Breadth in Design Problem Scoping:
Using Insights from Experts to Investigate Student Processes

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Conceptual Foundation

Design in Context

Motivation
- "Engineer of 2020"
- ABET learning outcomes

- **Problem scoping –** a stage in the design process where designers define the nature of the design problem and the space in which they will search for solutions.

- Understanding problem scoping may suggest ways to improve engineering education with targeted consideration of contextual issues.

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Objectives

This paper explores how broadly novices and experts define a hypothetical engineering problem, and what are some important features of expert thinking about engineering problems.

Goals

- To characterize expert design thinking in terms of breadth of problem scoping.

  - Expert "cases" are checked for common features with regard to the breadth of problem scoping, based on a given coding scheme.

  - Results are situated relative to a "novice" dataset, explored through the same analytical lens.

- To investigate through narrative analysis any interesting and/or consistent problem frames or reasoning patterns in expert responses.

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Research Questions

- What are expert ways of thinking about a problem scoping design task?

- Are there regularities among expert responses with regard to breadth of problem scoping?

- Are there qualities of expert thinking that can inform how we understand novice thinking?

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Participant Selection

Participants

Experts

- Experienced engineers (n=4)
- 4 "most expert" participants selected from a sample of 19 experienced engineers.

Participant Pseudonym	Area of Specialization	Years of Experience	Sex
Ann	Industrial Engr.	22	F
Eric	Mechanichal Engr.	29	M
John	Systems Engr.	32	M
Peter	Civil Engr.	24	M

Novices

- First-year students in Academic Pathways Study (n=124)
- A convenience sample of students participating in the Academic Pathways Study at four diverse universities.

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Data Collection Overview

Instrument

> *"In the past, the Midwest has experienced massive flooding of the Mississippi River. What factors would you take into account in designing a retaining wall system for the Mississippi?"*

Data collection

Experts: Verbal Protocol Analysis
- Given 30 minutes and prompted to think aloud as they wrote their answers.
- Experts' verbal responses were audio recorded and transcribed for subsequent segmenting, coding, and interpretation.

Novices
- Given 10 minutes to write their answers.
- Written answers were transcribed, segmented, and coded.

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Method: VPA & Coding Scheme

Verbal Protocol Analysis

- Useful and rigorous lens for making systematic comparisons of the content of ideas between subjects and across samples. Involves segmenting verbal transcripts into "thought units" and coding on the dimensions of the breadth of problem scoping.

### *Dimensions of the Coding Scheme*

Physical location

- Indicates the physical focus of each idea: the wall itself, the water, the riverbank, or the wider surroundings beyond.

Frame of reference

- Indicates the perspective represented in each idea: technical, logistical, natural, or social.
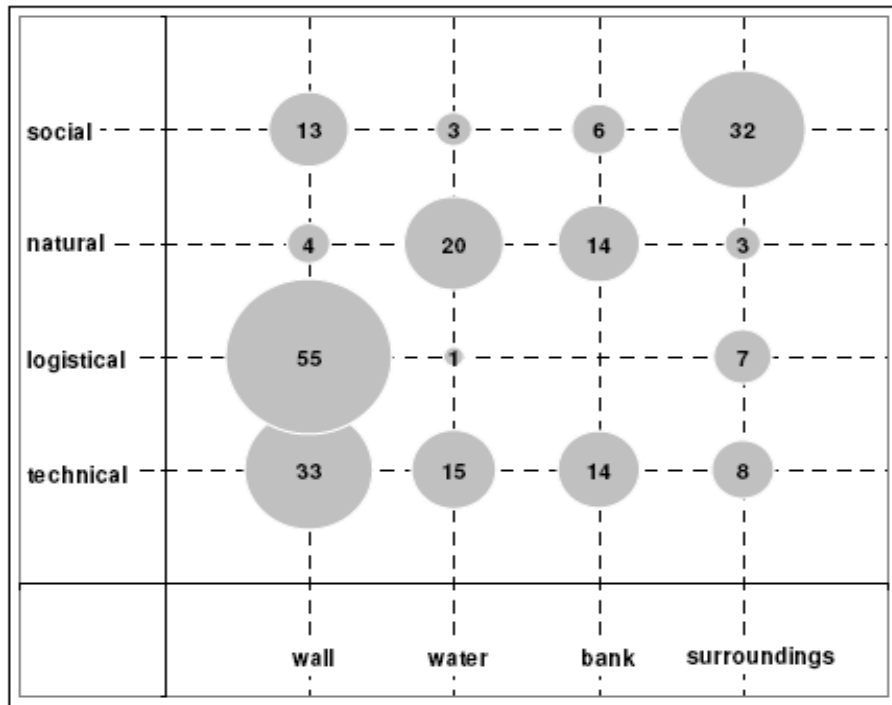
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Dimensions of the Coding Scheme

