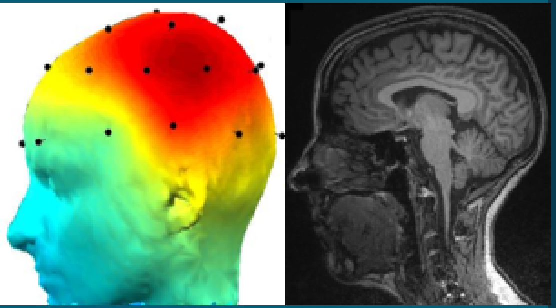
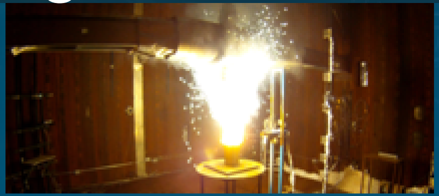
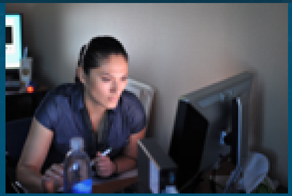
SAND2021-13905PE

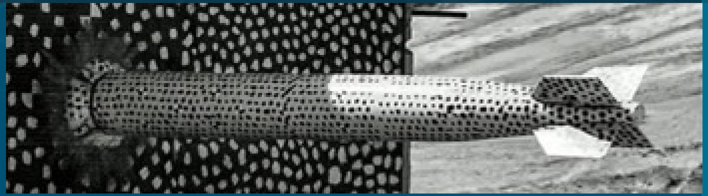
Sandia National Laboratories

Where are we going and where have we been? Examining the effects of maps on spatial learning in an indoor guided navigation task









Mallory Stites, Ph.D.

Applied Cognitive Science Department (5572)

U.S. DEPARTMENT OF ENERGY NNSA

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

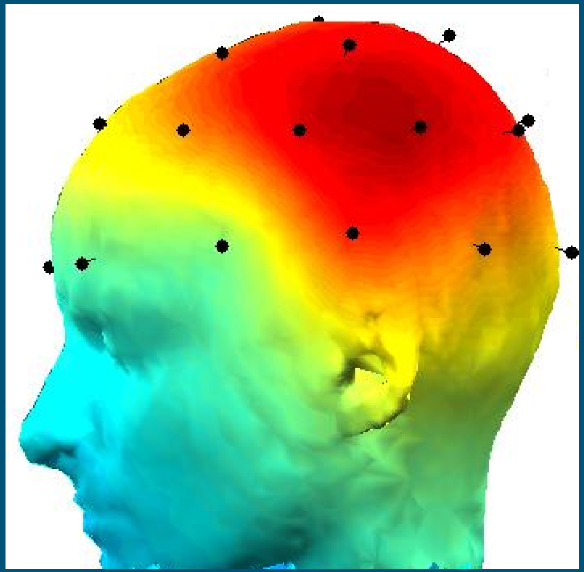
Within Sandia: Key Cognition Research Areas

Decision making in high-consequence environments
- Assessing and improving human performance
- Optimizing human-system interactions
- Situational Awareness

Visual Cognition
- Informing the design of scalable human-computer imagery analysis systems
- Studying development of expertise in professional analysts

Mitigating errors and cognitive biases
- Training and expert/novice differences
- Tracking analytic progress
- Communicating uncertainty

Knowledge Transfer
- Human-human handoffs
- System-human handoffs
- Team cognition



Humans Interacting with Information

Trying to make sense of it
Trying to remember it
Trying to pass it to other people or systems

Detect the diversion of nuclear materials

Detect the misuse of nuclear facilities

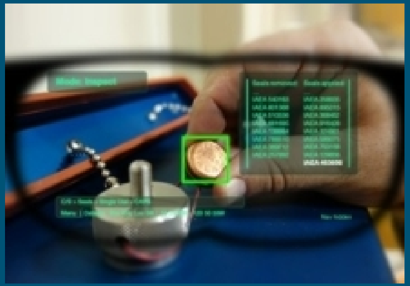
Detect the development of unknown nuclear facilities

