

# Progress toward NLP-assisted formative assessment feedback

Matthew Beckman  
Penn State University

August 8, 2024

Slides: [mdbeckman.github.io/JSM2024/](https://mdbeckman.github.io/JSM2024/)

# Overview

- “short-answer” tasks are good for students, but hard to scale
- Can NLP tools help instructors give students feedback?
  - Evaluate & group student responses
  - Compare agreement between NLP & humans
  - What might scalable, personalized feedback look like anyway?

# Spoilers!

- “short-answer” tasks are good for students, but hard to scale
- Can NLP tools help instructors give students feedback?
  - Evaluate & group student responses
  - Compare agreement between NLP & humans
  - What might scalable, personalized feedback look like anyway?
- Results
  - Instructor agreement ( $QWK \approx 0.7$  to  $0.8+$ )
  - UTA agreement ( $QWK \approx 0.6$  to  $0.7+$ )
  - NLP algorithm agreement with instructors ( $QWK \approx 0.7+$ )
  - Human-Algorithm partnership may be even better ( $\approx 0.85+$ )
  - Pursuing multiple avenues for grouping & feedback

## Motivation

- “Write-to-learn” tasks improve learning outcomes (Graham, et al., 2020)
- Critical for citizen-statisticians to communicate effectively (Gould, 2010)
- Frequent practice w/ communicating improves statistical literacy and promotes retention (Basu, et al., 2013)
- Formative assessment benefits both students & instructors (Black & Wiliam, 2009; GAISE, 2016; Pearl, et al., 2012)
- A majority of U.S. undergraduates at public institutions take at least one large-enrollment STEM course (Supiano, 2022)
- **Logistics of constructed response tasks jeopardize use in large-enrollment classes** (Garfield & Ben-Zvi, 2008; Woodard & McGowan, 2012)

Easy!



Erm...



## Goal

*Develop technology that can assist instructors for large (STEM) classes with providing targeted formative assessment feedback to students, such that instructor burden is similar to small class (~30 students)*

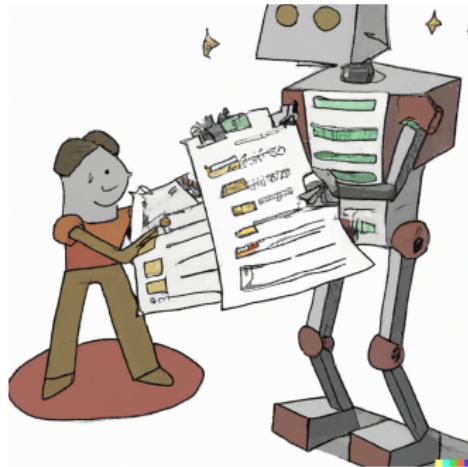
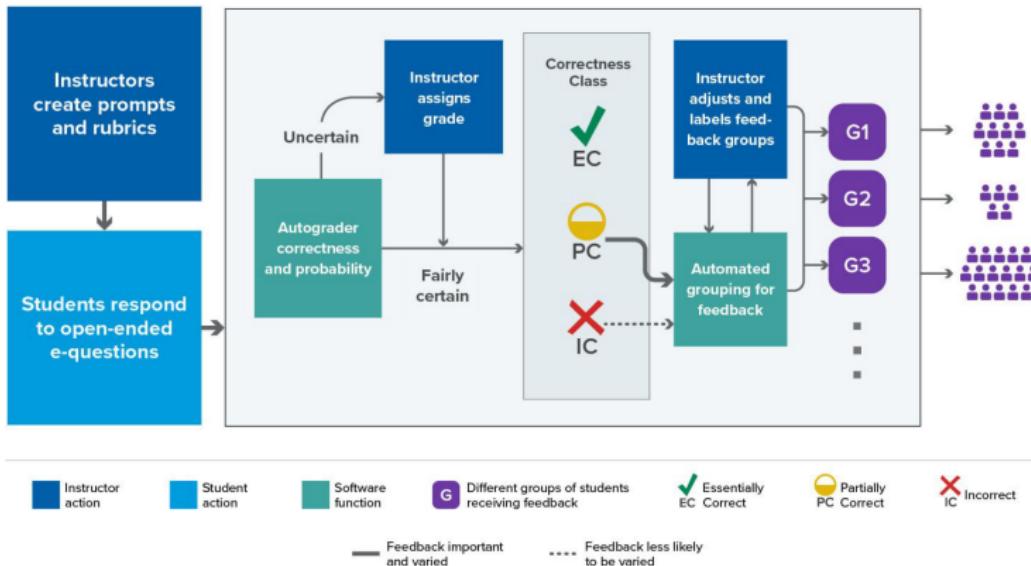


