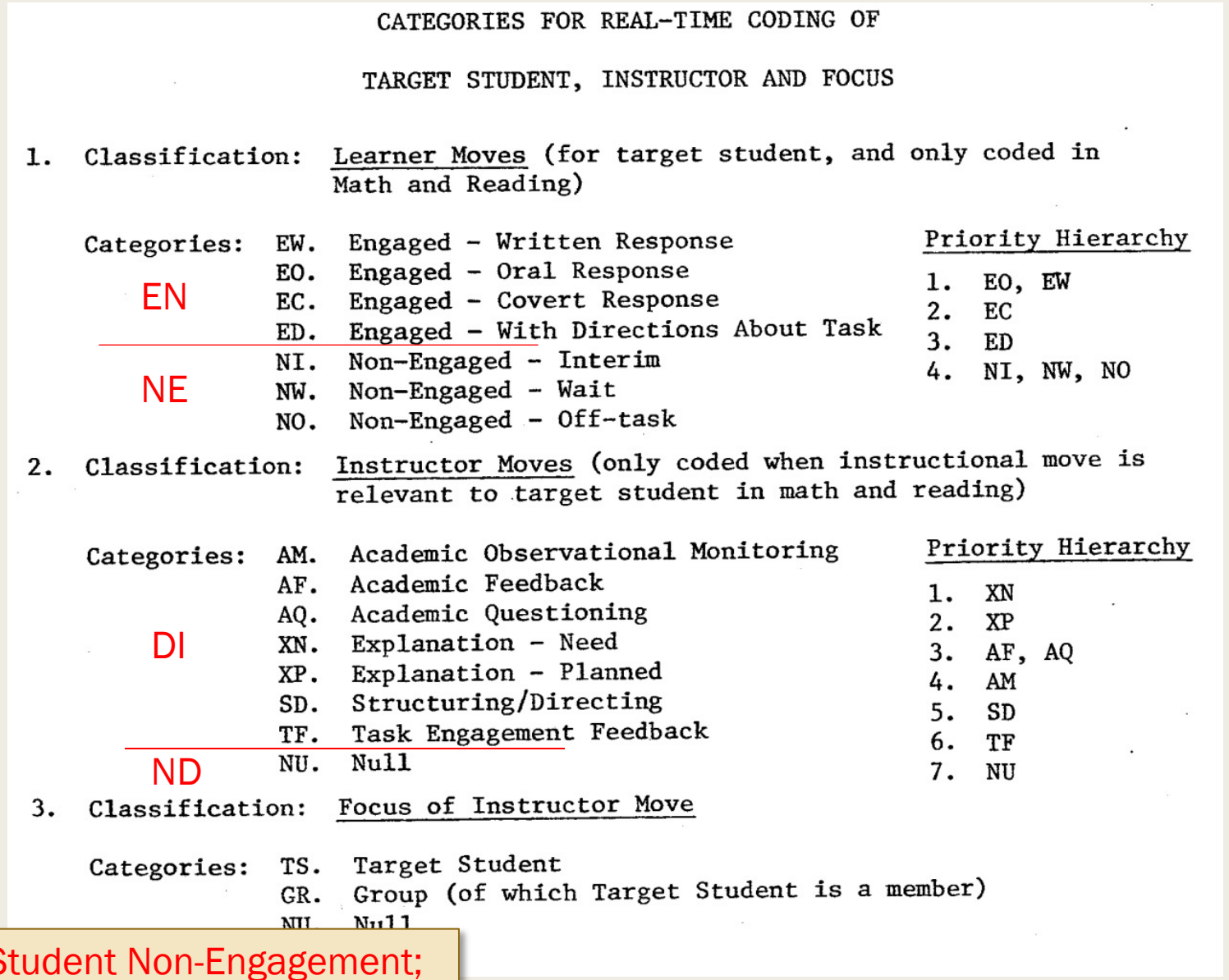
TIME	1. LEARNER MOVES	INSTRUCTOR 2. MOVES	3. FOCUS	NOTES	
:					1
:					2
:					3
:					4
:					
:					
:					
:					
:					
:					
:					
:					12

Trained classroom observers followed target students for a total of 8-10 hours each over several days, recording their codes on *paper* forms similar to this one. This resulted in temporal maps of what each target student and their teachers did during reading and math activities.