Images: IAEA Imagebank, Flic

Overall Project Goals

- Draw from cognitive science literature to develop recommendations for the most effective ways to present information to safeguards inspectors in the field
  - Optimize current methods
    - (typically paper and pencil + measurement tools)
  - Inform development of future methods
    - (AR/VR, new technologies)

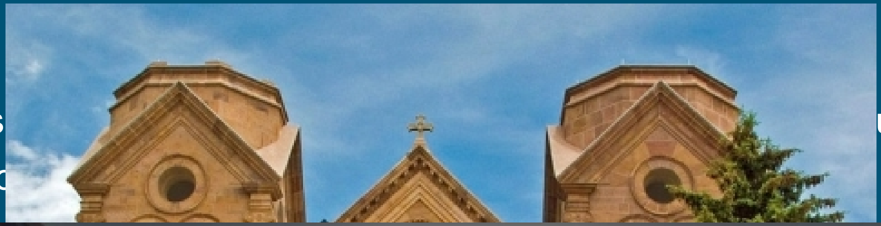
- Focus areas identified:
  - Visual Inspection
  - Knowledge Transfer
  - **Indoor Wayfinding**

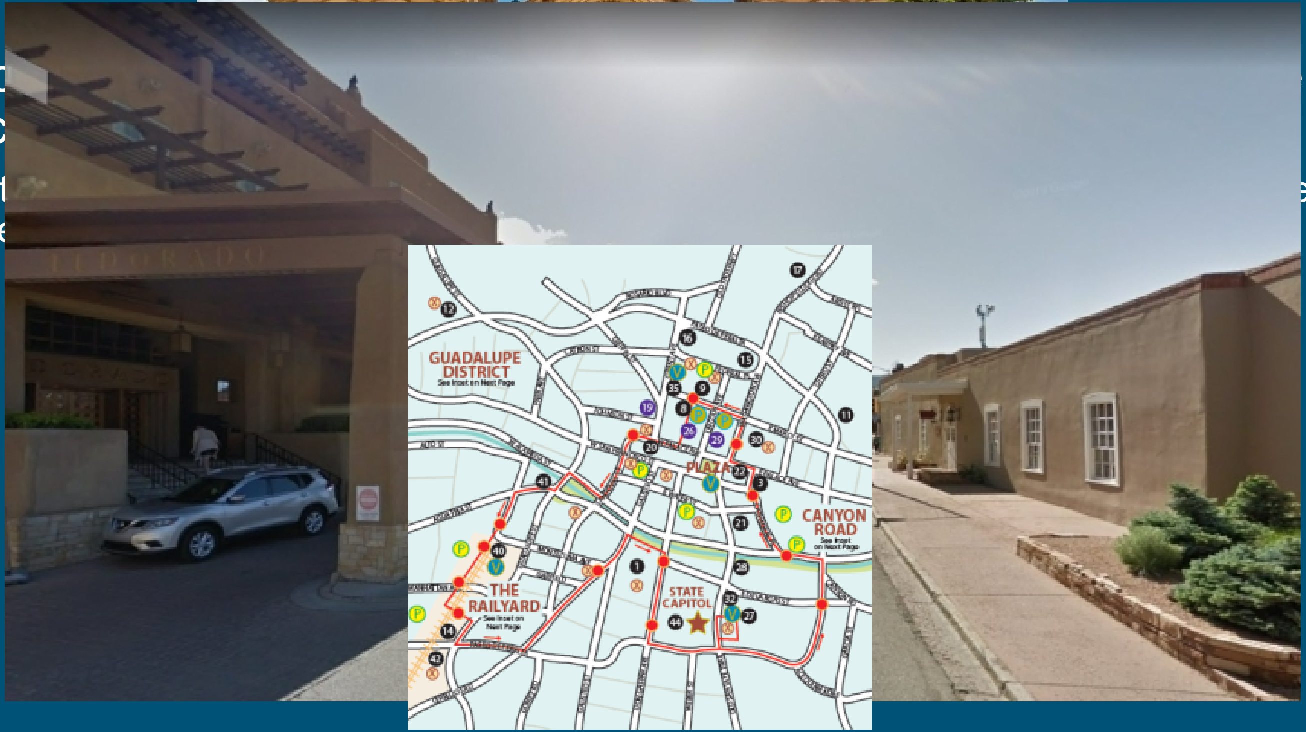


Prior research on spatial learning

There are at least three different levels of spatial knowledge:

- Landmark knowledge – memory for objects encountered in the environment
  - Does not include memory for the landmark's location
- Route knowledge – (egocentric point of view)
  - Does not include areas ute
  - Does not include metric
- Survey kno environment (allocentric
  - Marked by t person did not travel between the





Spatial Navigation in Safeguards

What's special about navigation for safeguards?

- Guided (or passive) navigation
- Indoors
- Restrictions on use of GPS or other electronics
- May or may not have access to facility maps before or during inspection
- Potential for deception
    - Facility changes
    - Avoiding parts of facility

Research Questions

How does the **presence** and type of map information impact spatial knowledge for an unfamiliar, complex industrial facility?

- Is having any map better than having no map?
- Are some maps better than others?
- Do some maps support different kinds of spatial learning?

How do individual differences in sense of direction interact with map effects?

- Do all people benefit equally from using a map?

Spatial Learning in the Nuclear Safeguards Context

120 Sandia employees (47 female, mean age 37, age range 18-69)
- 24 participants assigned to each of 5 spatial learning conditions

All participants began by studying a map (except for a no-map control group), then they were led through the basement and mezzanine of a former nuclear facility. The experimenter pointed out landmarks along the way.

After the tour, participants were tested on their spatial learning and memory for the landmarks

Landmark knowledge: Ability to distinguish between landmarks and unseen items

Route knowledge: Ability to draw the route and landmarks on a blank map

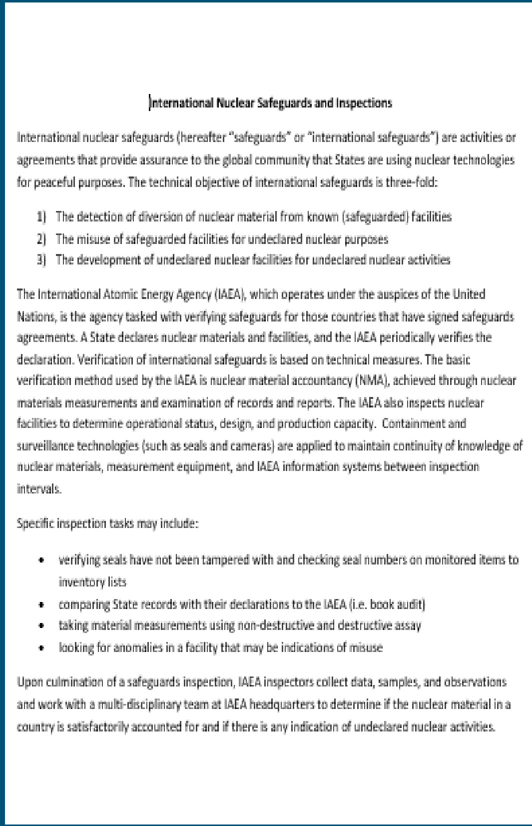
Survey knowledge: Ability to point to landmarks from the starting point of the route

Ability to find shortcuts between pairs of landmarks

Participants were divided in the analysis based on their sense of direction, as measured by the Santa Barbara Sense of Direction Scale (Hegarty et al., 2002)

Experimental Environment

Map Conditions



International Nuclear Safeguards and Inspections

International nuclear safeguards (hereafter "safeguards" or "international safeguards") are activities or agreements that provide assurance to the global community that States are using nuclear technologies for peaceful purposes. The technical objective of international safeguards is three-fold:

1) The detection of diversion of nuclear material from known (safeguarded) facilities
2) The misuse of safeguarded facilities for undeclared nuclear purposes
3) The development of undeclared nuclear facilities for undeclared nuclear activities

The International Atomic Energy Agency (IAEA), which operates under the auspices of the United Nations, is the agency tasked with verifying safeguards for those countries that have signed safeguards agreements. A State declares nuclear materials and facilities, and the IAEA periodically verifies the declaration. Verification of international safeguards is based on technical measures. The basic verification method used by the IAEA is nuclear material accountancy (NMA), achieved through nuclear materials measurements and examination of records and reports. The IAEA also inspects nuclear facilities to determine operational status, design, and production capacity. Containment and surveillance technologies (such as seals and cameras) are applied to maintain continuity of knowledge of nuclear materials, measurement equipment, and IAEA information systems between inspection intervals.

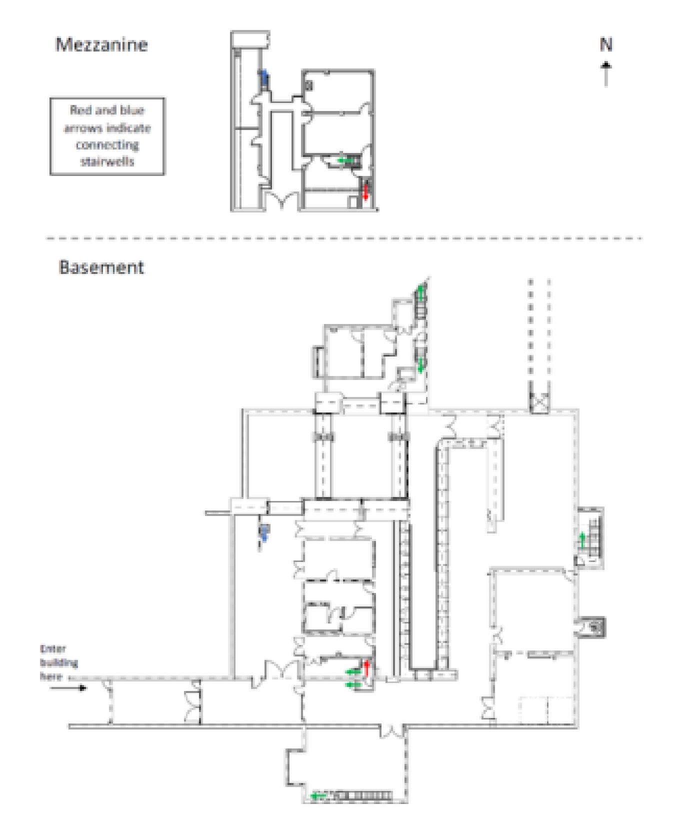
Specific inspection tasks may include:

- verifying seals have not been tampered with and checking seal numbers on monitored items to inventory lists
- comparing State records with their declarations to the IAEA (i.e. book audit)
- taking material measurements using non-destructive and destructive assay
- looking for anomalies in a facility that may be indications of misuse

Upon culmination of a safeguards inspection, IAEA inspectors collect data, samples, and observations and work with a multi-disciplinary team at IAEA headquarters to determine if the nuclear material in a country is satisfactorily accounted for and if there is any indication of undeclared nuclear activities.