Figure 1: image created with assistance of DALL·E 2 by Open AI

# Project Schematic



*Goal: Computer-assisted formative assessment feedback for short-answer tasks in large-enrollment classes, such that instructor burden is similar to small class (~30 students)*

## Research Questions

- **RQ1:** What level of agreement is achieved among trained human raters labeling (i.e., scoring) short-answer tasks?
- **RQ2:** What level of agreement is achieved between human raters and an NLP algorithm?
- **RQ3:** What sort of NLP representation leads to good clustering performance, and how does that interact with the classification algorithm?

### Pilot Study

Lloyd, S. E., Beckman, M., Pearl, D., Passonneau, R., Li, Z., & Wang, Z. (2022). Foundations for AI-Assisted Formative Assessment Feedback for Short-Answer Tasks in Large-Enrollment Classes. In *Proceedings of the eleventh international conference on teaching statistics*. Rosario, Argentina.

# Collaborators

Susan Lloyd



Dennis Pearl



Zhaohui Li



Matt Beckman



Becky Passonneau



Semantic Feature-Wise  
Transformation Relation  
Network (SFRN)



## Methods (Sample)

Study utilized de-identified extant data & scoring rubrics (Beckman, 2015)

- 6 short-answer tasks
- 1,935 students total
- 29 class sections 15 distinct institutions

Note: this sample was *not* a single large class at one institution; these data include introductory statistics students from many class sections at many institutions—some large, others small.



Figure 2: image created with assistance of DALL·E 2 by Open AI

## Methods (Short-answer task)

4. Walleye is a popular type of freshwater fish native to Canada and the Northern United States. Walleye fishing takes much more than luck; better fishermen consistently catch larger fish using knowledge about proper bait, water currents, geographic features, feeding patterns of the fish, and more. Mark and his brother Dan went on a two-week fishing trip together to determine who the better Walleye fisherman is. Each brother had his own boat and similar equipment so they could each fish in different locations and move freely throughout the area. They recorded the length of each fish that was caught during the trip, in order to find out which one of them catches larger Walleye on average.

a. Should statistical inference be used to determine whether Mark or Dan is a better Walleye fisherman? Explain why statistical inference should or should not be used in this scenario.

b. Next, explain how you would determine whether Mark or Dan is a better Walleye fisherman using the data from the fishing trip. *(Be sure to give enough detail that a classmate could easily understand your approach, and how he or she would interpret the result in the context of the problem.)*

Figure 3: Sample task including a stem and two short-answer prompts.

## Methods (RQ1)

- 3 raters typical of large-enrollment instruction team
- (6 tasks) x (1,935 students) distributed among the team
- sufficient intersection to assess inter-rater agreement
- responses judged Correct / Partial / Incorrect against rubric

### Summer 2024 Team

- 4 Undergraduate Teaching Assistants (UTA's) join team
- UTA's are important part of large-enrollment teaching team
- (4 tasks) x (63 students) scored by each UTA

Matt Beckman



Ben Fry



Sean Burke



Susan Lloyd



Luke Patterson



Jack Fiochetta



Elle Tang



## Results (RQ1)

**RQ1:** What level of agreement is achieved among trained human raters labeling (i.e., scoring) short-answer tasks?

| Comparison        | Reliability |
|-------------------|-------------|
| Rater A & Rater C | QWK = 0.83  |
| Rater A & Rater D | QWK = 0.80  |
| Rater C & Rater D | QWK = 0.79  |

Reliability interpretation<sup>1</sup>:  $0.6 <$  substantial  $< 0.8 <$  near perfect  $< 1.0$

---

<sup>1</sup>Viera & Garrett (2005)

