Designing Adaptive Dialogs in Inquiry Learning Environments to Promote Science Learning

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Research Goals

How does an NLP-based adaptive dialog support students to build on their ideas to deepen understanding of the greenhouse effect?

Students need opportunities to reflect on, elaborate, distinguish among, and refine their ideas to develop integrated understanding (Linn & Eylon, 2011). Teachers notice students' sense-making and want to respond to the ideas of each student (Luna, 2018). Using state of the art idea-detection NLP, we designed a **dialog** for **a knowledge integration explanation item about the greenhouse effect** to elicit student ideas and scaffold development of integrated understanding. Students wrote initial explanations, responded to **adaptive guidance tailored to their idea(s),** and revised their explanations.

Detecting Student Ideas & Designing Guidance

"Car on a Cold Day" Problem: On a cold winter day Akbar is walking to his car that is parked in the sun. The sun has been shining on the car for the whole day. How will the temperature inside the car feel?

MC: The temperature inside the car will feel: (a) colder than outside; (b) warmer than outside; (c) exactly the same as outside.

Explain! Use what you've learned about how the Sun warms the Earth to explain your choice.

> "When the car is left out in the winter for a whole week cold air could get trapped inside and have no way to escape making the car colder."

> "The air will be warmer because the light can escape the car but the heat cannot."

> "Because if the sun warms the car then the inside is going to be warm too. I know because when it's hot, the inside of my moms car is always hot too."

Sample of Detectable Ideas. Full rubric includes 21 ideas

Ideas to be Detected	KI	Assigned Adaptive Guidance in Dialogue Round 1
Non-normative conclusion: Car is colder than outside	2	Interesting idea! Can you tell me about how you feel if you are sitting inside a car and the sunlight shines on you through the window?
Inaccurate mechanism: thermal equilibrium idea	2	You're right that heat energy moves from warmer objects to colder ones until they reach the same temperature. Can you tell me more about how energy gets from the sun to the car?
Inaccurate mechanism: talks about conduction	2	You're right that heat energy moves between objects that touch each other. Since the Sun is far away, how can its energy warm the car?
Heat comes directly from the sun	2	Can you tell me more about the forms of energy that come from the sun?