No Map

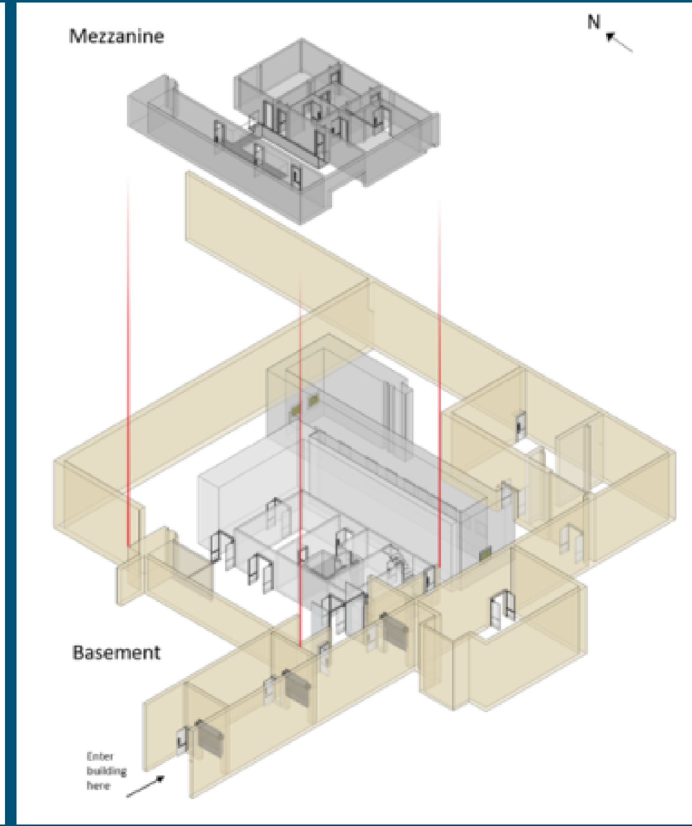
Read handout



2D Simple Map

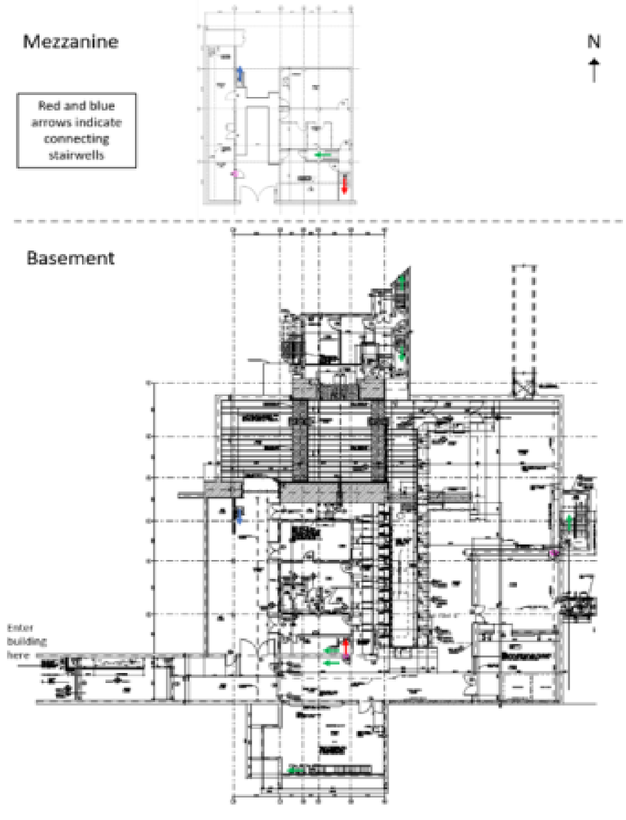
Study only

Study + carry



3D Simple Map

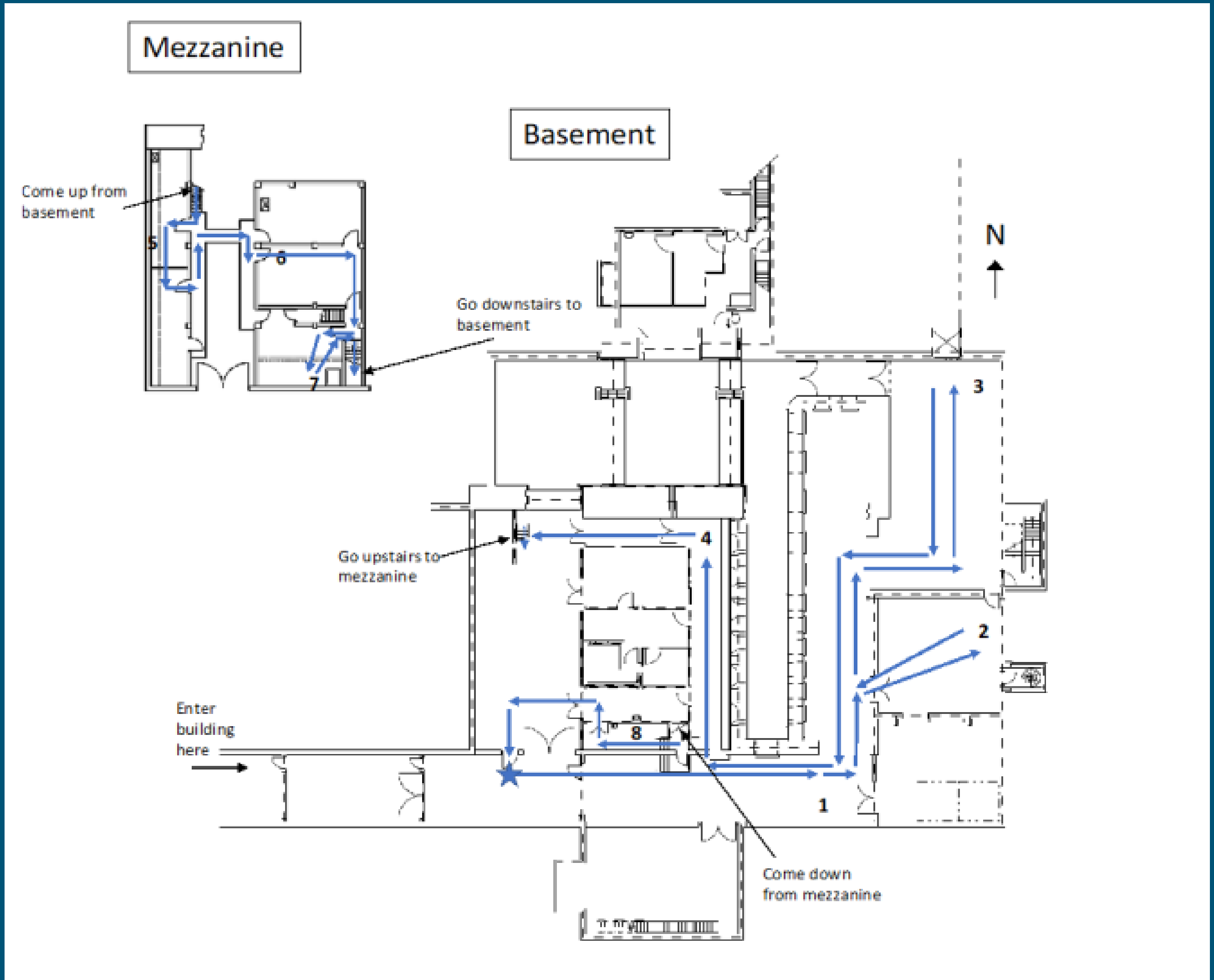
Study + carry



2D Blueprint

Study + carry

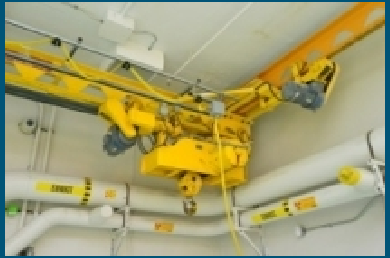
Route and Landmarks



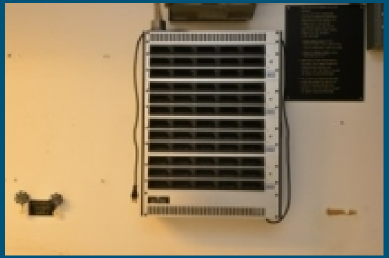
Landmarks

1. Manipulator mockup
2. Glove box
3. Overhead crane
4. Instrument cabinet
5. Atom art
6. Capped Pipe
7. Water meter
8. Dosimeter charger





