Main points

1. The idea of an information gap is relevant across many fields
2. There is no consensus on how to define an information gap
3. There is potential for conflicting results that arise from different operational definitions
   1. Education vs. neuroscience (difference score vs. confidence)
   2. Metacognitive vs. ground truth (e.g., our paper)
4. Review dimensions of information gaps that may matter
   1. Metacognitive vs. real gap
   2. Resolvability (expectations)
   3. Cost
   4. Reward
   5. Incremental / insight
5. Conclusion…
   1. Be specific? Or don’t use information gap at all?

**What is an information gap?**

**What is being learned?**

Information gaps may differ in terms of the kind of knowledge that is missing (e.g., declarative information, perceptual information, procedural information, causal information, reward outcome, distributional information).

**How do we measure information gap?**

Information gaps may refer to a ground truth gap (e.g, in computer science and machine learning), or a subjective estimate of an information gap (e.g., in human learning and education). Importantly, metacognitive abilities and how calibrated they are to the real world differs across domains, tasks, and learners, and learner ability levels (cite Kruger-Dunning, Overconfidence, etc papers).

Relative: compare across conditions (e.g., certainty / uncertainty conditions)

Absolute: CS/ML - hypothesis space size, entropy, surprisal, prediction error

**Resolvability**

How does the learner expect the gap to be resolved? Is the information gap something that can be resolved in one word (e.g., a trivia question answer) or one book (e.g., a textbook for a class)? When information is presented to close the information gap, will it *actually* close the information gap or is the information gap too far removed from the learner’s current knowledge state? For example, you can know that E = MC2, but may not understand the implications of this formula because of your lack of knowledge in the domain of physics.

**Cost**

Does the learner need to exert effort to close the information gap? Is there an opportunity cost incurred by filling the gap (e.g., not being able to fill another gap in the future; waiting to attend to other information gaps)?

**Reward**

What is the information worth to the learner? (e.g., is it mere pennies, or much more than that?) For example, knowing your result on an important exam (e.g., the SAT, GRE, MCAT, or LSAT) or a medical test (e.g., a pregnancy test) may have for far-reaching consequences than knowing which celebrity couple filed for divorce today. A pregnancy test result contains 1 bit of information (there are two possible outcomes), less information than finding out who filed for divorce today (there are more than two possible outcomes). There may be individual differences in the intrinsic and extrinsic motivation of a learner to acquire certain kinds of information.

**Final thoughts**

*Are we testing information gap or something else?*

* Information gaps can be correlated with other factors, such as prior knowledge. Are we actually studying the role of information gaps, or the role of prior knowledge, metacognitive ability/expertise, etc?

**Marketing**

The term ‘information gap’ has also been used to in the domains of marketing and decision-making to refer to the mystery identity of a reward (e.g., van Dijk & Zeelenberg, 2007; Goldsmith & Amir, 2010; Hill, Fombelle, & Sirianni, 2016). When presented with the choice of a known reward or a mystery reward, people are more likely to choose the mystery reward with information about the mystery reward is revealed regardless of the decision, compared to when the identity of the mystery item will only be revealed if you select it (Van Dijk, xxxx). Additionally, shoppers will experience a greater state of curiosity and engage in more shopping when the identity of a mystery prize is withheld until checkout compared to when the identity of the mystery prize is revealed ahead of time (CITE).

**Computer science**

In the domain of computer science and machine learning, information gap has been defined in multiple ways, including entropy, surprisal (e.g., Burda et al), prediction error (e.g., Oudeyer & Kaplan, 2007), and the size of the hypothesis space (e.g., Langford & Zhang, 2008). Surprisal refers to the amount of information gained by sampling the variable. In contrast, entropy refers to the average amount of information that could be gained about a system by variable sampling (used by Loewenstein, 1994, as an information gap proxy; and in economic decision models; Golman & Loewenstein, 2013; 2015). Prediction error refers to the difference between a predicted outcome and the actual observed outcome. It is the mechanism by which learning is hypothesized to occur in learning models such as the Rescorla-Wagner model and has been used in learning theories (e.g., Oudeyer & Kaplan, 2007) and as a measure of information gap in studies on curiosity and learning (e.g., Marvin & Shohamy, 2016; Wilson, et al., 2003). Information gap may also refer to the size of the hypothesis space, particularly when a learner is trying to identify the underlying distribution function of a reward system (e.g., bandit tasks; Langford & Zhang, 2008).

Marvin & Shohamy (2016) - information prediction error (the difference between satisfaction and curiosity for the answer to trivia questions) predicts learning. Larger difference between curiosity and satisfaction is predictive of learning.