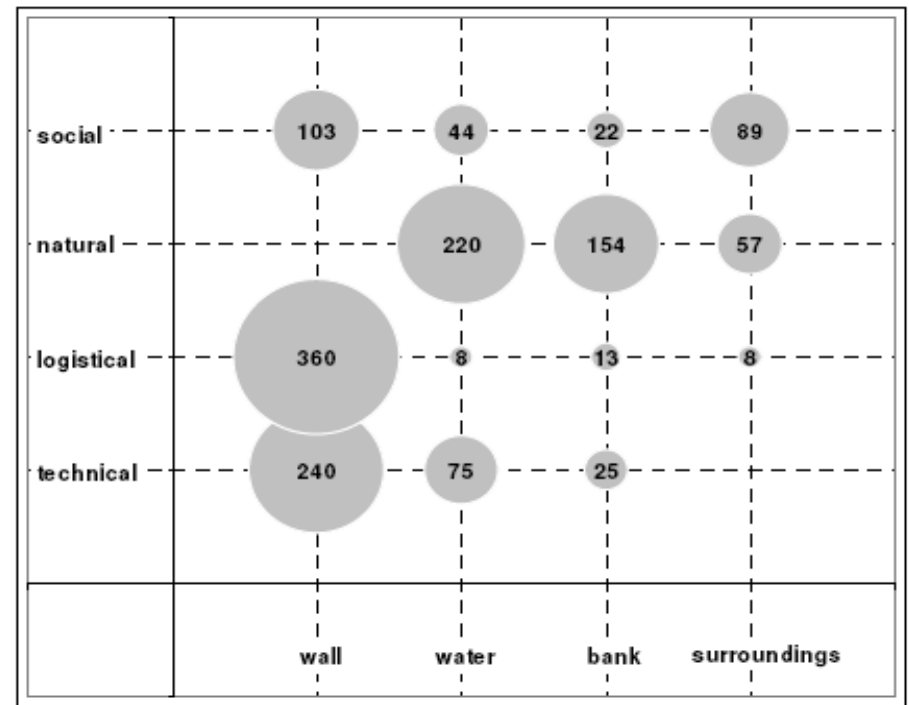Interpretation of the Midwest Floods problem codes
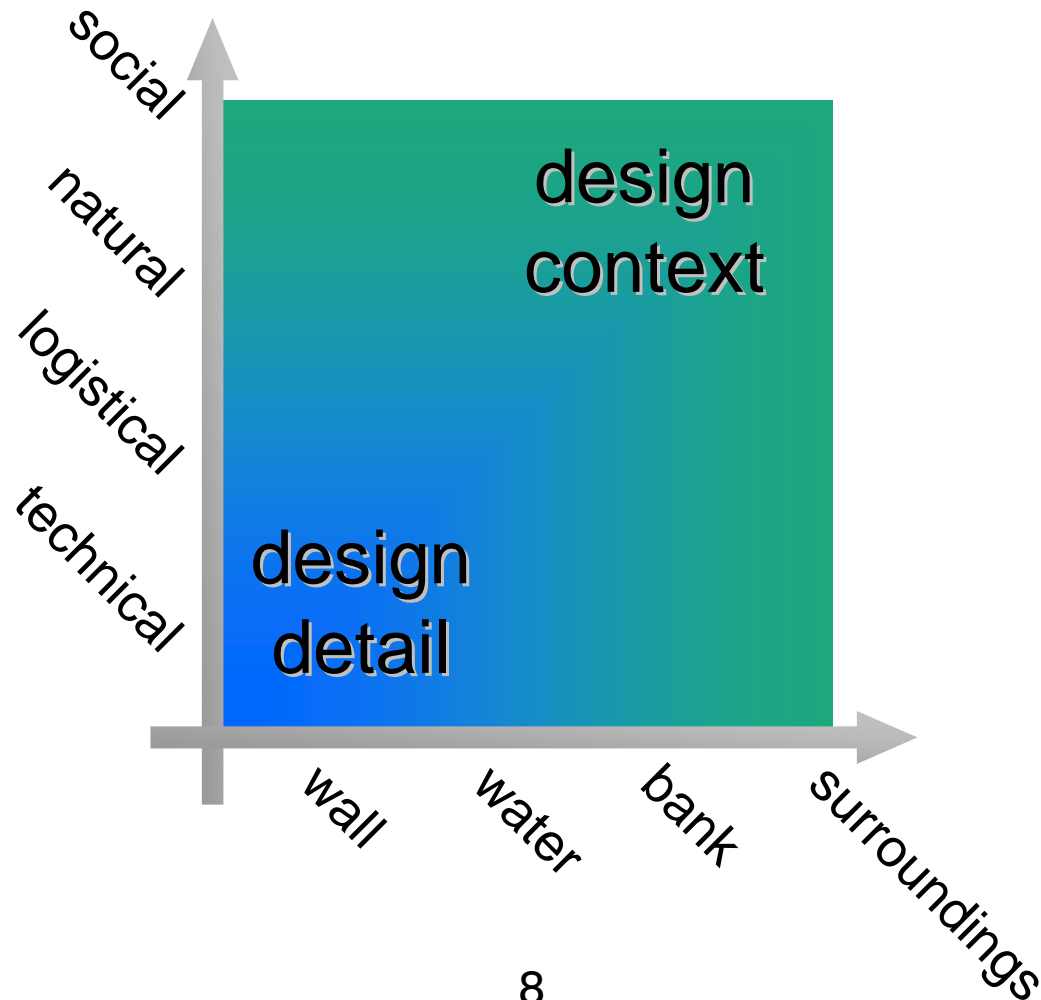
Findings: VPA

