

Identifying science concepts and student misconceptions in an interactive essay writing tutor

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Example Student Misconceptions

Common student misconceptions:

- Water is food for plants
- A constant force is needed to keep an object moving at constant speed
- Earth's plates are located deep within the earth and are not exposed at the earth's surface
- In sexually reproducing organisms, half of the organism's body cells contain DNA from the mother and half contain DNA from the father

Persistent: $\geq 50\%$ of 9-12 graders (AAAS Project 2061)

Open Educational Resources (OERs)

“Earth’s plates are feet thick”



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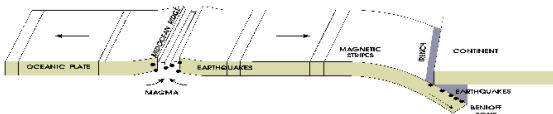
Photos

Publications

Earthquakes and Plate Tectonics

The world's earthquakes are not randomly distributed over the Earth's surface. They tend to be concentrated in narrow zones...

We now know that there are seven major crustal plates, subdivided into a number of smaller plates. They are about 80 kilometers thick, all in constant motion relative to one another, at rates varying from 10 to 130 millimeters per year. Their pattern is neither symmetrical nor simple. As we learn more and more about the major plates, we find that many complicated and intricate maneuvers are taking place. We learn, too, that most of the geological action - mountains, rift valleys, volcanoes, earthquakes, faulting - is due to different types of interaction at plate boundaries.



A Misconception-Driven Essay Tutor

Goal:

- Correct student science misconceptions

Context:

- Students writing essays on science topics

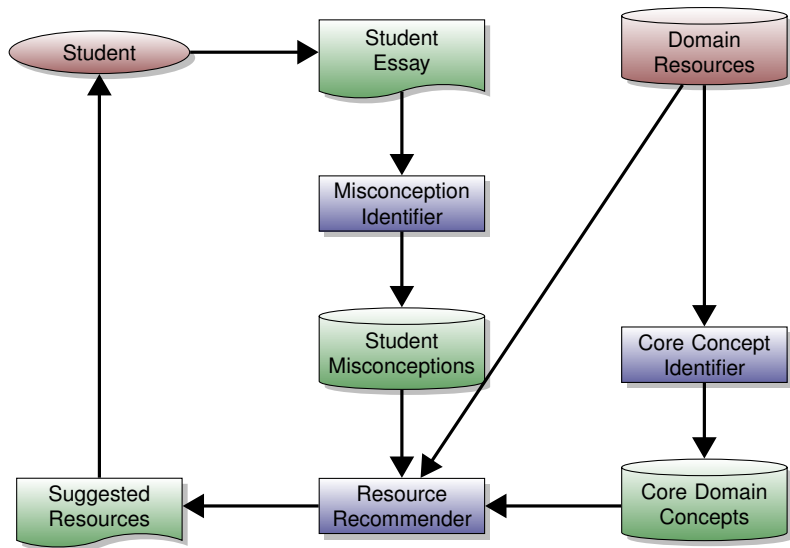
CLICK (de la Chica et al. 2008a):

- **C**ustomized **L**earning **S**ervice for **C**oncept **K**nowledge
- Addressed misconceptions via concept maps

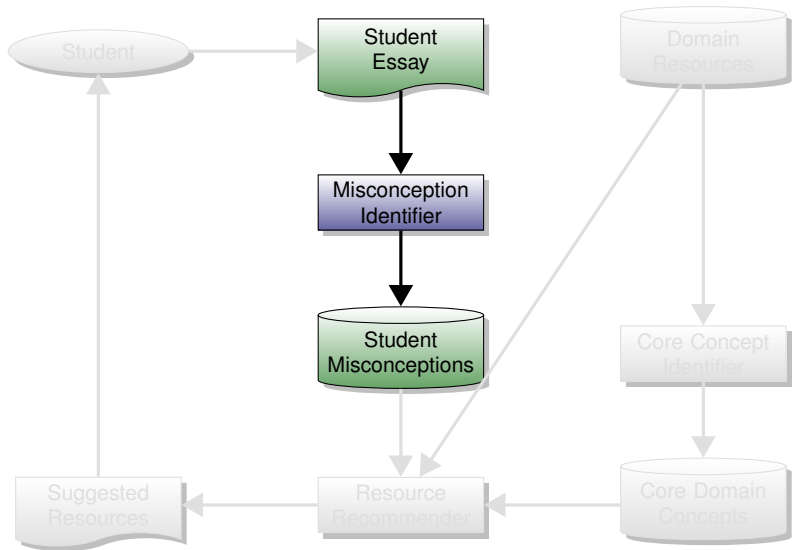
CLICK2 (current work):

- Address misconceptions directly from text
- Establish baselines for various components
- End-to-end system for use in learning study