ALTOS

Event classifications and categories

[Source: Frick & Reith, 1981]



CATEGORIES FOR REAL-TIME CODING OF

TARGET STUDENT, INSTRUCTOR AND FOCUS

1. Classification: Learner Moves (for target student, and only coded in Math and Reading)

Categories:

EN	EW.	Engaged - Written Response
	EO.	Engaged - Oral Response
	EC.	Engaged - Covert Response
	ED.	Engaged - With Directions About Task
NE	NI.	Non-Engaged - Interim
	NW.	Non-Engaged - Wait
	NO.	Non-Engaged - Off-task

Priority Hierarchy

1. EO, EW
2. EC
3. ED
4. NI, NW, NO

2. Classification: Instructor Moves (only coded when instructional move is relevant to target student in math and reading)

Categories:

DI	AM.	Academic Observational Monitoring
	AF.	Academic Feedback
	AQ.	Academic Questioning
	XN.	Explanation - Need
	XP.	Explanation - Planned
	SD.	Structuring/Directing
	TF.	Task Engagement Feedback
ND	NU.	Null

Priority Hierarchy

1. XN
2. XP
3. AF, AQ
4. AM
5. SD
6. TF
7. NU

3. Classification: Focus of Instructor Move

Categories:

TS. Target Student
GR. Group (of which Target Student is a member)
NU. Null

EN = Student Engagement; NE = Student Non-Engagement;
DI = Direct Instruction; ND = Non-Direct Instruction

1983: Frick dissertation findings: NTPA

Student	p(DI)	p(EN)	p(DI ∩ EN)	p(DI ∩ NE)	p(ND ∩ EN)	p(ND ∩ NE)	p(EN | DI)	p(EN | ND)
1	0.50	0.80	0.46	0.04	0.34	0.16	0.92	0.67
2	0.39	0.49	0.37	0.02	0.12	0.49	0.95	0.20
3	0.27	0.56	0.26	0.01	0.30	0.43	0.97	0.41
4	0.34	0.69	0.34	0.00	0.35	0.31	1.00	0.53
5	0.48	0.73	0.47	0.01	0.25	0.26	0.98	0.49
6	0.40	0.75	0.39	0.01	0.35	0.25	0.98	0.59
7 - 25	…	…	…	…	…	…	…	…
Mean (SD)	0.432 (0.144)	0.741 (0.101)	0.416 (0.139)	0.015 (0.010)	0.324 (0.114)	0.243 (0.104)	0.967 (0.029)	0.573 (0.142)

Key: DI = Direct Instruction; EN = Student Engagement;
NE = Student Non-Engagement; ND = Non-Direct Instruction

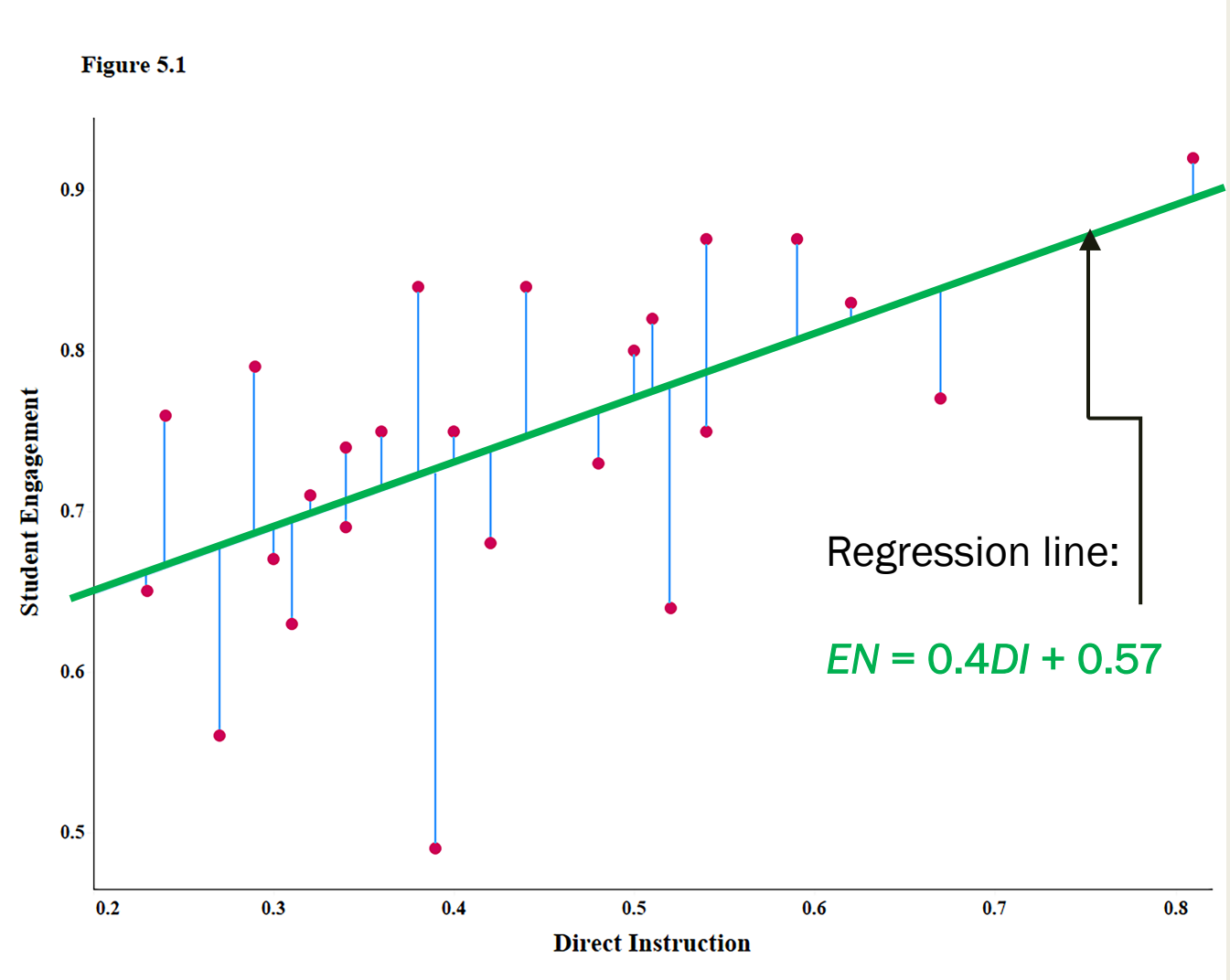
1983: Linear models scatterplot [Frick]