Building an NLP Idea-Detection Model

Data Set: 1,000+ responses from students in schools with demographics similar to those that will use the dialog, collected in prior research.
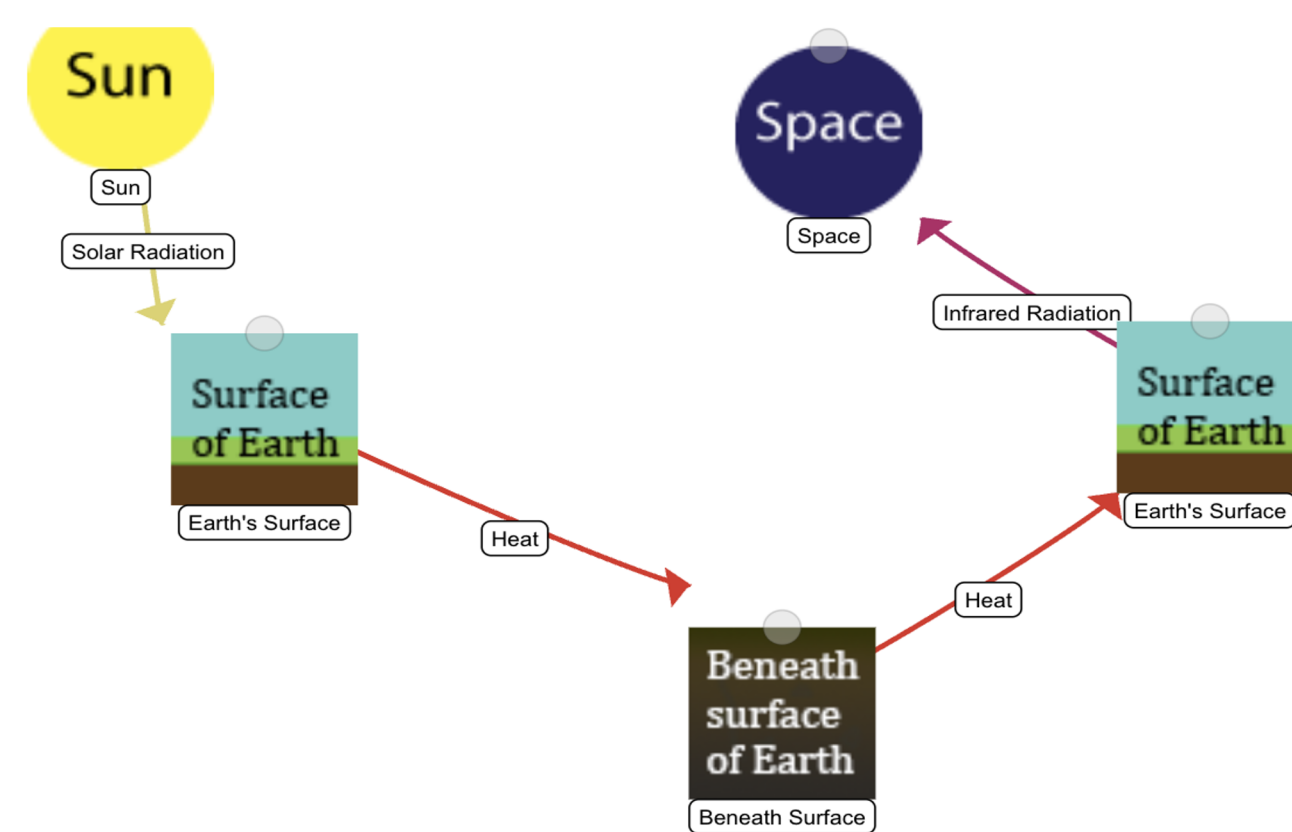
Data Annotation: Two science ed. researchers reach IRR using the idea-detection and KI rubrics. Researchers annotate student responses to identify expression of ideas and assign an overall KI score.