## Preliminary Results: Summer 2024 UTA's

- pairwise agreement with “instructor” (rater A)
- Results from beginning and end of 10 week program

| Comparison        | Week 1 Agreement | Week 10 Agreement |
|-------------------|------------------|-------------------|
| Rater A & Rater E | QWK = 0.57       | (TBD)             |
| Rater A & Rater F | QWK = 0.72       | QWK = 0.78        |
| Rater A & Rater G | QWK = 0.73       | (TBD)             |
| Rater A & Rater H | QWK = 0.71       | QWK = 0.68        |

Reliability interpretation<sup>2</sup>:  $0.6 <$  substantial  $< 0.8 <$  near perfect  $< 1.0$

---

<sup>2</sup>Viera & Garrett (2005)

## Methods (RQ2)

**RQ2:** What level of agreement is achieved between human raters and an NLP algorithm?

Susan Lloyd



Dennis Pearl



Zhaohui Li



Matt Beckman



Becky Passonneau



Semantic Feature-Wise Transformation Relation Network (SFRN)



### Paper introducing SFRN

Li, Z., Tomar, Y., & Passonneau, R. J. (2021). A Semantic Feature-Wise Transformation Relation Network for Automatic Short Answer Grading. In *Proceedings of the 2021 Conference on Empirical Methods in Natural Language Processing*, pp. 6030–6040. Association for Computational Linguistics.  
<https://aclanthology.org/2021.emnlp-main.487>

## Meet the “machine”

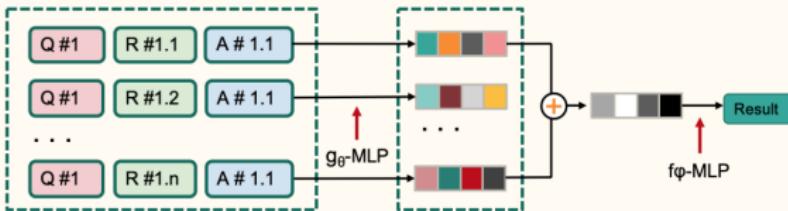


Figure 4: SFRN schematic: encoder (Left); fusion function (Middle); classifier (Right)

### Semantic Feature-Wide Transformation Relation Network (SFRN):

- architecture inspired by work from computer vision
- end-to-end model with three components:
  - pretrained BERT encoder (LLM) » vector representations
  - learned feature-wise transformation function fuses multiple representations, if necessary (e.g., multiple reference answers)
- relation networks designed to learn generalizations that infer meaning in a data-efficient way
- data augmentation during training step

## Results (RQ2)

**RQ2:** What level of agreement is achieved between instructors and the machine (an NLP algorithm)?

| Comparison     | Reliability |
|----------------|-------------|
| Rater A & SFRN | QWK = 0.79  |
| Rater C & SFRN | QWK = 0.82  |
| Rater D & SFRN | QWK = 0.74  |

Reliability interpretation<sup>3</sup>:  $0.6 <$  substantial  $< 0.8 <$  near perfect  $< 1.0$

---

<sup>3</sup>Viera & Garrett (2005)

## Human-Machine Partnership Method

Want to evaluate accuracy of marking algorithm when designed to “defer” to human judgment

- algorithm evaluates a probability for each label (EC, PC, IC)
  - if a label has high probability, use algorithm label
  - if no label has sufficiently high probability, defer to human
- interests
  - estimate how frequently the algorithm defers
  - estimate accuracy of the combined process

## Human-Machine Partnership Results

*Our work is first that we know of to implement controllable, selective prediction deferral policy for the classifier (i.e., scoring) step*

| Threshold | Deferral Rate | Simulated HIL Accuracy |
|-----------|---------------|------------------------|
| 0.68      | 0.095         | 0.855                  |
| 0.75      | 0.132         | 0.861                  |
| 0.80      | 0.160         | 0.871                  |
| 0.85      | 0.202         | 0.884                  |
| 0.90      | 0.256         | 0.899                  |

## Methods (RQ3)

How similar is feedback provided by trained humans?