Pearson correlation

$r = 0.57$
$r^2 = 0.33$

NTPA probabilities

$p(EN|DI) = 0.97$
$p(EN|ND) = 0.57$
$p(NE|DI) = 0.03$
$p(NE|ND) = 0.43$



Key: DI = Direct Instruction; EN = Student Engagement;
NE = Student Non-Engagement; ND = Non-Direct Instruction

1983: Conclusion from *same classroom observations*

- NTPA approach
  - *When direct instruction is occurring, mildly handicapped students in elementary schools are engaged about 97 % of the time.*
  - *When direct instruction is not occurring, those students are engaged about 57 percent of the time. Students are about 13 times more likely NOT to be engaged in academic tasks when NO direct instruction is occurring.*
- Linear models approach
  - *The amount of time spent in direct instruction is correlated moderately and positively with the amount of student engagement time ($r = 0.57$)*
  - *33 % of the variance in student engagement time is predicted by the amount of direct instruction time; 67 % of the variance in student engagement time is NOT predicted by the amount of direct instruction ($r^2 = 0.57^2 = 0.33$; $1 - 0.33 = 0.67$)*

1983: Why the difference in conclusions from *same classroom observations?*

- NTPA approach ***measures the relations***

  whereas

- Linear models approach ***relates the measures***

- This is not a play on words, but a profound difference in approach to characterizing relations.

1990:

NTPA name changed to:

Analysis of Patterns in Time
(APT)

American Educational Research Journal
Spring 1990, Vol. 27, No. 1, pp. 180–204

Analysis of Patterns in Time: A Method of Recording and Quantifying Temporal Relations in Education

Theodore W. Frick
Indiana University

Analysis of patterns in time (APT) is a method for gathering information about observable phenomena such that probabilities of temporal patterns of events can be estimated empirically. If appropriate sampling strategies are employed, temporal patterns can be predicted from APT results. As an example of the fruitfulness of APT, it was discovered in a classroom observational study that elementary students were on task 97% of the time if some form of direct instruction was occurring also, whereas they were on task only 57% of the time during nondirect instruction. As a second example, APT results were used as a rule base for an expert system in adaptive computer-based testing. When two different computer tests were studied, average samples of 9 and 13 test items were required to make mastery and nonmastery decisions when items were selected at random. These decisions were, respectively, 94% and 98% accurate compared to those reached from two much larger test item pools. Finally, APT is compared to the linear models approach and event history analysis. The major difference is that in APT there is no mathematical model assumed to characterize relations among variables. In APT the model is the temporal pattern being investigated.

What is Analysis of Patterns in Time (APT)?

- APT is a research methodology invented by Frick in 1970s
- APT is an alternative to the linear models approach (LMA—e.g., multiple regression, ANOVA): In the 1970s
  - *LMA was the prevalent quantitative approach to educational research*
  - *Qualitative methods were rarely used in educational research*
- APT draws from general systems theory, information theory, set theory, probability theory, and Bayesian reasoning
- ***Temporal maps*** are created as the main source of data for APT
- APT queries are then used to segment temporal maps for matching conditions, and for counting occurrences of temporal patterns
- APT queries result in probabilistic measures of temporal patterns (likelihoods, odds, cumulative time)