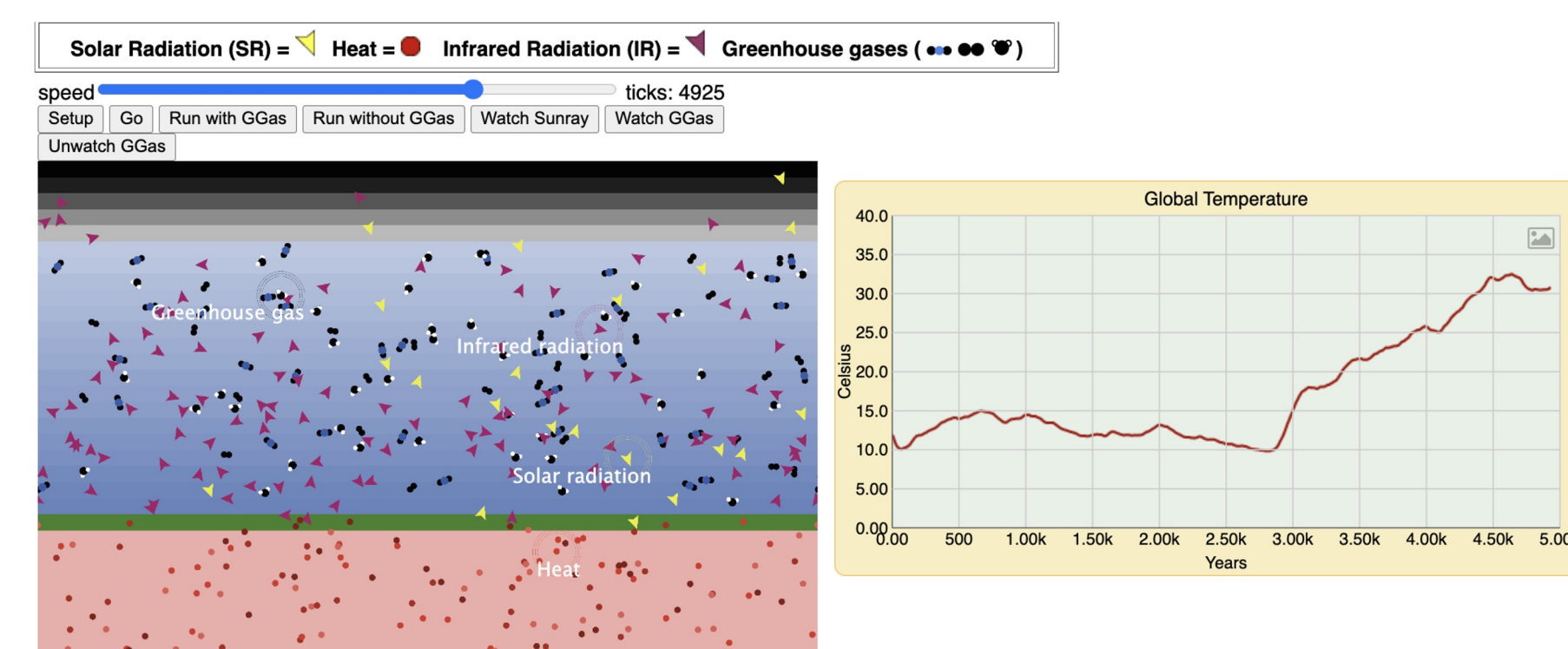**NLP Model**: Idea-Detection Model: F-score=.592; KI Model QWK=.889
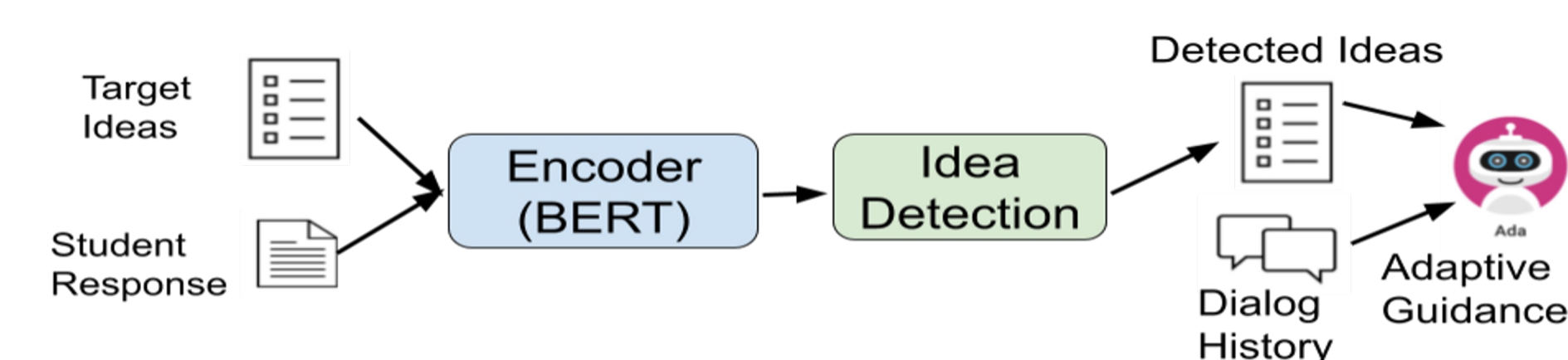
Embed the Dialog in Urban Heat Islands Inquiry Unit

Lesson 1: How does the Sun warm the Earth?

Lesson 2: What affects how much heat stays?

Lesson 3: Chat with a Thought Buddy about Your Ideas for Car Item

- The student selected an avatar from a given set as their "thought buddy". This student chose Emina.
- NLP detects idea #4 in the student response and responds with an adaptive prompt, tailored to the idea. It is designed to affirm their idea, and elicit further reasoning.
- The computer responds with a generic prompt that is the same for all students and is designed to elicit additional ideas. (This prompt is adaptive in current work)

Revised explanation:

The car probably absorbed some of the heat from the sun but not all of it so it will be warmer than the air outside. Outside of the car it still is sending heat outside the earth's atmosphere releasing some of the temperatures, so it is cooler outside.