- Experiment #1: Humans
  - Two reviewers independently evaluated 100 “partial credit” responses
  - Each reviewer provided free-text feedback to each student
  - Verbatim feedback captured for each reviewer and cross-tabulated for analysis.
- Experiment #1: NLP Tools
  - retrain k-means & k-medoids clustering & evaluate stability
  - compare representations with higher & lower dimensionality
- Experiment #2
  - if feedback labels are pre-determined, how consistently are they applied?
  - (i.e., clustering => FB Classifier??)
  - Both Humans & NLP Tools attempt
  - New tool “AsRRN” (Li, Lloyd, Beckman, & Passonneau, 2023)

# Results (RQ3 humans)

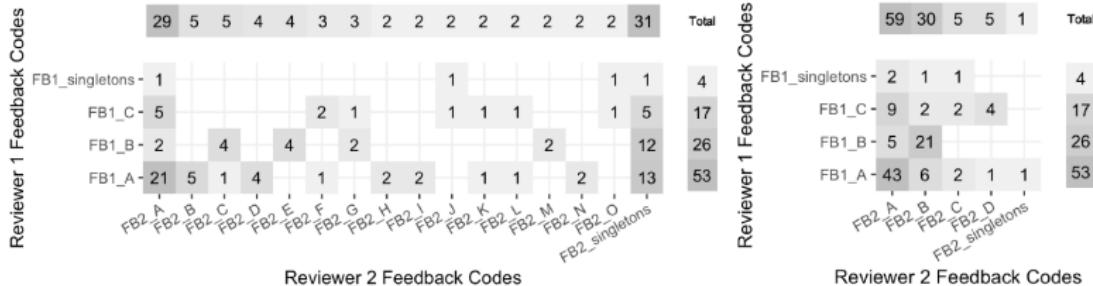


Figure 5: Cross-tabulation of feedback distribution for the two reviewers for the initial feedback (left) compared with the same analysis for the portion of feedback related to the statistical concept at issue (right).

- Reviewer 1 favored feedback on statistical concepts (only).
- Reviewer 2 provided same, plus a quote from the student
- Reviewer 2 parsed feedback to compare remarks related to the statistical concepts (only) with that of Reviewer 1.

## Results (RQ3 humans)

| Feedback Code         | Feedback verbatim text suggested by the Reviewer   |
|-----------------------|--|
| FB1_A<br>(Reviewer 1) | What can we do to evaluate whether [the] result is better than we would expect for someone that is strictly guessing?  |
| FB2_A<br>(Reviewer 2) | Think about what inferential statistical method might we use to evaluate the percentage of correctly identified notes.   |
| FB1_B<br>(Reviewer 1) | Good idea to have a threshold for comparison, but it's very important that it be established carefully. For example, how might you establish a threshold that... |
| FB2_B<br>(Reviewer 2) | Why this threshold? What inferential statistical method might we use to evaluate the percentage of correctly identified notes?                                   |

Figure 6: Verbatim feedback most frequently provided by each reviewer for responses to task 2B.

## Results (RQ3 machines)

**RQ3:** What sort of NLP representation leads to good clustering performance, and how does that interact with the classification algorithm?

- SFRN ( $D = 512$ ) produced reasonably consistent clusters when retrained (0.62)
- Highest consistency (0.88;  $D = 50$ ) was achieved using a matrix factorization method that produces static representations (WTMF; Guo & Diab, 2011)
- AsRRN compared to humans (A & B) grouping students by pre-determined feedback categories:

| Task | Sample Size | A & B | A & AsRRN | B & AsRRN |
|------|-------------|-------|-----------|-----------|
| 1    | 90          | 0.71  | 0.53      | 0.69      |
| 2    | 100         | 0.45  | 0.70      | 0.41      |

# Discussion



OFFICE OF  
Educational Technology

# Artificial Intelligence and the Future of Teaching and Learning

*Insights and Recommendations*

May 2023

|   |           |
|---|-----------|
| <b>Recommendations .....</b>  | <b>52</b> |
| Insight: Aligning AI to Policy Objectives .....   | 52        |
| Calling Education Leaders to Action .....   | 53        |
| Recommendation #1: Emphasize Humans in the Loop .....                                   | 53        |
| Recommendation #2: Align AI Models to a Shared Vision for Education .....               | 54        |
| Recommendation #3: Design Using Modern Learning Principles .....                        | 56        |
| Recommendation #4: Prioritize Strengthening Trust .....                                 | 57        |
| Recommendation #5: Inform and Involve Educators .....                                   | 57        |
| Recommendation #6: Focus R&D on Addressing Context and Enhancing Trust and Safety ..... | 59        |
| Recommendation #7: Develop Education-Specific Guidelines and Guardrails .....           | 60        |
| Next Steps .....  | 60        |

