# Supporting Science Learning and Teaching in Middle School Classrooms Through Automated Analysis of Students' Writing (Collaborative Research: Puntambekar)

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## MOTIVATION & GOALS

- Scientific writing and explanation is a core science practice, but students find it difficult to write and use data as evidence
- Teachers find it challenging to provide comprehensive, constructive feedback in real-time
- NLP technologies can help by providing:
  - Students with timely and personalized feedback
  - Teachers with information about students' progress
- Our goal – Describe how ***PyrEval*** (Gao et al., 2018; Passonneau et al., 2018), an NLP technology, was used to: a) automatically assess students' essays and provided feedback and b) help students write about and learn science

### Research questions:

- How does automated feedback help students explain key ideas in their science essays?
- What are the opportunities and limitations of using automated feedback in classrooms?

## STUDY DESIGN & CONTEXT

- 264 students, 8th-grade, 3 public middle schools
- 3-week physics unit on the Law of Conservation of Energy and energy transformations using a roller coaster simulation
- Students used simulations and a digital notebook to conduct experiments and write essays
- Students wrote three essays:
  - Essay 1 (E1) → Feedback from PyrEval on Content Units (CUs)
  - Essay 2 (E2) → Feedback from PyrEval on CUs
  - Essay 2 revised (E2R)

**Table 1.** *Content units and corresponding feedback*

| Content Unit (CU) | Idea | If absent, the following comment was integrated into the feedback |
|---|---|---|
| **CU0** - Height and changes in energy | As the car moves down the hill, kinetic energy increases and potential energy decreases | "How does height affect PE and KE?" |
| **CU1** - Mass and energy | A cart with greater mass will have greater energy in motion or at rest | "Have you thought about how mass affects PE and KE?" |
| **CU2** - Law of Conservation of Energy | The Law of Conservation of Energy states that energy cannot be created or destroyed, only transformed | "Think about how height affects PE and KE while explaining Law of Conservation of Energy." |
| **CU3** - Initial drop in relation to hill height | The initial drop height should be higher than the hill height | "Think about whether the initial drop height should be higher or smaller than or the same as the hill height." |

## RESULTS

### Repeated measures analysis:

- Conducted with students who completed all 3 essays (*N=228*)
- Students included significantly more CUs in:
  - E2 than in E1 (*M=3.68, SD=2.40*)
  - E2R (*M=5.05, SD=3.02*) than E2 (*M=4.77, SD=2.93*) ($F_{1,228}$=82.1889; *p*<.001; $\eta p^2$=.267)

### Sentence length:

- t-test on essays containing 25 words or fewer per sentence and more than 25 words
- PyrEval identified significantly more CUs when the sentence length was 25 words or less

### Other observations:

- Students often:
  - Used little or no punctuation
  - Repeated ideas across multiple sentences or paragraphs → more difficult for PyrEval to accurately detect
  - Made both successful and unsuccessful revisions based on the feedback

**Table 2.** *Types of successful and less successful responses to feedback*

| More Successful | Less Successful |
|---|---|
| Students:<br>• added new ideas<br>• better elaborated ideas<br>• explained directional relationships based on data<br><br>Suggests that the automated feedback helped students think about and/or understand the relationships between concepts more deeply. | Students:<br>• did not make any revisions<br>• mentioned data from their experiments without explaining relationships<br><br>May imply that students did not fully understand the feedback, understand the content, or thought they addressed the feedback, but did not improve their explainations |

**Table 3.** *Example of a successful student revision based on feedback*

| Revision Type | Essay 1 Response |
|---|---|
| Student improved by explaining the **directional relationship** between variables from E1 to E2 | "I believe the initial drop height should be 5 meters. The PE at the beginning at 5 meters was 2443 Joules and the KE at the bottom of the roller coaster was 2443 Joules. This is going to create enough speed/velocity to get us over our hills, loops, and to the end of the roller coaster since it has the most energy." |
| ***Feedback*** | **Essay 2 Improvement** |
| *Can you explain how height affects PE and KE?* | "When we **increase the height the PE and total energy go up** … . Height is a part of the PE and total energy formula but not the KE formula. For example, when the height was 3 meters, the PE was 2446 Joules and the KE was 0 Joules. But when the height was 5 meters …" |

### Wilcoxon signed-rank tests:

- Significant differences between E1 and E2R for CUs 2, 3, 4, 7, 10, 11, 14
  - Students included more of these CUs in E2R compared to their E1
- No significant differences for the other CUs (0, 1, 5, 6, 8, 9, 12)

**Table 4.** Wilcoxon signed-ranks, adjusted α, and z scores for the significant CUs

| CU and Meaning | Ranks: Positive (P), Negative (N), Ties (T) | | | Adjusted α | *z* score | *p* value |
|---|---|---|---|---|---|---|
| | N | P | T | | | |
| CU 2: The Law of Conservation of Energy states that energy cannot be created or destroyed, only transformed | 4 | 34 | 195 | .0036 | 4.664 | <0.001 |
| CU 3: The initial drop height should be higher than the hill height | 14 | 39 | 181 | .0038 | 3.643 | <0.001 |
| CU 4: Kinetic energy is the energy of an object in motion | 5 | 31 | 198 | .0042 | 3.780 | <0.001 |
| CU 10: The speed of the cart is proportional to the height of the hill | 7 | 46 | 181 | .0045 | 5.082 | <0.001 |
| CU 11: Greater ID or hill height means greater PE | 7 | 45 | 182 | .0050 | 4.919 | <0.001 |
| CU 14: Objects with more mass have greater kinetic energy | 3 | 18 | 213 | .0056 | 3.273 | .001 |
| CU 7: The car has kinetic energy as it goes down the hill | 4 | 18 | 212 | .0063 | 2.985 | .003 |

## NEXT STEPS

**Distributed scaffolding where feedback from the teacher and from PyrEval work synergistically to support students**

- PyrEval can provide:
  - Timely and immediate feedback to students
  - Feedback multiple times without burdening the teacher
  - Class-level summaries of the CUs students included in their essays to the teacher
- The teacher can:
  - Model how to revise
  - Help students reflect on feedback
  - Design instruction based on the trends provided to them from the class-level summaries from PyrEval

## PROJECT TEAM


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