> Revise your explanation using ideas from the dialog

Lesson 4: How does climate change impact humans?

Lesson 5: Develop evidence-based solutions to UHI in your community

> Some neighborhoods become heat islands because of dark buildings, concrete, dark rooftops and tall building all put close together. These areas are hotter because of less circulation and heat becoming trapped in that area of the city.

Classroom Research

Participants: 1 9th grade teacher and their 89 students used the Global Climate Change and Urban Heat Islands (https://wise.berkeley.edu) as a part of their science curriculum

Data collection: Initial explanation, response to the adaptive prompt, response to the generic prompt, revised explanation.

Embedded in the unit; Repeated at the end of the unit

Data analysis: We analyzed the automated KI scores (1-5 scale) and ideas detected for each student's initial explanation, response to the adaptive and generic prompts, and their revised explanation. We used a revision rubric to categorize how students integrated ideas when revising.

Knowledge Integration Rubric for Car on a Cold Day

	KI Level	Student Examples
1	**Off-task or Irrelevant**	"I don't know"
2	**Vague or incomplete** ideas or links	"the air is warmer inside because it had no contact with cold air outside" "The car is hotter because it's been parked in the sun." [accurate conclusion, no mechanism]
3	**Partial link** Isolated normative idea OR Normative and non-normative ideas linked	"Since cars absorbed heat doesn't go anywhere, it warms up the car inside rather than the outside" [heat is trapped inside of car] "Energy from the sun warms up the car" [explains energy source]
4	**Full link** One complete and valid connection between 2 ideas	"the temperature will be hotter than the outside because the heat inside the car cant escape and is trapped inside, the heat is added and added until is hotter than the outside" [heat is trapped + reabsorbed]
5	**Complex links** Two or more scientifically complete and valid connections	"Energy comes from the sun and is absorbed in the car to turn to heat. The heat is stuck in the car because the windows trap it making it hotter" [energy from sun + solar radiation to heat + heat is trapped]

Revision Rubric for Dialog

| Category Description	Initial Response	Dialog Response	Revised Response
Integrated New Connects idea elicited in the dialog to their initial idea by elaborating, extending or contrasting.	I think it will be warmer because any heat will get trapped inside the car causing it to be warmer	The heat from the sun reflects off the car and some gets absorbed by the surface what heat gets absorbed will get trapped inside the car making it warmer	I think that the car will be warmer because **the heat from the sun reflects off of the car and also gets absorbed by the car** which gets trapped in the car **causing it to heat up** and be warmer than outside
Added Disconnected Writes new response or adds new idea without editing or connecting to the initial response.	As the SR enters the Earths environment as some of the SR is turned into IR and is then reflected or absorbed and turned to heat.	The sun will heat up the car.	As the SR enters Earth atmosphere and turns into IR and later into heat. **The car absorbs the heat from the sun rays, causing it to be hotter then weather outside.**
Integrated Redundant Adds an idea that repeats the initial idea or paraphrases, does not add new science idea	If the weather outside is cold, the the air inside the car will also be cold since there is no sun to heat it up.	Dialog response: it would be cold even if the sun is shining	The weather outside will be the same as inside.

