LSA Applications in Learning Environments and Discourse Technologies

Art Graesser

Psychology, Computer Science, & the Institute for Intelligent Systems

Funding: National Science Foundation, Office of Naval Research, Department of Defense, & Institute for Education Sciences
My LSA Collaborators:
Zhiqiang Cai & Xiangen Hu
Who is that character in the middle?
Overview

• Setting the stage:
  – Research centers at University of Memphis
  – Learning and discourse technologies we have developed

• Some uses of LSA in learning environments

• Learner feedback

• Learner emotions
FedEx Institute of Technology
Institute for Intelligent Systems
Memphis Systems

AutoTutor

Good Job!

iSTART

HURA Advisor
Ideal Vision

electronic Personal Advisor for Learning

24x7 Dialog as Tutor & Mentor

- Animated conversational agent
- Intelligent human-computer interface
- Intelligent sensing

Maintains Learner Profile

- Demographic data
- Subject matter knowledge
- Performance on tests
- Cognitive/metacognitive abilities
- Motivation and emotion
- Personality traits
- Dialog history

Large Courseware Repository

- Computer-based training
- Multimedia
- Interactive simulation
- Intelligent tutoring systems
- Games
- etc.

Intelligent Action Selection

- Next learning environment
- Next problem to work on
- Next dialogue act:
  - Suggestion, hint
  - Question
- Distributed over time
Exploring a Sea of Animated Conversational Agents

AutoTutor  Adele  STEVE  Carmen  SI Agent  Laura
BEAT  PKD Android  Leonardo  iMAP  Casey
iSTART  TLTS  Spark  MRE
Coh-Metrix

Analysis of text on language and cohesion

Google Coh-Metrix

Okay, let's begin. Suppose a runner is running in a straight line at constant speed, and the runner throws a pumpkin straight up. Where will the pumpkin land? Explain why.

The pumpkin will land at the point directly below the point it was thrown from.

Table:

<table>
<thead>
<tr>
<th>Text on a page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The pumpkin will land at the point directly below the point it was thrown from.</td>
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<table>
<thead>
<tr>
<th>Measures from Coh-Metrix</th>
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<tbody>
<tr>
<td><strong>Source</strong></td>
</tr>
<tr>
<td><strong>Job Code</strong></td>
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<td><strong>Adjacent anaphor reference</strong></td>
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<td><strong>Adjacent argument overlap</strong></td>
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<tr>
<td><strong>Argument overlap</strong></td>
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<tr>
<td><strong>Adjacent stem overlap</strong></td>
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<tr>
<td><strong>Stem overlap</strong></td>
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<td><strong>Content word overlap</strong></td>
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<table>
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<tr>
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<th>Value</th>
<th>Description</th>
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<td>Anaphor reference, adjacent, unweighted</td>
</tr>
<tr>
<td>CREFPau</td>
<td>0.031</td>
<td>Anaphor reference, all distances, unweighted</td>
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<tr>
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<tr>
<td>CREFC1u</td>
<td>0.038</td>
<td>Proportion of content words that overlap between adjacent</td>
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</table>
### Example Coh-Metrix Measures

#### Basic Measures
- Words per turn
- Turns per problem
- Type-token ratio
- Syntactic complexity
- Grade level (Flesch-Kincaid)

#### Co-reference & Semantics
- Argument overlap
- Stem overlap
  - (lemmas: *run, runs, runner*)
- Latent semantic analysis (LSA)

#### Connectives & Negations
- All connectives
- Logical operators
  - *and, or, therefore, if, then, not*
- Negations

#### Causal Content
- Causal particles
  - Connectives (*because, so*)
  - *Cause, make, enable*
- Event verbs (Miller’s WordNet)
- Causal cohesion
  - Causal particles/event verbs
What is AutoTutor?

- Learn by conversation in natural language


Talking head
- Gestures
- Synthesized speech

Presentation of the question/problem

Dialog history with
- tutor turns
- student turns

Student input (answers, comments, questions)
Expectations and misconceptions in Sun & Earth problem

**EXPECTATIONS**

- The sun exerts a gravitational force on the earth.
- The earth exerts a gravitational force on the sun.
- The two forces are a third-law pair.
- The magnitudes of the two forces are the same.

