Capturing expert mental models of quantum sensing using concept maps

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Motivation

- Most QISE courses focus on quantum computing[1]
- No standard textbooks on quantum sensing
- Educators struggle to access primary literature[1]
- There is a need for curriculum development focused on quantum sensing.

[1] J. C. Meyer, G. Passante, S. J. Pollock, and B. R. Wilcox, Physical Review Physics Education Research 18, 010150 (2022).
[2] How People Learn: Brain, Mind, Experience, and School: Expanded Edition (National Academies Press, Washington, D.C., 2000).
[3] B. Crandall, G. A. Klein, and R. R. Hoffman, Working Minds: A Practitioner's Guide to Cognitive Task Analysis

Background

- Experts possess deeply structured knowledge organized in intricate networks.[2]
- Cognitive Task Analysis (CTA) methods like concept mapping -- technique for visually organizing information -- can elicit expert knowledge.[3]
- Concept maps made by experts can help to identify learning outcomes, inform the curricular structure, and suggest models / frameworks.

Methods : Developing expert concept maps

Participants

Target population: Experts in quantum sensing (grad students, postdocs, faculty, or researchers in academia/industry).

Expert criteria: ~2+ years of experience in sensing-related projects.

Category	No. of participants
Grad students	7
Postdoc	9
Faculty	4
Research scientists	2

Training phase

Training materials shared a week before interview to help participants prepare:

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- A **short tutorial video** on using Lucidspark (virtual whiteboard tool).
- **Practice concept map** (on quantum measurement) provided for hands-on engagement.
- **Interview protocol outline** also shared in advance to set expectations.

Interview and Concept mapping

Interview format: Conducted on Zoom, fully recorded with consent; typically involves two interviewers.

Opening section (~10 mins):
- Background questions
- Broad questions on sensing, measurement, and quantum advantage.

Main section (~40 mins):
- Focuses on a specific quantum sensing platform and protocol chosen by the participant.
- Participant collaborates live on Lucidspark to build a concept map—organizing, connecting, and labeling concepts.

Final section (~10 mins):
- Focuses on teaching quantum sensing at the undergrad level.
- Discusses prerequisite physics concepts, student difficulties, and effective toy models.

Analysis

- Two rounds of revision
- Round 1 - Add missing concepts and connections
- Round 2 - Add additional concepts and clarifying information
- Identify clusters or common themes

1. Making the map
On the Lucidspark interface 'sticky notes' are used to represent concepts and arrows are used to represent the connecting ideas / reasonings

2. Initial step
Interviewee begins with verbal description – key concepts mentioned are placed here temporarily before organizing them into the final concept map.

3. Making the map
These concepts are then moved into the main concept map to be connected with related ideas.

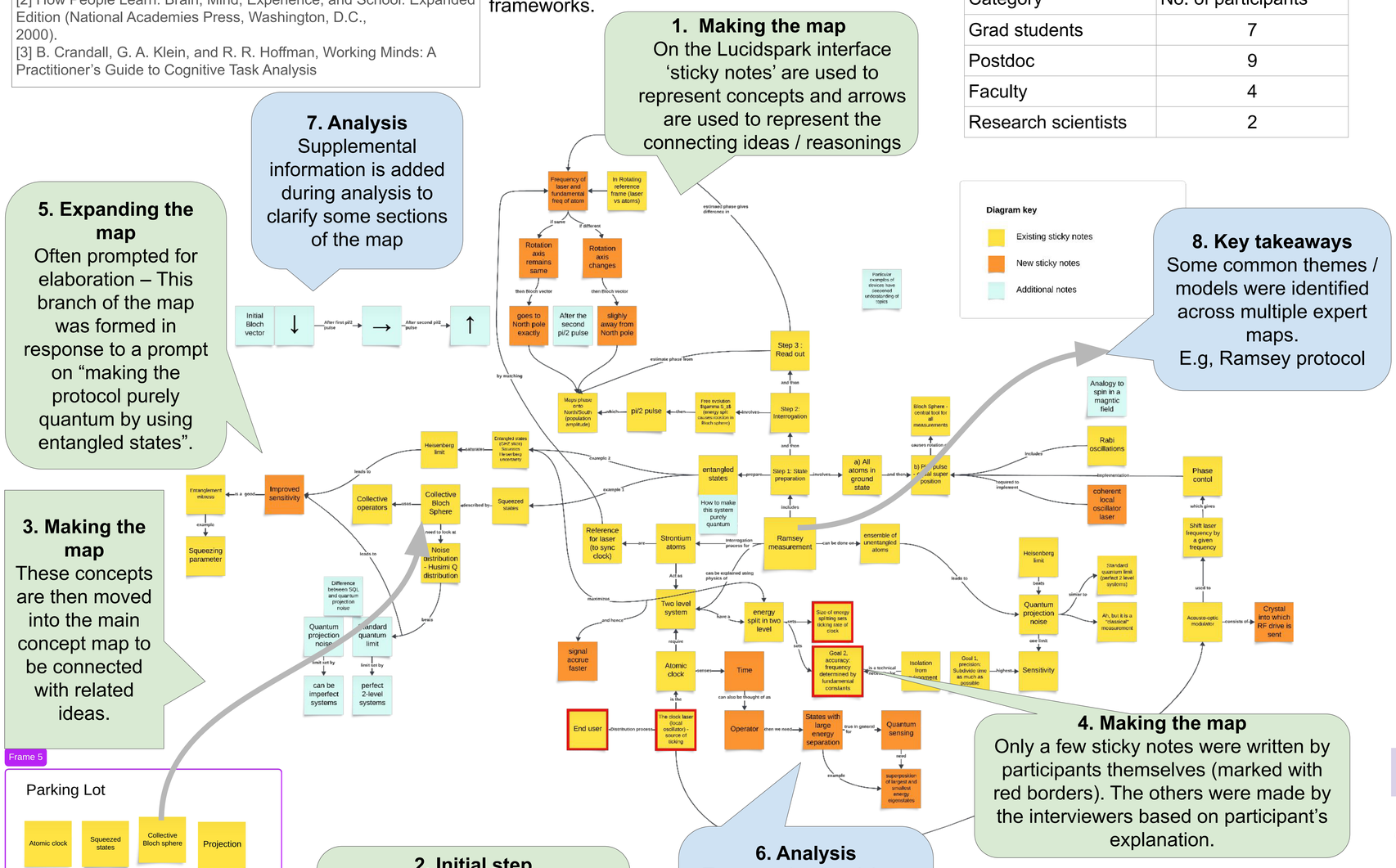
4. Making the map
Only a few sticky notes were written by participants themselves (marked with red borders). The others were made by the interviewers based on participant's explanation.

5. Expanding the map
Often prompted for elaboration – This branch of the map was formed in response to a prompt on "making the protocol purely quantum by using entangled states".

6. Analysis
Two rounds of revision - 1) reorganize and add missing connections / text 2) additional concepts (orange sticky notes) added for clarification

7. Analysis
Supplemental information is added during analysis to clarify some sections of the map

8. Key takeaways
Some common themes / models were identified across multiple expert maps.
E.g, Ramsey protocol



Challenges and Limitations

- Cognitive overload - some participants could not engage fully with the mapping while thinking aloud.
- Required more prompts for elaboration at times
- Required explicit questions to elicit reasoning and relationships between concepts
- Need for scaffolded prompts to guide the discussion
- Need to provide a general structure for the process while still allowing enough flexibility

Acknowledgement

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