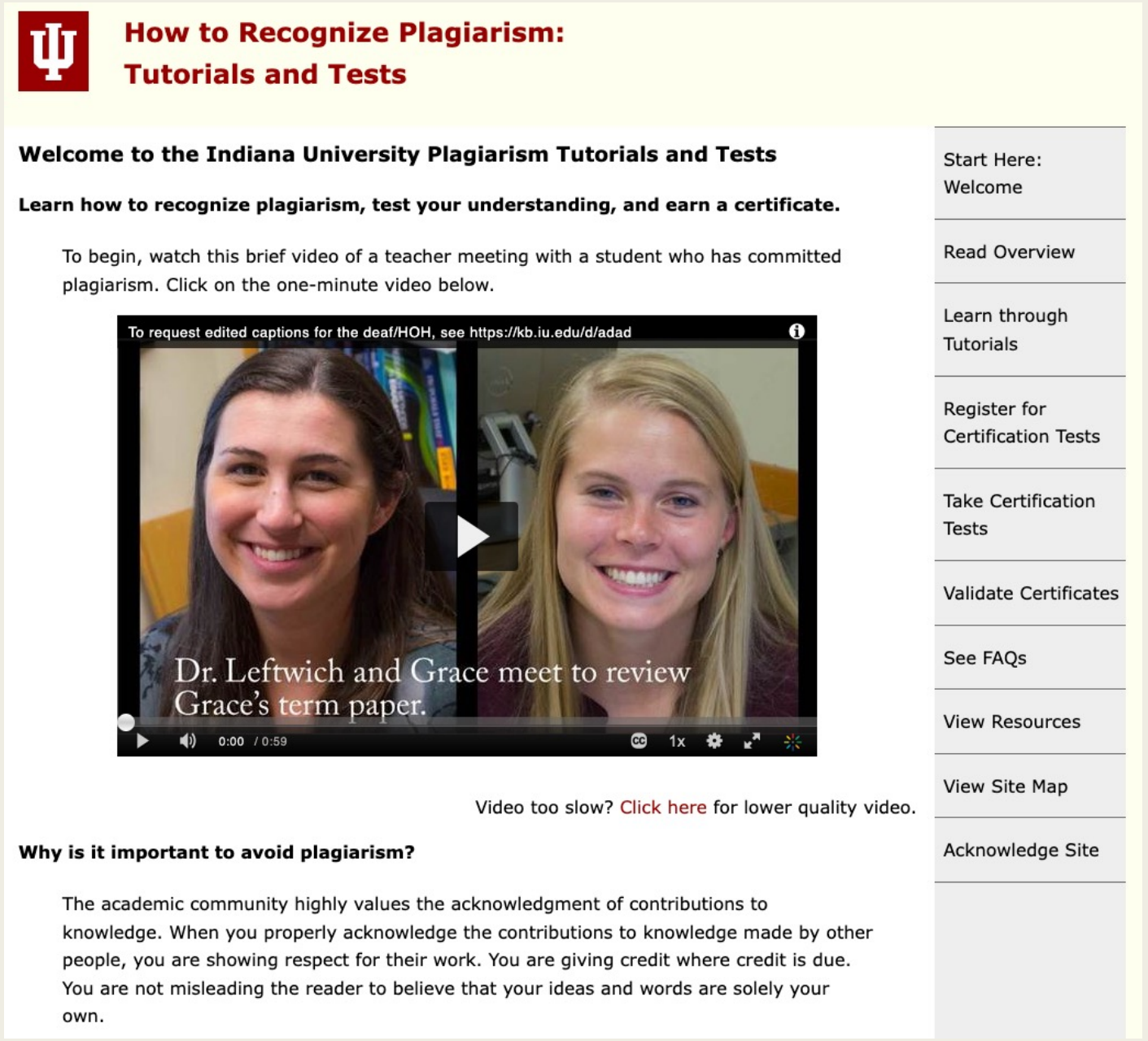
SKIP 26 YEARS AHEAD

A lot happened with APT between 1990 and 2016

2016:

[Redesign of Indiana University Plagiarism Tutorials and Tests (IPTAT) using First Principles of Instruction]