Expert / Novice

Experts

(n=228 statements)

Novices

(n=1418 statements)

	Ann	Eric	John	Peter	Total
Number of statements	20	61	118	29	228
Design detail	30%	51%	47%	38%	46%
Design context	70%	49%	53%	62%	54%

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Findings: VPA

Breadth of Problem Scoping on the Midwest Floods problem

Element	Novices (n=124, # segments=1418)	Experts (n=4, # segments=228)
Design Detail (%)	48	46
Design Context (%)	52	54
Frame of Reference Codes (%)		
Technical	24	30
Logistical	27	28
Natural	30	18
Social	18	24
Physical Location Codes (%)		
Wall	50	46
Water	24	17
Bank	14	15
Surroundings	12	22

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Method: Narrative Analysis

- *Narratives are*
  - *the telling of a sequence of events or ideas that are bound to one another coherently*
  - *the way people make sense of and know the world*
- *Narrative analysis*
  - *Involves close independent readings of the expert transcripts, looking for emergent themes and narrative structures*
  - *Allows observing and understanding how experts organize their knowledge as they proceed in problem solving*
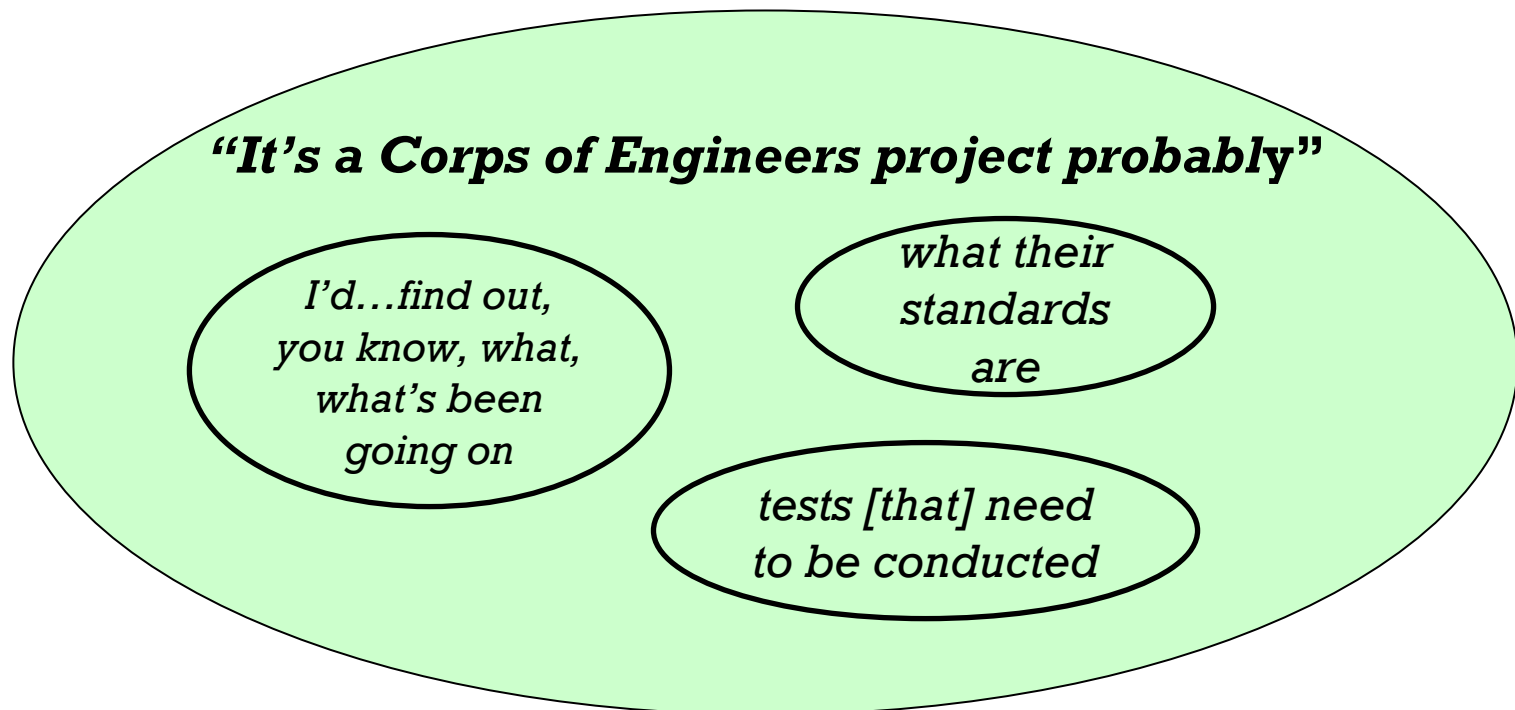
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Findings: Narrative Analysis