Results: Eliciting and Building on Ideas

The **66 students expressed 70 new ideas** in their revised explanations. The **adaptive prompt was more effective than the generic prompt** in eliciting new, normative ideas.
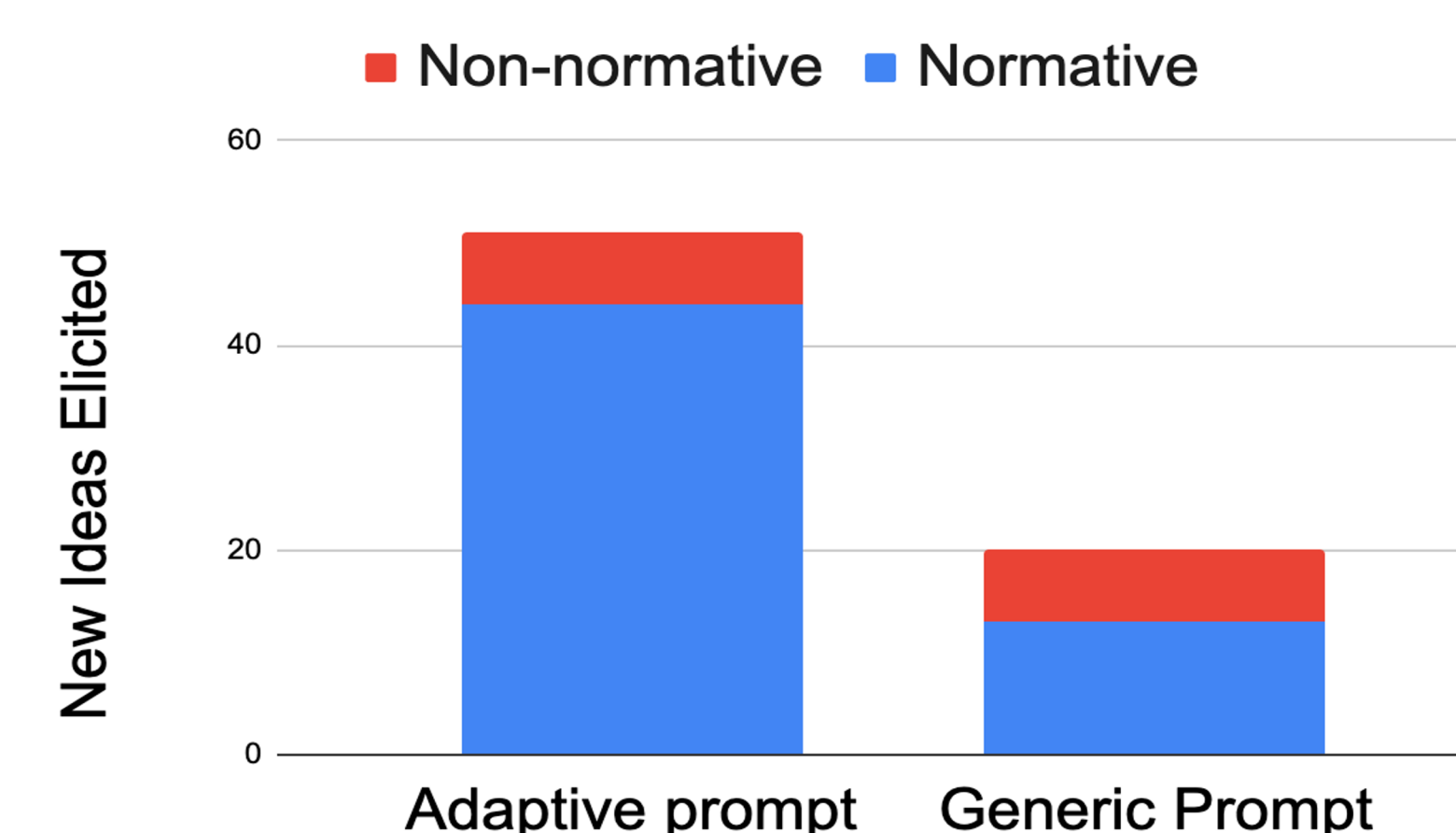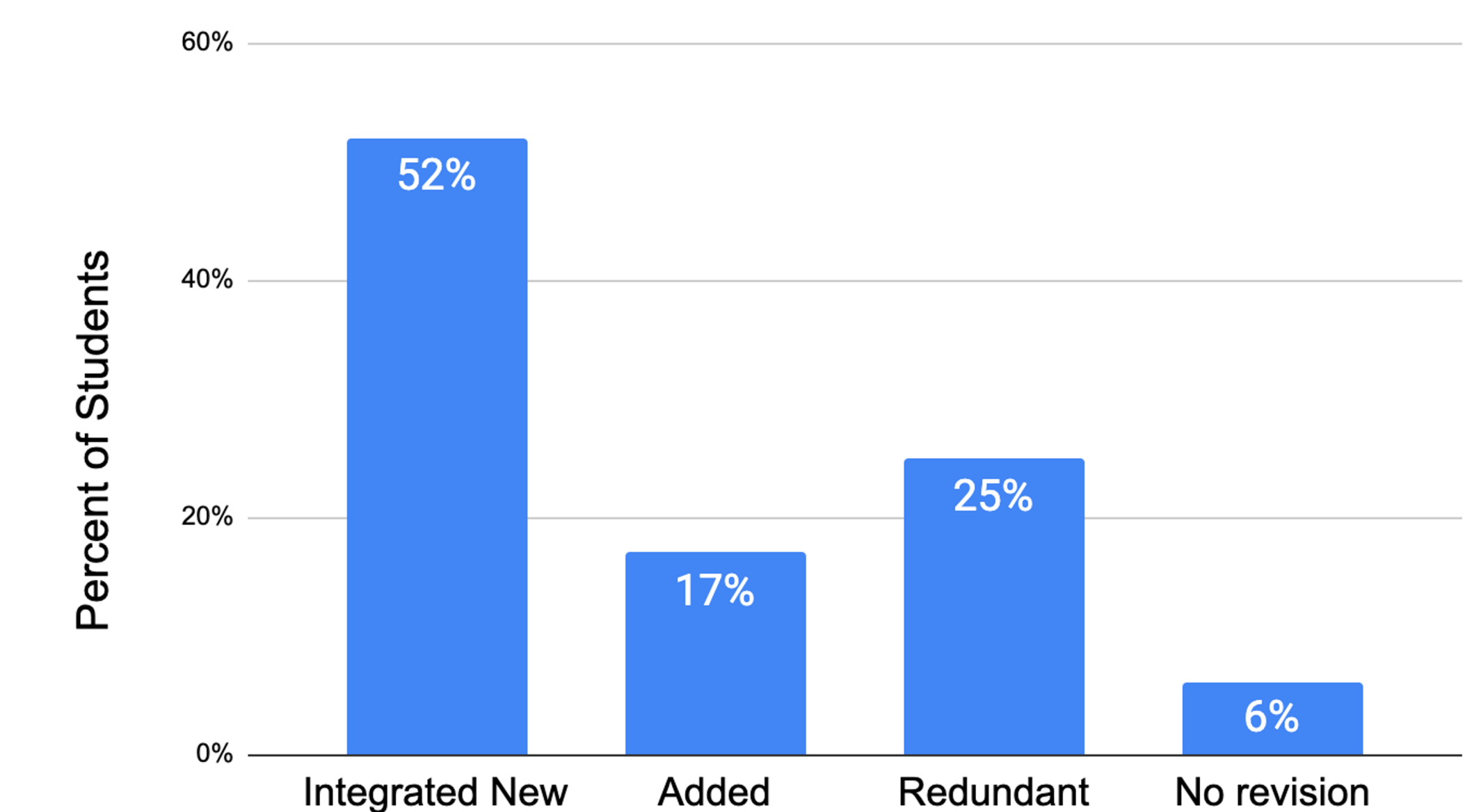