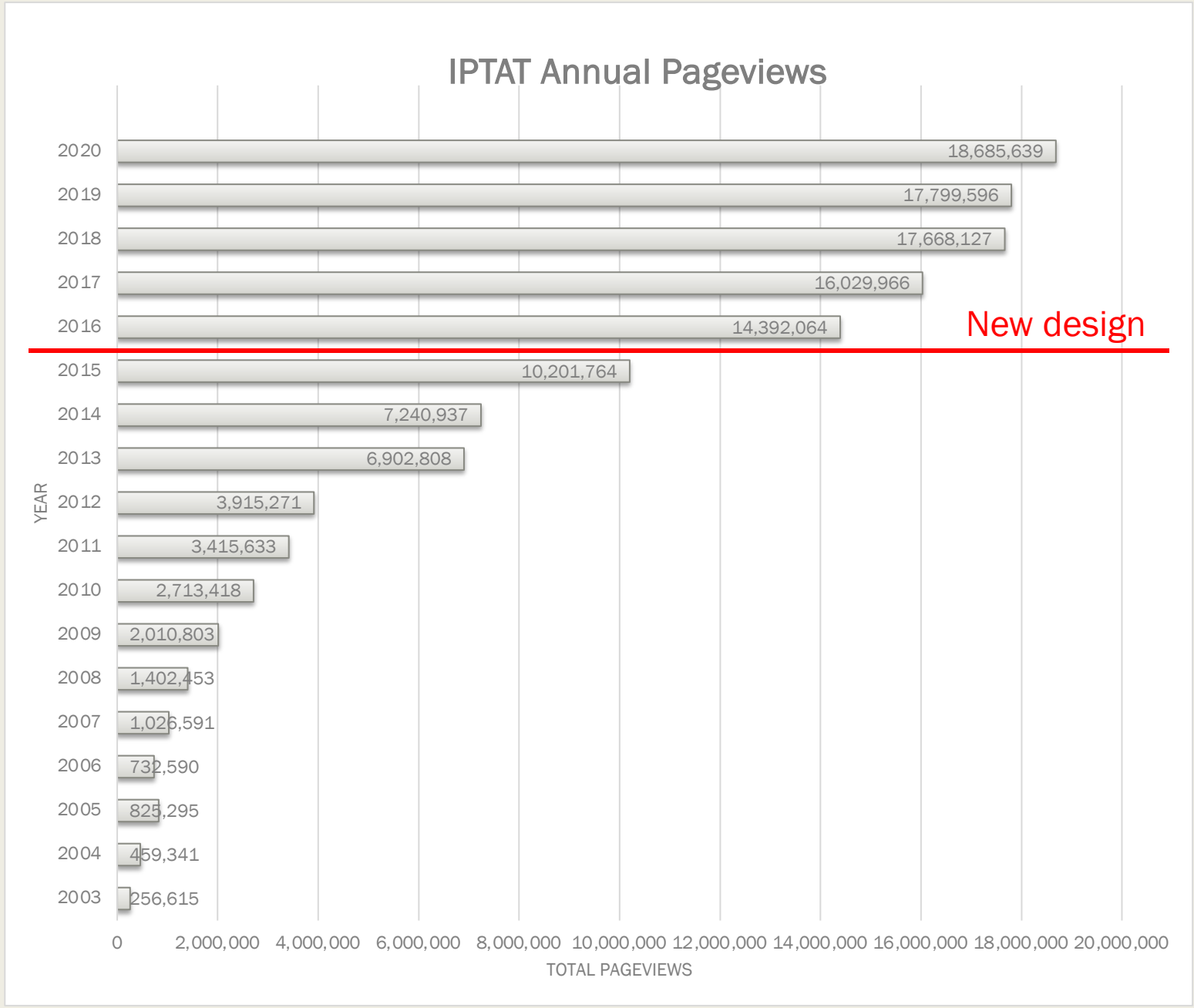
[Initial design was in 2002]



2002 – 2020:

125 million IPTAT pageviews

IPTAT redesigned in 2015, went live in 2016



First Principles of Instruction (FPI) used to redesign IPTAT: [Source: Merrill, 2020]

1. ***Authentic problems or tasks*** for students to do, arranged from simple to complex (e.g., https://plagiarism.iu.edu/tutorials/index.html);
2. ***Activation*** of student learning by helping students connect new learning with what they already know or believe (e.g., https://plagiarism.iu.edu/tutorials/task1/activation.html);
3. ***Demonstration*** of what is to be learned, by showing a variety of examples (e.g., https://plagiarism.iu.edu/tutorials/task1/demonstration.html);
4. ***Application*** of what is being learned, so students can try themselves and feedback is provided (e.g., https://plagiarism.iu.edu/practiceTest.php?task=1&item=1); and
5. ***Integration*** of what has been learned into students' own lives (e.g., https://plagiarism.iu.edu/tutorials/task1/integration.html).

SKIP 4 YEARS AHEAD

From 2016 through 2020, Google Analytics was creating millions of APT temporal maps on IPTAT usage,
but we did not know we could do APT queries with Google Analytics

2020: Serindipitous discovery that Google's Universal Analytics could do some of APT

- We added Google Analytics tracking code in 2016 to most IPTAT webpages
- We did not realize that GA could be used to do parts of APT at that time
- In early 2020, during COVID lockdown, I discovered that GA, if used creatively, could do some parts of APT
  - *GA tracking sessions were indeed temporal maps*
  - *GA segmenting of temporal maps could approximate APT queries*
  - *Data from GA reports could be imported into Microsoft Excel to do further APT computations*

Melinda's Learning Journey

Temporal Map

Part of GA 'session' on Sunday, October 4, 2020.