**MISCONCEPTIONS**

- Only the larger object exerts a force.
- The force of earth on sun is less than that of the sun on earth.
Computer Literacy

How is the packet switching model of message transmission like the postal system?

Packets are sent to intermediate destinations before being routed to their final destination.
What does AutoTutor do?

- Asks questions and presents problems
- Evaluates meaning of the learner’s answers
- Gives feedback on answers
- Display facial expressions with emotions
- Nods and gestures
- Hints
- Prompts for specific information
- Adds information that is missed
- Corrects bugs and misconceptions
- Answers student questions
- Holds mixed-initiative dialog in natural language
Expectation and Misconception-Tailored Dialog: Pervasive in AutoTutor & human tutors

- Tutor asks question that requires explanatory reasoning
- Student answers with fragments of information, distributed over multiple turns
- Tutor analyzes the fragments of the explanation
  - Compares to a list of expected good idea units
  - Compares to a list of expected errors and misconceptions
- Tutor posts goals & performs dialog acts to improve explanation
  - Fills in missing expected good idea units (one at a time)
  - Corrects expected errors & misconceptions (immediately)
- Tutor handles periodic sub-dialogues
  - Student questions
  - Student meta-communicative acts (e.g., What did you say?)
Major Dialogue Moves

- Positive immediate feedback: “Yeah” “Right!”
- Neutral immediate feedback: “Okay” “Uh huh”
- Negative immediate feedback: “No” “Not quite”

- Pump for more information: “What else?”
- Hint: “What about the earth’s gravity?”
- Prompt for specific information: “The earth exerts a gravitational force on what?”
- Assert: “The earth exerts a gravitational force on the sun.”

- Correct: “The smaller object also exerts a force.”
- Repeat: “So, once again, …”
- Summarize: “So to recap,…”
- Answer student question:
How to cover a single expectation

The earth exerts a gravitational force on the sun.

• Who articulates it: student, tutor, or both?
• Fuzzy production rules drive dialog moves
• Progressive specificity drives dialog moves
  Hint → Prompt → Assertion cycles
• Strategies tailored to student knowledge and abilities
Managing One AutoTutor Turn

- Short feedback on the student’s previous turn
- Advance the dialog by one or more dialog moves that are connected by discourse markers
- End turn with a signal that transfers the floor to the student
  - Question
  - Prompting hand gesture
  - Head/gaze signal
Fishics AutoTutor

Andrew Olney
What about Learning Gains?
<table>
<thead>
<tr>
<th>Effect Size</th>
<th>Tutor Type and Description</th>
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<tbody>
<tr>
<td>.42</td>
<td>Unskilled human tutors</td>
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<tr>
<td></td>
<td>(Cohen, Kulik, &amp; Kulik, 1982)</td>
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<tr>
<td>.80</td>
<td>AutoTutor (14 experiments)</td>
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<tr>
<td></td>
<td>(Graesser and colleagues)</td>
</tr>
<tr>
<td>1.00</td>
<td>Intelligent tutoring systems</td>
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<tr>
<td></td>
<td>PACT (Anderson, Corbett, Aleven, Koedinger)</td>
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<td></td>
<td>Andes, Atlas (VanLehn)</td>
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<td></td>
<td>Diagnoser (Hunt, Minstrell)</td>
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<tr>
<td></td>
<td>Sherlock (Lesgold)</td>
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<tr>
<td>(?)</td>
<td>Skilled human tutors</td>
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<tr>
<td></td>
<td>(Bloom, 1987)</td>
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</tbody>
</table>
Conceptual Physics
(Graesser, Jackson, et al., 2003)

Three tutoring conditions

- AutoTutor
- Read textbook
- Read nothing
Example Multiple Choice Test Item
(similar to Force Concept Inventory)

As a truck moves along the highway at constant speed, a nut falls from a tree and smashes into the truck’s windshield. If the truck exerts a 1,000 N force on the nut, what is the magnitude of the force that the nut exerts on the truck?

a) 1,000 N
b) less than 1,000 N
c) N (the nut does not exert a force on the truck)
d) greater than 1,000 N (because the nut hit the truck, it exerts a greater force on the truck than the truck exerts on the nut)
Multiple Choice Test on Physics

- **AutoTutor**
  - Pretest: 0.6
  - Posttest: 0.7
  - Adjusted posttest: 0.7

- **Read Textbook**
  - Pretest: 0.5
  - Posttest: 0.6
  - Adjusted posttest: 0.6

- **Read nothing**
  - Pretest: 0.6
  - Posttest: 0.6
  - Adjusted posttest: 0.6
Evaluations
Conceptual Physics
(VanLehn, Graesser, et al., in press)

Three conditions
1. Human tutors
2. Why/Atlas
3. Why/AutoTutor
Physics Tests

Pretest
Posttest
Adjusted Posttest

Human Tutor
Why Atlas
Why AutoTutor

Proportions
How does AutoTutor compare to comparison conditions on tests of deep comprehension?