Content Themes

1. **Existing engineered solutions**
2. **Alternative Solutions**
3. **Costs and Benefits**
4. **Priorities**
5. **Temporality**

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Findings: Narrative Analysis

Thought Patterns

1. **Developing narrative sets of related factors**

    - *Stating a broad "framing" factor, then elaborating and expanding upon it by brainstorming a list of related detailed factors.*
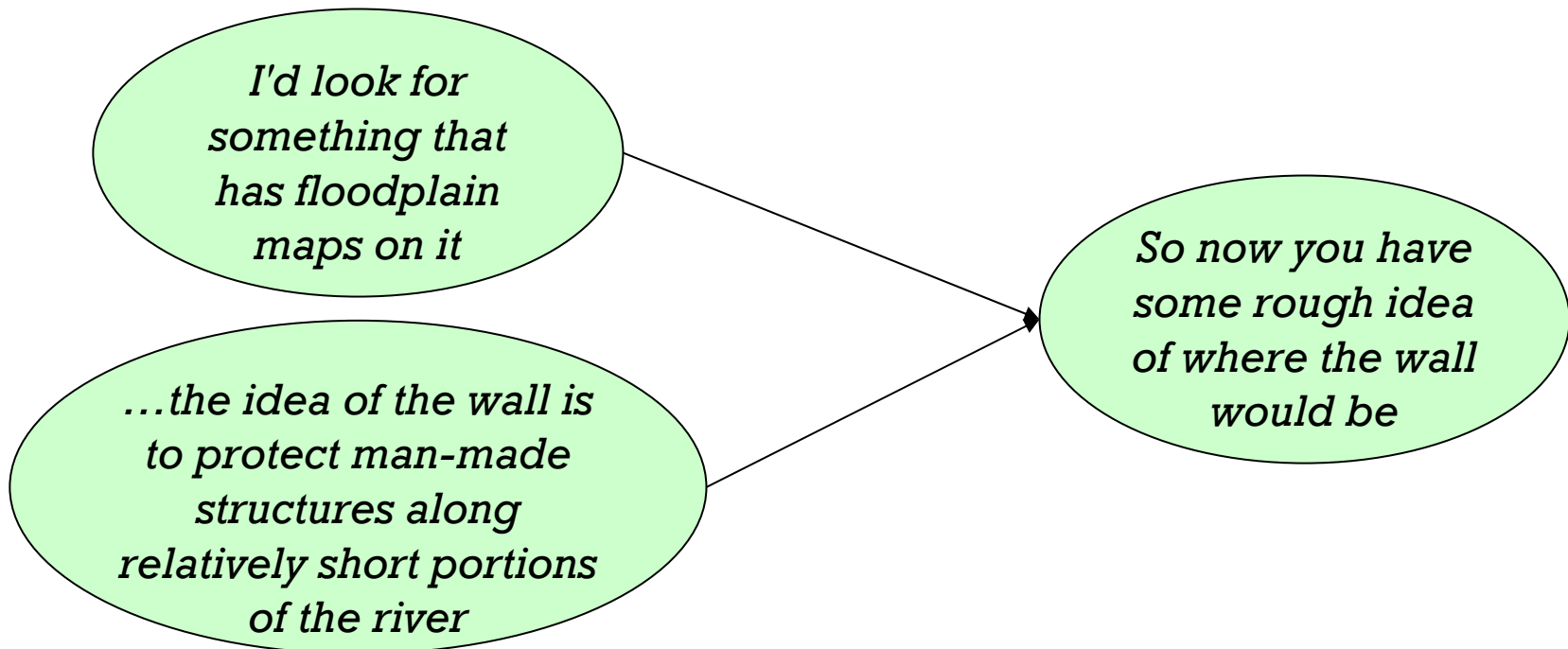
"It's a Corps of Engineers project probably"