## Discussion

- **RQ1:** Substantial agreement achieved among trained human raters provides context for further comparisons
- **RQ2:** NLP algorithm produced agreement reasonably aligned to results achieved by pairs/groups of trained human raters
  - Human-in-the-Loop » Instructor / Algorithm partnership
- **RQ3:** Promising results based on “man-made clusters” but classification and clustering have competing incentives when it comes to dimensionality of NLP vector representations
  - Lower Dim is generally better for cluster stability
  - Higher Dim better for classification reliability
  - Exploring Topological Analysis as alternative to clustering
  - Feedback as a classifier (Li et al., 2023)

# Current Events

- challenge system with diverse tasks, institutions, student populations;
  - partnering with ISU, MSU, PSU, UCSB, UF, & UTEP
  - two “consensus” tasks implemented by all
  - 2-3 local tasks at each institution
  - (so far) approx 22,300 responses from ~ 13,000 students
- accumulated data to be shared with broader NLP community
  - this will be among the largest *open* data sources of it's kind
  - addresses barriers imposed by proprietary data sources on NLP research
- shiny new algorithm: AsRRN
  - contrastive loss function
  - correct answers are similar; there are a few distinct ways to earn partial credit; there are many diffuse ways to be incorrect
  - accommodates more complex task structure

## Acknowledgment

- We're grateful to the US National Science Foundation for funding this research; Project CLASSIFIES (NSF DUE-2236150).
- Thanks to students and faculty at partner institutions that have assisted us with data collection.

## References (1/3)

- ① Attali, Y., Powers, D., Freedman, M., Harrison, M., & Obetz, S. (2008). Automated Scoring of Short-Answer Open-Ended Gre® Subject Test Items. *ETS Research Report Series*, 2008(1), i–22.
- ② Basu, S., Jacobs, C., & Vanderwende, L. (2013). Powergrading: a Clustering Approach to Amplify Human Effort for Short Answer Grading. *Transactions of the Association for Computational Linguistics*, 1, 391–402. [https://doi.org/10.1162/tacl\\_a\\_00236](https://doi.org/10.1162/tacl_a_00236)
- ③ Beckman, M. (2015). Assessment Of Cognitive Transfer Outcomes For Students Of Introductory Statistics.  
<http://conservancy.umn.edu/handle/11299/175709>
- ④ Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability*, 21, pp 5-31. <https://doi.org/10.1007/s11092-008-9068-5>
- ⑤ GAISE College Report ASA Revision Committee (2016). Guidelines for Assessment and Instruction in Statistics Education College Report 2016. URL: <http://www.amstat.org/education/gaise>

## References (2/3)

- ⑥ Gould, R. (2010). Statistics and the Modern Student. *International Statistical Review / Revue Internationale de Statistique*, 78(2), 297–315. <https://www.jstor.org/stable/27919839>
- ⑦ Guo, W., Diab, M. (2012) Modeling Sentences in the Latent Space. In *Proceedings of the 50th Annual Meeting of the Association for Computational Linguistics*, pages 864–872. Association for Computational Linguistics.
- ⑧ Graham, S., Kiuhara, S. A., & MacKay, M. (2020). The Effects of Writing on Learning in Science, Social Studies, and Mathematics: A Meta-Analysis. *Review of Educational Research*, 90(2), 179–226.
- ⑨ Li, Z., Tomar, Y., & Passonneau, R. J. (2021). A Semantic Feature-Wise Transformation Relation Network for Automatic Short Answer Grading. In *Proceedings of the 2021 Conference on Empirical Methods in Natural Language Processing*, pp. 6030–6040. Association for Computational Linguistics.  
<https://aclanthology.org/2021.emnlp-main.487>
- ⑩ Li, Z., Lloyd, S., Beckman, M. D., & Passonneau, R. J. (2023). Answer-state Recurrent Relational Network (AsRRN) for Constructed