A Misconception-Driven Essay Tutor



Misconception Identification



Misconception Identification

Task:

- Given student sentences S and domain sentences D
- Determine which sentences $s \in S$ are misconceptions

Coverage model: lexical coverage + lexical expansion
(Shnarch, Goldberger, and Dagan 2011):

$$\text{SCORE}(s) = \frac{|s \cap d|}{|s|} \quad d = \bigcup_{s' \in D} \text{EXPAND}(s')$$

Retrieval model: information retrieval + lexical expansion:

$$\text{SCORE}(s) = \sum_{s' \in D} \text{SCORE}_{\text{lucene}}(s, \text{EXPAND}(s'))$$

AAAS Science Assessments Data

Idea: The outer layer of the earth – including the continents and the ocean basins – consists of separate plates.

- The rock layer beneath the surface of the earth is divided into massive sections of solid rock, called “plates.” The plates fit closely together such that all of the edges of a plate touch the plate next to it. . .

Items:

- PT009001: Earth’s plates are made of solid rock, and they can be seen where they are not covered by soil, loose rocks, or water.
- PT005001: Both ocean basins and continents are part of earth’s plates. . .

Misconceptions:

- PTM104: Earth’s plates are located deep within the earth and are not exposed at the earth’s surface
- PTM011: Plates are made of melted rock. . .

Misconception Identification Results

Evaluation setup:

- Domain knowledge \approx AAAS idea + sub-ideas
- Student essays \approx AAAS items + misconceptions

EXPAND chosen on development data:

- WordNet paths of length ≤ 4 of synsets, derived forms, hyponyms, meronyms

Results:

<i>Model</i>	<i>MAP</i>	<i>P@1</i>
Randomly ordered	0.487	0.487
Coverage model	0.603	0.578
Retrieval model	0.644	0.625

Correcting Misconceptions

Task:

- Given misconception m and domain concepts C
- Determine which concepts $c \in C$ align to m

Example:

- $m =$ *There are no single-celled organisms*
- $c =$ *Different organisms range in the number of cells they have, from only one cell to many millions.*

Model: information retrieval + lexical expansion:

$$\text{SCORE}(c) = \text{SCORE}_{\text{lucene}}(m, \text{EXPAND}(c))$$

Correcting Misconceptions Results

Evaluation setup:

- Student misconception \approx AAAS misconception
- Domain concepts \approx all AAAS items from same idea
- Correct concept(s) \approx aligned AAAS item(s)

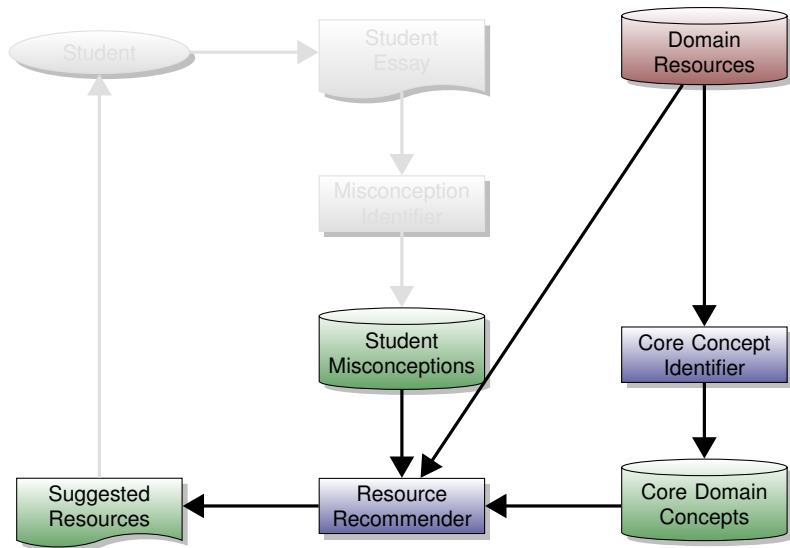
EXPAND chosen on development data:

- WordNet synset lemmas

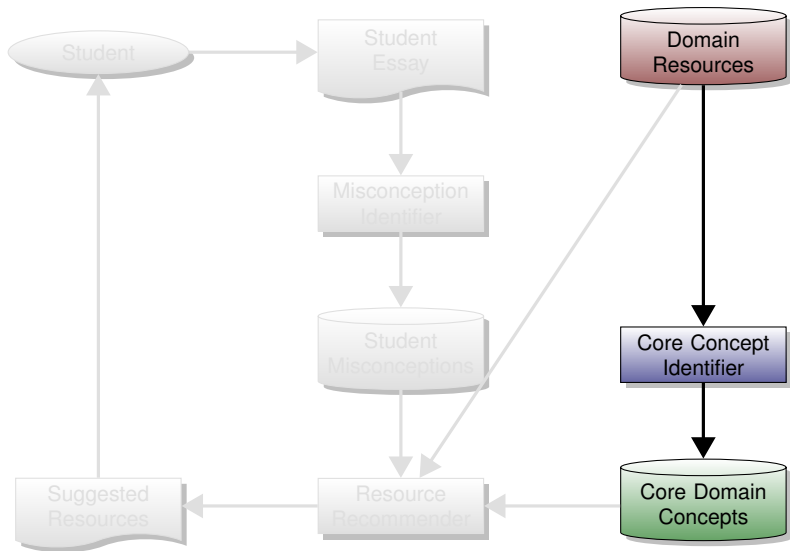
Results:

<i>Model</i>	<i>MAP</i>	<i>P@1</i>
Randomly ordered	0.259	0.259
Retrieval model	0.704	0.611

Resource Recommender



Core Concept Identification



Core Concept Identification

Task:

- Given domain sentences D
- Determine which sentences $s \in D$ are “core”
- Coreness = centrality to AAAS learning goals

Example (for the “Cells” domain):

- CORE: *Cells vary in size, shape, and specialized functions.*
- NOT-CORE: *Prokaryotes were the only form of life on Earth for millions of years.*

Model:

- COGENT (de la Chica et al. 2008b)
- Extractive summarizer including educational features

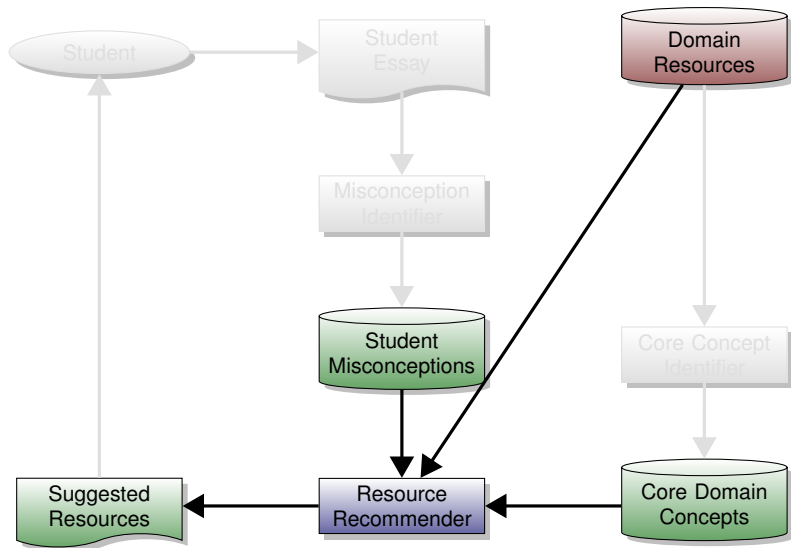
Core Concept Identification Results

Evaluation setup (Foster et al. 2012):

- Sentences from resources on *Plate Tectonics*, *Weather and Climate*, and *Biological Evolution*
- Experts rated coreness of sentences on 1-4 scale
- COGENT extracts summary of size N%

Domain	Best N%	Average coreness
<i>Plate Tectonics</i>	0.5%	3.3
<i>Weather and Climate</i>	0.5%	3.1
<i>Biological Evolution</i>	2.5%	2.5

Resource Recommendation



Resource Recommendation

Task:

- Given student misconceptions M
- Given domain resources D
- Given core concepts C
- Prioritize misconceptions and suggest resources

Current approach:

- Sequence core concepts
- Align misconceptions to concepts (*covered earlier*)
- Retrieve resources for misconceptions

Sequencing core concepts

Data:

- Experts annotated possible core concept sequences

Model: COGENT (de la Chica et al. 2008b)

Model: word-based pair-wise classifier

- Pair-wise classification ($C_1 < C_2$ vs. $C_1 \geq C_2$)
- Classifiers: Naive Bayes, MaxEnt, SVM
- Training on proxy task:
 - Sentence pair classification: middle vs. high school
- Features (Tanaka-Ishii et al. 2010)
 - Local word count (count of word in sentence)
 - Global word count (log ratio: sentence vs. Gigaword)

Results: COGENT gives best accuracy (57-63%)

Retrieving Resource Recommendations

Model:

- Misconception as query to index of resources

Data:

- Experts aligned 11 misconceptions to ≥ 1 of 37 pages

Results:

- P@5 of 32% (random baseline of 9%)

Summary and Future Work

A misconception-driven essay writing tutor:

- Identifies science misconceptions
- Identifies core science concepts
- Recommends resources to address misconceptions

Ongoing work:

- Learning study to measure effect on students

Future work:

- Deeper models for misconception identification
- Integrating misconception and concept ordering
- Providing useful snippets in recommendations

Thanks!

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