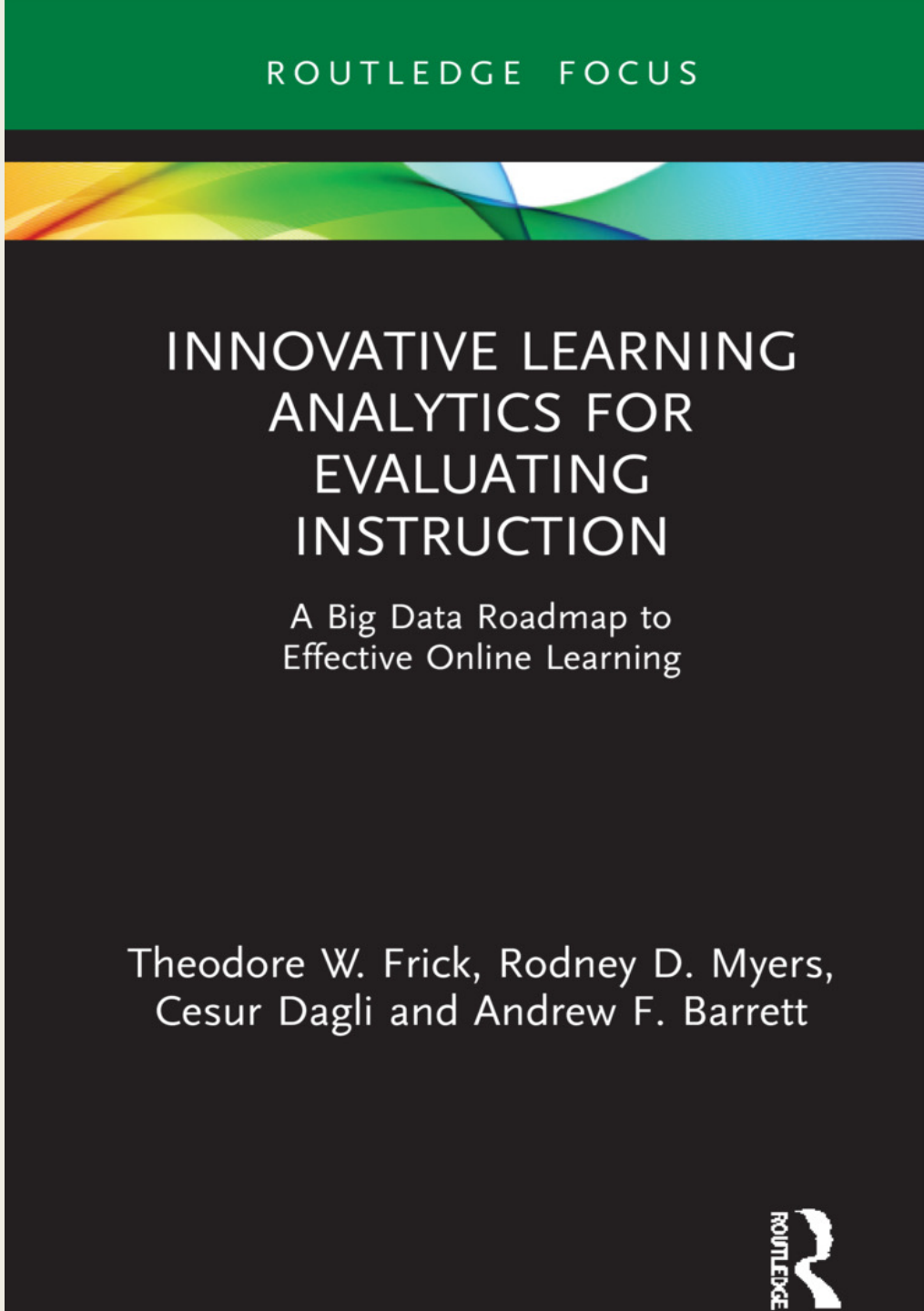
Melinda had 2 GA sessions, totaling 148 minutes in duration, separated by a 52-min. break between sessions.