I'd…find out, you know, what, what's been going on

what their standards are

tests [that] need to be conducted

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Findings: Narrative Analysis

Expert Design Thinking – Thought Processes

2. **Connecting sets of related factors logically**

- *Including logical connections among sets of related factors. The broad ideas of the two sets containing elaborating factors are connected.*

I'd look for something that has floodplain maps on it

…the idea of the wall is to protect man-made structures along relatively short portions of the river

So now you have some rough idea of where the wall would be

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Findings: Narrative Analysis

Expert Design Thinking – Thought Processes

3. Embedding a narrative set within another narrative set

- *Embedding a set of related ideas within another set of related ideas. An elaborating factor from one narrative set subsequently becomes the framing factor for a new narrative set.*
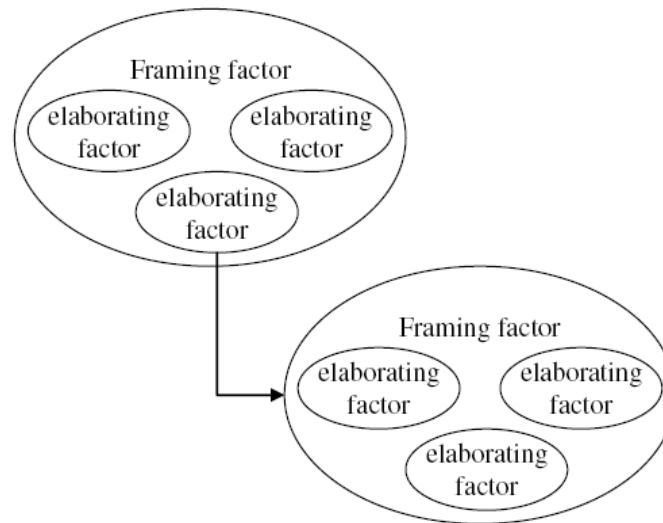
"you just want to look at probabilities of exceeding certain flood heights"

Because maximum flood height needs to be defined

[Are you] talking about a fifty-year flood, a hundred-year flood, a thousand-year flood?

it needs to be defined by recurrence interval

"Ok, we need to select the reasonable recurrence interval"

that needs to be based on what are you protecting

…is it a hospital, police station, farmland?

we don't want to waste a lot of money protecting something that is not of high value

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Discussion and Implications for Future Research

Verbal Protocol Analysis

- The four experts exhibited little commonality with one another when analyzed using the VPA coding scheme for breadth of problem scoping.
  - Total number of segments
  - Distribution of segments across categories
- Analysis of the remainder of the 19 experts' responses should provide a more reliable expert-novice comparison

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Discussion and Implications for Future Research

Expert Design Thinking

- Narrative analysis revealed five significant content themes in the experts' narratives.

- A similar analysis of novices' written responses would illuminate substantive similarities and differences in content knowledge and engineering design priorities.

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Discussion and Implications for Future Research

- Narrative analysis illuminates relationships between and among an expert's ideas

- Analysis of the remainder of the 19 experts' transcripts should reveal additional instances of previously described patterns of thought, as well as others.

- A narrative theory of expert design thinking complements verbal protocol analysis, providing additional insight into design thinking and prioritizing.

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Acknowledgements

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