## References (3/3)

- ⑩ Page, E. B. (1994). Computer Grading of Student Prose, Using Modern Concepts and Software. *The Journal of Experimental Education*, 62(2), 127–142.
- ⑪ Pearl, D. K., Garfield, J. B., delMas, R., Groth, R. E., Kaplan, J. J., McGowan, H., & Lee, H. S. (2012). Connecting Research to Practice in a Culture of Assessment for Introductory College-level Statistics. URL: <http://www.causeweb.org/research/guidelines/> ResearchReport\_Dec\_2012.pdf
- ⑫ U.S. Department of Education, Office of Educational Technology (2023). Artificial Intelligence and Future of Teaching and Learning: Insights and Recommendations, Washington, DC.
- ⑬ Viera, A. J., & Garrett, J. M. (2005). Understanding interobserver agreement: the kappa statistic. *Family Medicine*, 37(5), 360–363.
- ⑭ Woodard, R., & McGowan, H. (2012). Redesigning a large introductory course to incorporate the GAISE guidelines. *Journal of Statistics Education*, 20(3).

Thank You

## Progress toward NLP-assisted formative assessment feedback

Matthew Beckman  
Penn State University

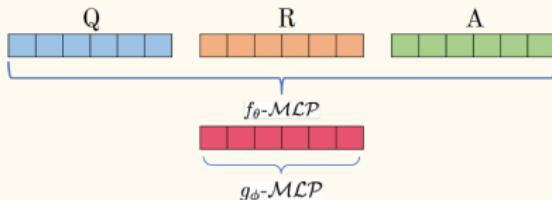
August 8, 2024

Slides: [mdbeckman.github.io/JSM2024/](https://mdbeckman.github.io/JSM2024/)

## NLP for Educational Use

- Natural language processing (NLP) involves how computers can be programmed to analyze language elements
- NLP-assisted feedback for educational use:
  - automated short-answer grading (ASAG) from 2009
  - essays & long-answer tasks earlier
- Human-machine collaboration is a promising mechanism to assist rapid, individualized feedback at scale (Basu, 2013)
- Deep neural networks application since 2016
- Relational (neural) networks

## Motivation for a Relation Network



- Many short-answer datasets have triples
  - Question prompt
  - Rubric OR Reference answers
  - Answer from student
- Transformers are less practical
  - Datasets are often relatively small
  - Learning a single vector can efficiently capture relational structure

**Q:** Susan has samples of 5 different foods. Using only the results of her experiment, how will Susan know which food contains the **most sugar**? (**Gas volume** is evaluated by **tube**)

**R:** Susan should compare the amount of **gas** in each **bag**. The **bag** with the most **gas** contains the **food** with the **most sugar**.

**A:** Susan will know how **much sugar** is in the **foods** by putting each **bag** in a **volume tube**. When her finder stops after pushing the top, the bottom of the part she pushes down will be on a number. That number is the milliliters of **sugar** in the **food**. Whichever number is the highest, that means that **food** has the **most sugar**.

# SFRN Detail (Li et al., 2021)

SFRN is an end-to-end model with 3 components:

- ① encode QRA triples producing vector representations for question (Q), a possible reference (R), and student answer (A)
- ② when relation network includes multiple QRA triples, a learned feature-wise transformation network merges all relation vectors for a student answer into a single relation vector by leveraging attentions calculated by a QRA triple;
- ③ the resulting vector representation is passed as an input to a classifier (i.e., neural network)

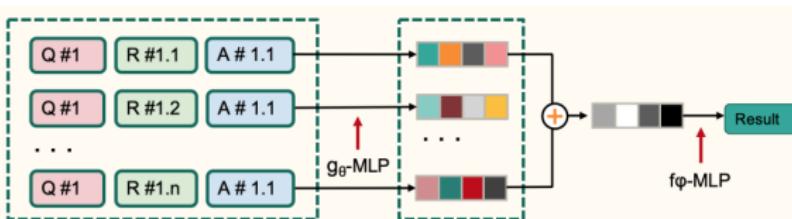


Figure 7: The  $g_\theta$  MLP function computes the relation vector for each [Q,R,A] triple. A set of relation vectors is combined (+) using SFT. The  $f_\phi$  MLP function is the assessment classifier.

# Google Photos Illustration



Same or different person?



Same



Different



Not sure

# Google Photos “Deferral”



Can you identify this person?



Same



Different



Not sure