Time	Web Page HTML Title	Web Page URL at https://plagiarism.iu.edu
5:53 p.m.	Certification Tests	/certificationTests/index.html
5:54 p.m.	Welcome	/index.html
5:54 p.m.	Certification Tests	/certificationTests/index.html
6:01 p.m.	Welcome	/index.html
6:05 p.m.	Organization of Instruction	/organization.html
6:06 p.m.	How to Navigate	/navigation.html
6:06 p.m.	Overview	/overview/index.html
6:07 p.m.	What you should do	/overview/shouldDo.html
6:08 p.m.	But I won't get caught	/overview/easyDetection.html
6:10 p.m.	R U a dupe?	/overview/RUAdupe.html
6:14 p.m.	The Slippery Slope with Symbolic Signs	/overview/signs.html
6:29 p.m.	Cases of Plagiarism	/overview/cases.html
6:33 p.m.	Tutorials and Practice Tests	/tutorials/index.html
6:33 p.m.	Task 1 Overview	/tutorials/task1/index.html
6:37 p.m.	A Video Case	/tutorials/task1/activation.html
6:44 p.m.	Demonstration	/tutorials/task1/demonstration.html
6:47 p.m.	Demonstration Continued	/tutorials/task1/demonstration2.html
6:50 p.m.	Practice with One Item at a Time	/practiceTest.php?task=1&item=1
6:51 p.m.	Practice Question Result and Feedback	/practiceTestResults.php
6:51 p.m.	Practice with One Item at a Time	/practiceTest.php?task=1&item=2
6:52 p.m.	Practice Question Result and Feedback	/practiceTestResults.php
6:52 p.m.	Practice with One Item at a Time	/practiceTest.php?task=1&item=3
6:52 p.m.	Practice Question Result and Feedback	/practiceTestResults.php
6:53 p.m.	Practice with One Item at a Time	/practiceTest.php?task=1&item=4
6:53 p.m.	Practice Question Result and Feedback	/practiceTestResults.php
6:53 p.m.	Task 1 Integration	/tutorials/task1/integration.html

Etc.

New book: Big study over 2 years, 2019-2020

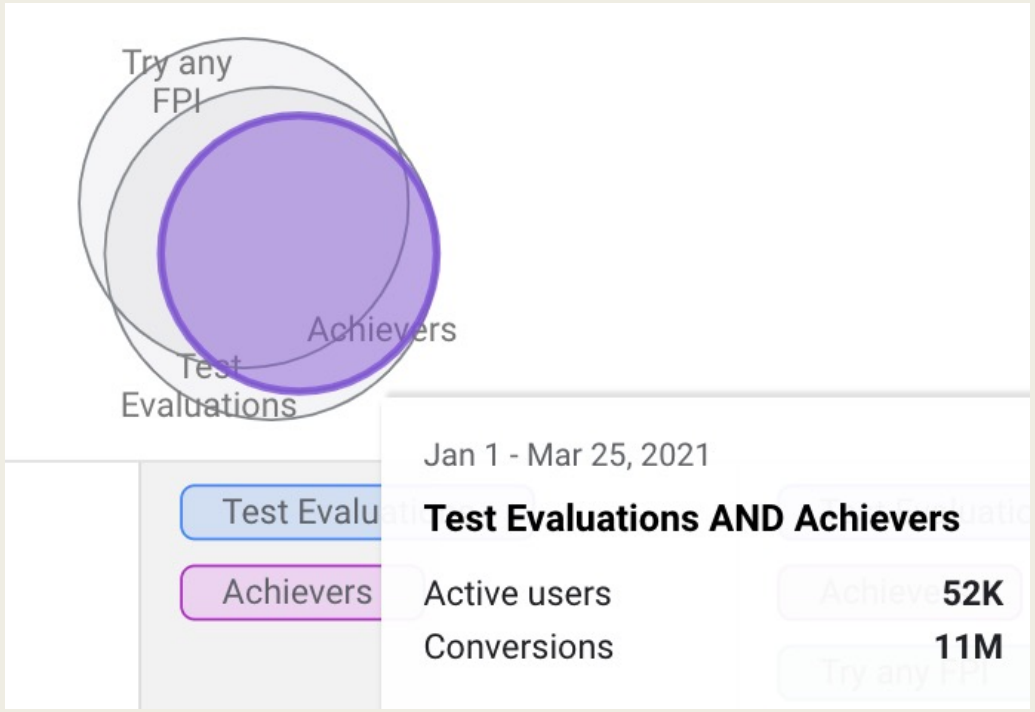
- Google Analytics tracked student use of IPTAT website
  - *Approximately 936,000 learning journeys, students from 222 countries and territories worldwide*
  - *About 1.9M temporal maps, 36M pageviews*
- We discovered in 2020 that Google's Universal Analytics (UA) could be leveraged to do Analysis of Patterns in Time (APT) when coupled with Excel spreadsheets.
- Main APT finding: Successful students viewed 3 to 4 times as many unique Web pages designed with First Principles of Instruction as did unsuccessful students.