Results: Integrating Ideas in Revision

- Students significantly improved their explanations from before the dialog to after.
- Shifted from expressing mostly vague ideas, to expressing one normative idea.
- Suggests **students elaborated their initial idea to add a normative mechanism.**
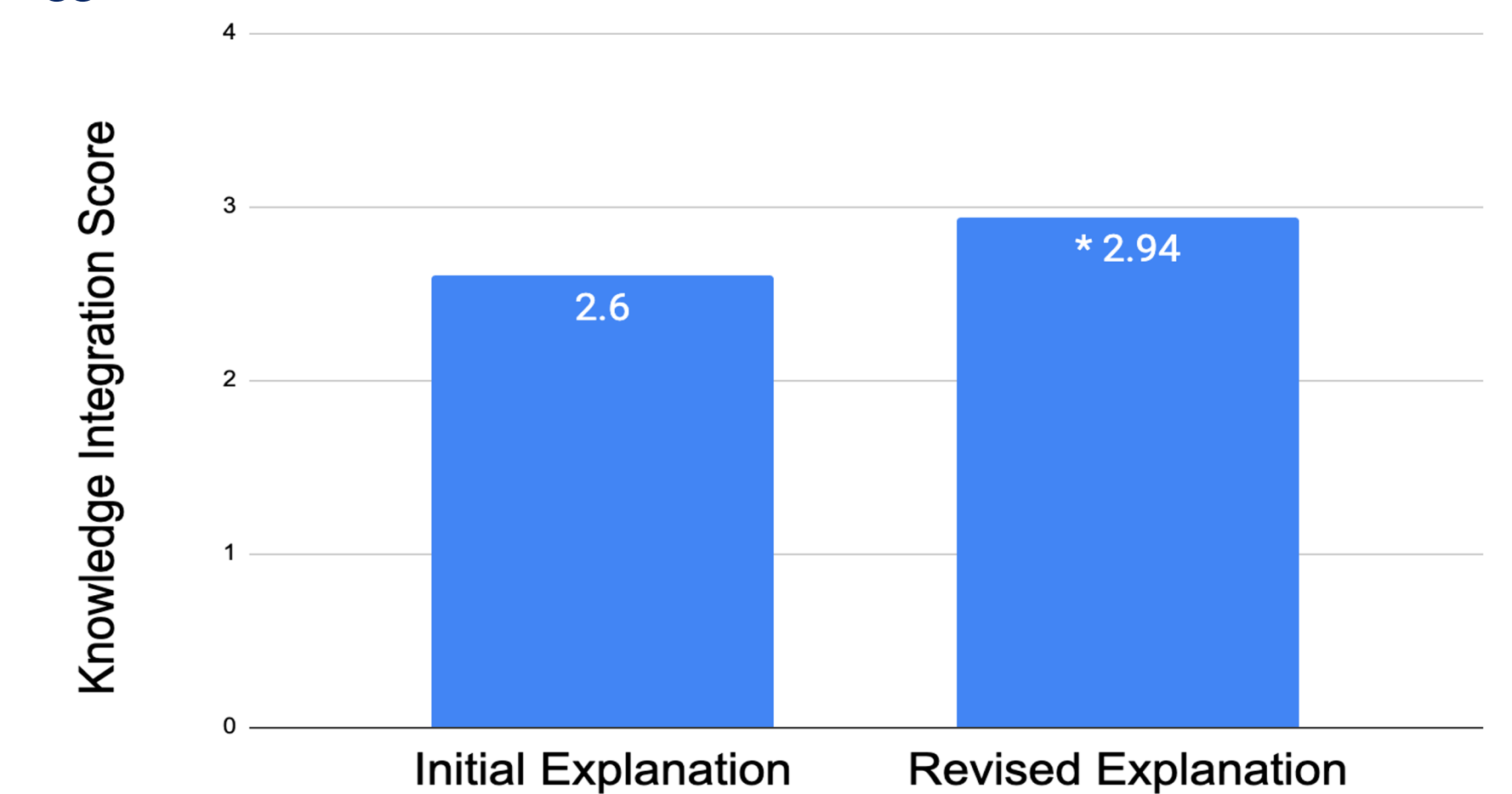
- Majority of students revised their initial explanation after the dialog (94%), a higher rate of revision compared to prior studies reporting under 50% of students engaging in sustained revision when an activity calls for it.
- More students engaged in making integrated revisions than in prior studies (40% avg)

Results: Integrating Ideas in Revision

> "Talking to someone gives you more motivation to keep going. It gave me a few ideas."

> "I guess these questions were more like what a professional would ask, because it seems like it knows what it is doing. Where if I was talking to my friends, they would expect me to know the answer, but these seem like they are asking me to make me think more."

> "It ended the conversation a little soon. I had more ideas to talk about. "

Conclusions and Future Directions

- The NLP-based idea-detection dialog **engaged the majority of students in revising** and **improving** their science explanations.
- The majority of the students **elaborated the mechanism underlying their initial idea** by incorporating a new idea elicited in the dialog into their revised explanation
- Future directions: Combining the KI score and Idea Detection to personalize guidance; Studying additional NLP modeling techniques to identify the lower frequency ideas