**More thoughts**

**Information gap as incremental vs. insight -- effect of waiting time / information rate may vary, likely to observe differences in curiosity**

**-- Abby Hsiung DukeNeuro Adcock lab poster**

**-- our hangman stuff (not published)**

**-- trivia questions are presented as an insight problem (but they could be incremental if you present it in a different way)**

**-- waiting time - Noordeweier stuff**

**Is the information gap measure a real measure of gap or a metacognitive measure?**

**Differences may arise depending on how well-calibrated metacognition is to reality.**

**How is information gap defined / measured?**

**Varies greatly. Are people trying to learn about a system or fill a small gap in knowledge (no need to learn an underlying distribution, causal system, etc).**

**Information gap as a metacognitive assessment about a targeted answer (trivia question)**

* Measure confidence or certainty of the answer in order to determine information gap size
* Kang et al.: High uncertainty (intermediate confidence) related to greater curiosity.
* Litman, Hutchins, & Russon, 2005: FOK state related to curiosity, with highest curiosity for TOTs, then “I know” then “I Don't know”

**Information gap as a metacognitive assessment in education**

* Gentry et al. (2002) Gap is difference between rating of importance (how important they think something is) and confidence (what the student believes that they know) about different topics.
* Students with large information gaps more likely to do worse on first exam or assignment than students with small or moderate information gaps.

**Information gap as waiting time**

* Noordeweir: curiosity similar across waiting time durations (but nature of feelings associated with curiosity change)
  + Task (see video after a specific waiting time)

**Information gap as perceptual gap**

* People recall more photos when there is resolved perceptual uncertainty than un-resolved perceptual uncertainty (Jepma, Verdonschot, Van Steenbergen, Rombouts, & Nieuwenhuis, 2012)
  + blurry photos of objects, compared to clear, identifiable ones. Blurry photos were sometimes followed with their clear counterparts or random, unrelated clear photos.
* AMT workers are more likely to finish all 30 HITs if they are in conditions that induce perceptual curiosity (presented with a scrambled photo vs. an ordered one, or with a narrative that contains missing parts + a task-relevant question vs. just the question). (Law et al., 2016)

**Information gap as a physical gap (not quite sure how to word this)**

* Surprise mystery item (Van Dijk)
  + Finding: More likely to take mystery reward when information about mystery reward is revealed regardless of decision **(check to make sure this is right)**, in contrast to when the identity reveal is tied to your decision. When information about the mystery item is expected, the person is more likely to take the mystery item. When the mystery item identity is tied to a decision, less likely to take a mystery item over a known one. (so you won’t actually seek the information out by selecting the item, you’ll avoid the information).
* Shopping/marketing studies -- higher state of curiosity/more shopping when you don’t know what the mystery prize is until checkout rather than knowing ahead of when you shop. Shopping while curious increases shopping.

**Information gap as entropy**

?? Loewenstein, 1994

**Information gap as surprisal**

* + Burda et al.: curiosity = rewarding exploration = maximizing surprisal; so surprisal = information that could be learned, information gap size.

**Information gap as prediction error**

* + Rescorla-wagner model - difference in expected vs. actual outcome
  + Non-model paper: Marvin and Shohamy (2016) - gap between reward expected and reward received. Drives learning.
  + Oudeyer & Kaplan 2007 (prediction error)
  + Cohn, D. A., Ghahramani, Z., & Jordan, M. I. (1996). Active learning with statistical models. *Journal of artificial intelligence research*, *4*, 129-145. (prediction error)
  + Wilson, et al., 2003: prediction error between a guess about what code will do and what it will actually do.
  + Trivia questions that require participants to generate answers??

**Information gap has hypothesis space size**

* + In bandit tasks, where you are trying to learn about the underlying distribution function for rewards
    - Langford, J., & Zhang, T. (2008). The epoch-greedy algorithm for multi-armed bandits with side information. In *Advances in neural information processing systems* (pp. 817-824).
  + Bayesian learning?

**Important considerations and dimensions of Information Gaps**

*What is the nature of the information gain/gap?*

* + declarative knowledge (e.g., trivia questions - Kang et al. & Gruber et al)
  + perceptual knowledge (e.g., Jepma et al. 2012)
  + procedural knowledge (how to do X)
  + causal knowledge (how X works)
  + mastery of some ability / learning space (AI, CS, ML)
  + reward outcome / decision outcome

*Beyond this, how is the information gap operationally defined?*

*Is it metacognitive in nature?*

* Is the operational definition dependent on metacognitive abilities of a learner, or is it derived objectively from a learning space/context?
  + Importantly, metacognitive abilities and how calibrated they are to the real world differs across domains, tasks, and learners, and learner ability levels.

*Information Gap Size (dimensions when calculating size)*

* + Resolvability: How does the learner expect the gap to be resolved? What is needed to resolve the gap, and in what manner is the gap resolved?
  + Cost: What is the cost to fill the gap? Does the learner need to wait, exert effort, or miss out on other opportunities to fill the gap?
  + Reward: What is the information worth to the learner? (e.g., is it mere pennies, or much more than that?) Example: paying to see exam scores early, getting allocation of juice for the day (monkeys), knowing the answer to one trivia question (probably worth much less). How motivated is the learner to acquire the information?

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* Information gaps can be correlated with other factors, such as prior knowledge. Are we actually studying the role of information gaps, or the role of prior knowledge, metacognitive ability/expertise, etc?

Next steps:

Refine outline, open position

Get in contact with PY about writing it - position piece, not review.

See if we can set up a skype call for feedback when we are writing it.

**-- somewhere, need to add Stahl & Feigenson, Baillargeon - VOEs as gaps in causal understanding of world**

**How can this be problematic?**

Two different things --

Sometimes familiarity, sometimes novelt

Need to talk about where the conflicts are, where the problem arises from different definitions