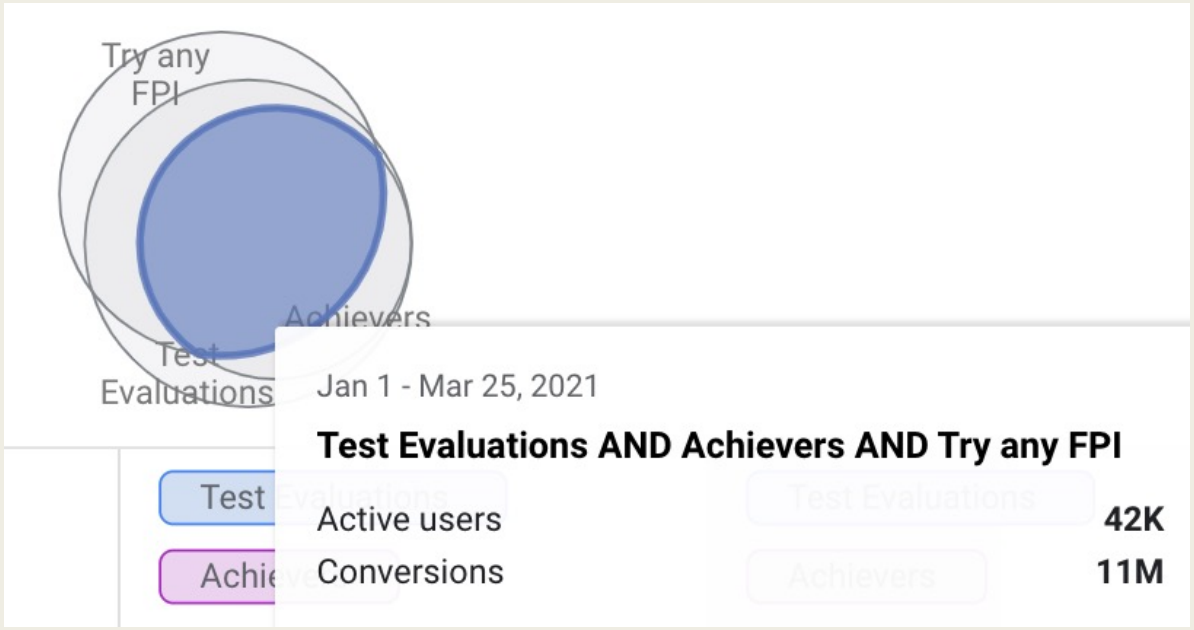


2022: Featured research paper in ETR&D (follow-up using Google Analytics 4 to do some of APT)

- GA4 tracked 172,417 learning journeys of students who were interacting with IPTAT from Jan. 1 through Mar. 25, 2021
- In 75,087 learning journeys, students took 2 or more Certification Tests (CTs)
  - *51,646 journeys resulted in passing a CT (Achievers)*
  - *23,307 did not pass a CT in 2 or more attempts (Nonmasters)*
- Of the 51,646 Achievers,
  - *42,046 had tried one or more IPTAT webpages designed with First Principles of Instruction (Traditionalists)*
  - *9,600 did NOT try any FPI webpages (Minimalists)*

Since 52K passed, and 42K had Tried any FPI, then about 10K passed without trying any FPI (Minimalist Achievers)





APT Query Results: Bayesian Outcomes

IPTAT FPI event type	*p*(A)	*p*(N)	*p*(A | FPI)	*p*(N | FPI)	Odds (A:N)
Activation	0.29	0.08	0.78	0.22	3.51
Demonstration	0.28	0.08	0.78	0.22	3.61
Application	0.28	0.07	0.79	0.21	3.81
Integration	0.27	0.07	0.80	0.20	3.95
Mastery_Test	0.29	0.08	0.79	0.21	3.66
Plagiarism_Patterns	0.45	0.18	0.71	0.29	2.49

Conclusion: Students were nearly 4 times more likely to be achievers when they tried webpages designed with First Principles of Instruction.

A Achiever
N Nonmaster
p probability
| given

FPI: First Principle of Instruction

IPTAT: IU Plagiarism Tutorials and Tests

You can view demonstration videos on the Web and read the research publication

Click here for list of 8 demonstration videos
(approximately 85 minutes in total)

This *ETR&D* publication explains our analysis in greater detail:

Analysis of Patterns in Time for
Evaluating First Principles of Instruction
(Frick, Myers & Dagli, 2022)

SUMMARY

After 50 years of research with Analysis of Patterns in Time

Summary: Analysis of Patterns in Time

- APT is a fruitful methodology for investigating the instrumental value of instruction to promote student learning achievement.
- GA4 when supplemented with Excel can do some kinds of APT as envisioned originally by Frick (1983, 1990) and Myers and Frick (2015).
- GA4 is somewhat easier to use for doing APT when compared with Google's earlier Universal Analytics. In both cases, Excel is needed for further computations of likelihoods and Bayesian analysis.
- For more on APT and designing online instruction with First Principles of Instruction, see our new book: *Innovative Learning Analytics for Evaluating Instruction: A Big Data Roadmap for Effective Online Learning* (2022, Routledge Focus Series)

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Links for Using Google Analytics to do Analysis of Patterns in Time (APT)

Video demonstrations

https://plagiarism.iu.edu/apt/demo/index.html

For background on APT, see also

https://plagiarism.iu.edu/apt/index.html

Slides of this presentation (PDF)

https://tedfrick.sitehost.iu.edu/apt/APT_LAsummit2022.pdf

Video of this presentation

https://plagiarism.iu.edu/apt/Frick_LA_Summit_2022.html