- 0.80 sigma compared to pretest, doing nothing, and reading the textbook
- 0.22 compared to reading relevant textbook segments
- 0.07 compared to reading succinct script
- 0.13 compared to AutoTutor delivering speech acts in print
- 0.08 compared to humans in computer-mediated conversation
- -0.20 compared to AutoTutor enhanced with interactive 3D simulation

ZONE OF PROXIMAL DEVELOPMENT
Analyses on Covering Expectations with LSA
Question: Suppose a man is running with a pumpkin and throws it in the air. Where will the pumpkin land?

Student’s Contribution:

**Answer:** As zero force is acting on it, it will have constant velocity hence it will land on his head.
**Answer:** As zero force is acting on it, it will have constant velocity hence it will land on his head.

**Expectation-1** The pumpkin has the same horizontal velocity as the runner.

**Expectation-2** Zero force is needed to keep an object going with constant velocity.

**Expectation-3** Vertical forces on the pumpkin do not affect its horizontal velocity.
**Hint:** What can you say about the horizontal velocity of the pumpkin?

**Student contribution:** The horizontal velocity of the pumpkin is the same as the runner.
LSA Evaluation

**Answer:** The horizontal velocity of the pumpkin is the same as the runner.

**Expectation-1** The pumpkin has the same horizontal velocity as the runner.

**Expectation-2** Zero force is needed to keep an object going with constant velocity.

**Expectation-3** Vertical forces on the pumpkin do not affect its horizontal velocity.
How LSA evaluates

• Expectation is covered when:
  • \( \cos(S, E) > T \)
  • S = student input
  • E = expectation
  • T = threshold
LSA Scoring of Learner Contributions
(Graesser, Penumatsa, Ventura, Cai, & Hu, 2007)

- LSA successes in AutoTutor
  - Coverage of expectations over dialogue
  - User modeling
  - Essay grading in physics & computer literacy \((r = .5)\)

- Value in decomposing ideal answers into sentences
  - No incremental value in syntactic decomposition
  - Syntactic analyses useless in speech recognition

- Student sentence-to-expectation matches with LSA are limited \((r = .3)\)
  - Word overlap and ordering have added value
Signal Detection Analyses
(Student essay to expectation)

![Graph showing hit rate, false alarm rate, and d' score against LSA threshold.](image-url)
Correlations between dialog moves and student ability (Jackson & Graesser, 2006)
Role of Feedback

Dissertation by Tanner Jackson
Content versus Progress Feedback

• Content Feedback
  • Qualitative information about the subject matter.
  • Local: Highlighting important words
  • Global: Summary of ideal answer

• Progress Feedback
  • Quantitative assessment of the student’s advancement through the material being covered
  • How far the student has come and how much farther they have to go?
  • Local: Progress on individual expectations.
  • Global: Points scored in session.
Suppose a boy is in a free-falling elevator and he holds his keys motionless right in front of his face and then lets go. What will happen to the keys? Explain why.

Log of previous responses:
Tutor: Suppose a boy is in a free-falling elevator and he holds his keys motionless right in front of his face and then lets go. What will happen to the keys? Explain why.
Student: the keys will fall to the floor of the elevator.
Tutor: You've established that.
Tutor: The keys will remain in front of the boy's face at all times during the fall.
Tutor: Yeah...
Tutor: Is there anything you can add to this?
Suppose a boy is in a free-falling elevator and he holds his keys motionless right in front of his face and then lets go. What will happen to the keys? Explain why.
Feedback Experiment \((n=83)\)

- **Pretest**
  - 26 conceptual physics questions \((\text{counterbalanced})\)

- **Interact with a version of AutoTutor**
  - All Feedback
  - Progress Only
  - Content Only
  - No Feedback

- **Posttest**
  - 26 conceptual physics questions \((\text{counterbalanced})\)
Adjusted Posttest Performance

- All Feedback
- Content Only
- Progress Only
- No Feedback
The Tutor Held my Interest

Rated from 1=Strongly Disagree to 6=Strongly Agree

- All Feedback
- Content Only
- Progress Only
- No Feedback

Institute for Intelligent Systems
Conclusions about Feedback Study

• **Content Matters:** Content feedback improved learning gains.

• **Progress feedback** had little to no effect on either learning or motivation.

• **Negative relationship between liking and learning**
  – Content feedback provides an increase in learning gains, but a decrease in user satisfaction.

• **Adding progress feedback to the content feedback** may have overloaded or distracted the learners.
Role of Emotions


Affective States

**BOREDOM**
Being weary or restless through lack of interest

**CONFUSION**
A noticeable lack of understanding

**DELIGHT**
A high degree of satisfaction

**FLOW**
A state of interest that results from involvement in an activity

**FRustrATION**
Dissatisfaction or annoyance

**SURPRISE**
Wonder or amazement, especially from the unexpected
An Emotion-sensitive AutoTutor

• Cognitive disequilibrium, confusion, and being stuck (Graesser, Gray, Litman, Mandler, Piaget, Picard, Stein)

• Flow versus boredom and zone of proximal learning (Csikszentmihalyi, Metcalfe)

• Academic risk taking in the face of challenges, impasses, and failure, with adventuresome versus cautious learners (Meyer, Turner)

• Empathy and motivation (Dweck, Lepper, Miller, Read)
How might AutoTutor be Responsive to the Learner’s Affect States

1) If learner is **frustrated**, then AutoTutor gives a hint.

2) If **bored**, then some engaging razzle dazzle

3) If **flow/absorbed**, then lay low

4) If **confused**, then intelligently manage optimal confusion
How do emotions correlate with learning gains?

Regression analysis

Posttest = 0.30 \times \text{Pretest} + 0.42 \times \text{Confusion}

R^2 = 0.33
QUESTION

How well can humans classify emotions of learners?


Interjudge Reliability
Mandatory versus Voluntary

Cohen's Kappa

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Mandatory</th>
<th>Voluntary</th>
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<tbody>
<tr>
<td>Self-Peer</td>
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<td>0.1</td>
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<tr>
<td>Self-Judge1</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Self-Judge2</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Peer-Judge1</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Peer-Judge2</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Judge1-Judge2</td>
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## Comparison with Other Affect Judgment Efforts

<table>
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<tr>
<th>Study</th>
<th>Kappa</th>
<th>Emotions</th>
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<tr>
<td><strong>Present study</strong></td>
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<td>Confusion, frustration, etc.</td>
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<tr>
<td>Ang, Dhillon, Krupski, Shriberg, &amp; Stolcke (2002)</td>
<td>.47</td>
<td>Frustration, Annoyance</td>
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<td>Shafran, Riley, &amp; Mohri (2003)</td>
<td>.32-.42</td>
<td>-</td>
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<td>Narayanan</td>
<td>.45-.48</td>
<td>Negative Emotions</td>
</tr>
</tbody>
</table>
QUESTION
How well can computers with sensing devices detect emotions of learners?


Conversational Cues

- **Temporal Information**
  - Turn number in problem
  - Problem number in session

- **Student Verbosity**

- **Student Answer Quality**
  - Local LSA
  - Global LSA

- **Tutor Directness**

- **Tutor Feedback**
Correlations with Emotions
[D’Mello et. al., 2006; Graesser et. al., in press]

Emote-Aloud Study (N = 7)

- Correlations with Emotions:
  - Eureka: 0.25
  - Confusion: 0.1
  - Frustration: 0.15

* $p < .05$
Conversational cues can detect learner’s affect

<table>
<thead>
<tr>
<th>Classification algorithm</th>
<th>Self</th>
<th>Peer</th>
<th>Judge-1</th>
<th>Judge-2</th>
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<tr>
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<td>Support vector machines</td>
<td>.36</td>
<td>.37</td>
<td>.49</td>
<td>.48</td>
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</tbody>
</table>

Contrasting 4 equally likely emotions: Chance = .25
Bayesian Diagnosticity

Facial Expressions = 2.935

Posture Features = 1.260

Dialogue Features = 1.572
Classification Accuracy [Overall]

Overall

- Dialog+Posture+Face
- Posture+Face
- Dialog+Face
- Dialog+Posture
- Face
- Posture
- Dialog

Kappa

0.1  0.2  0.3  0.4  0.5
Conclusions about Automated Emotion Classification

• Dialogue, face, and posture can classify as good as trained judges
  – But need facial action unit detectors in mouth & eyes

• Fusion of channels typically involves redundancy
  – But superadditivity in the case of boredom

• Different emotions are expressed in different channels
Our Next Challenge

How should AutoTutor to respond when emotions are detected?
Ideal Vision
electronic Personal Advisor for Learning

24x7 Dialog as Tutor & Mentor
- Animated conversational agent
- Intelligent human-computer interface
- Intelligent sensing

Maintains Learner Profile
- Demographic data
- Subject matter knowledge
- Performance on tests
- Cognitive/metacognitive abilities
- Motivation and emotion
- Personality traits
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- etc.

Intelligent Action Selection
- Next learning environment
- Next problem to work on
- Next dialogue act:
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  - Question
- Distributed over time
Force equals mass times acceleration

<table>
<thead>
<tr>
<th></th>
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<th>Pretest MC</th>
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<td>X1XX1X1XX1</td>
<td></td>
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</table>
Initial attempts to increase engagement

* Rude tutor
* Fishics tutor
* Serious games (NSF Science of Learning Center proposal with USC)
Example Dialog with RudeTutor

**Tutor:** Okay, let's begin. Suppose a runner is running in a straight line at constant speed, and the runner throws a pumpkin straight up. Where will the pumpkin land? Explain why.

**Student:** The pumpkin will land behind the runner.

**Tutor:** What a pathetically incorrect answer! So what can you say about the pumpkin's vertical velocity in relation to gravity?

**Student:** They are equal.

**Tutor:** Ouch, you must have been daydreaming in your high school football physics course. I doubt you can get this next question but let me give it a try. The direction in which a force is being applied to the pumpkin is what?

**Student:** Down.

**Tutor:** Let me hold my nose and grant you this one. It’s vertical. Let's move on...
Base Rates of LSA
(Penumatsa, Ventura, Graesser et al., in press)

![Graph showing LSA Cosine scores for Random Bags of Words (Student) with data points for Random 8 and Random 16 Words (Expectations).]
Are particular expectations (or misconceptions) present in essay-answers to physics problems?

Compute:
(a) Experts’ ratings of whether an essay answer has expectation E
   
   2 = explicitly present
   1 = implicitly present
   0 = no present

(b) Maximum LSA cosine between E and all possible combinations of sentences in essay

How do a and b compare?
5-step Tutoring Frame

1. Tutor asks difficult question
2. Initial student answer
3. Tutor short feedback (+, -, neutral)
4. Tutor and student collaboratively improve the answer via a multi-turn dialogue
5. Tutor confirmation of student understanding (often by asking students if they understand)
Example Dialog

**Tutor:** Okay, let's begin. Suppose a runner is running in a straight line at constant speed, and the runner throws a pumpkin straight up. Where will the pumpkin land? Explain why.

**Student:** The pumpkin will land behind the runner.

**Tutor:** Well, what can you say about the pumpkin's vertical velocity in relation to gravity?

**Student:** They are equal.

**Tutor:** Alright, I am sure you can get this. The direction in which a force is being applied to the pumpkin is what?

**Student:** Down.

**Tutor:** Excellent! Is vertical. Let's move on. After release the only force on the pumpkin is gravity, the horizontal velocity of the pumpkin is not affected. What can you say about the pumpkin's motion after its release?

**Student:** It is constantly moving forward.
Given-new contrast in expectation coverage

LSA -- COS of the angle between
1) Expectation and Input, or
2) Expectation and Covered Part
3) Expectation and span{Input 1}
The Second Input:
Is there any new Info?

Diagram:
- Old
- New

Arrows:
- Input 1
- Input 2
How is the new info relevant to the expectation?

LSA – \( \cos \) of the angle between the expectation and

1) the projection of the expectation to the span\{input 1, input 2\}

2) or equivalently, span\{input 1, input 2\}