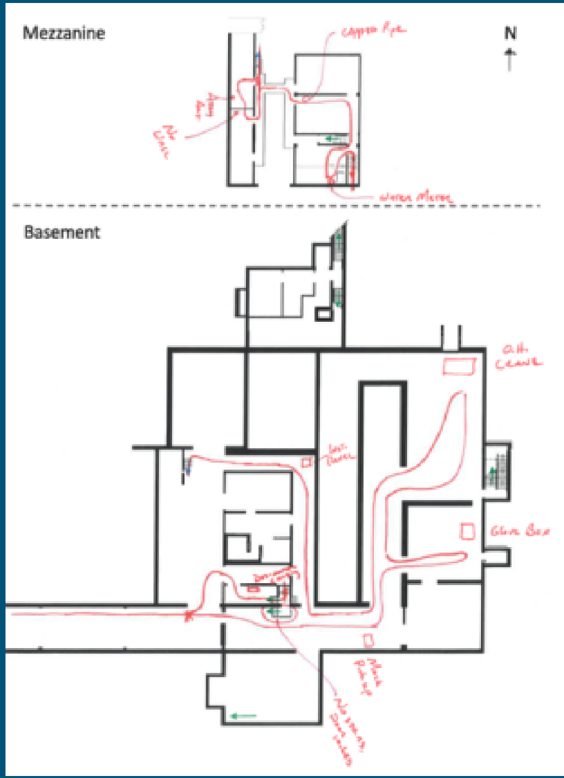


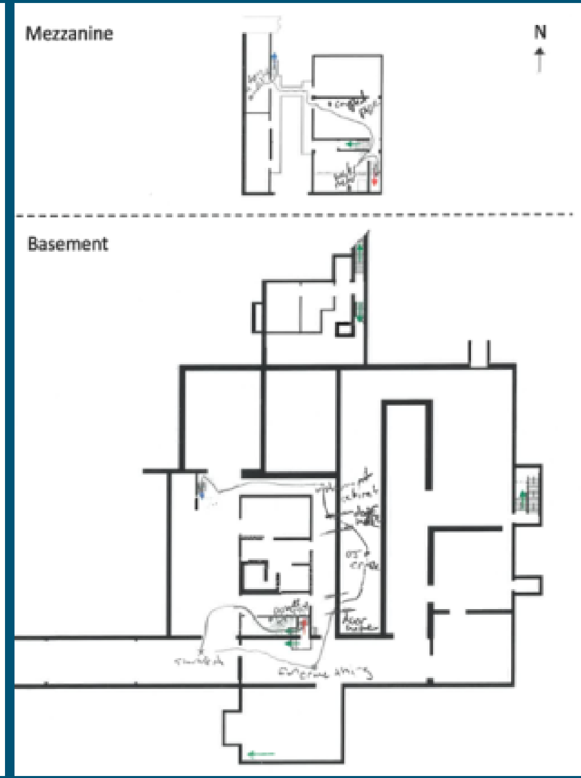



Tests of Spatial Learning

Landmark knowledge: Ability to distinguish between landmarks and unseen items

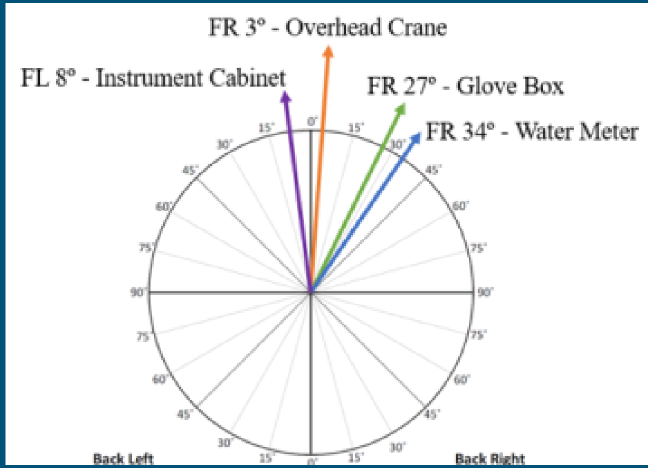
Route knowledge: Ability to draw the route and landmarks on a blank map

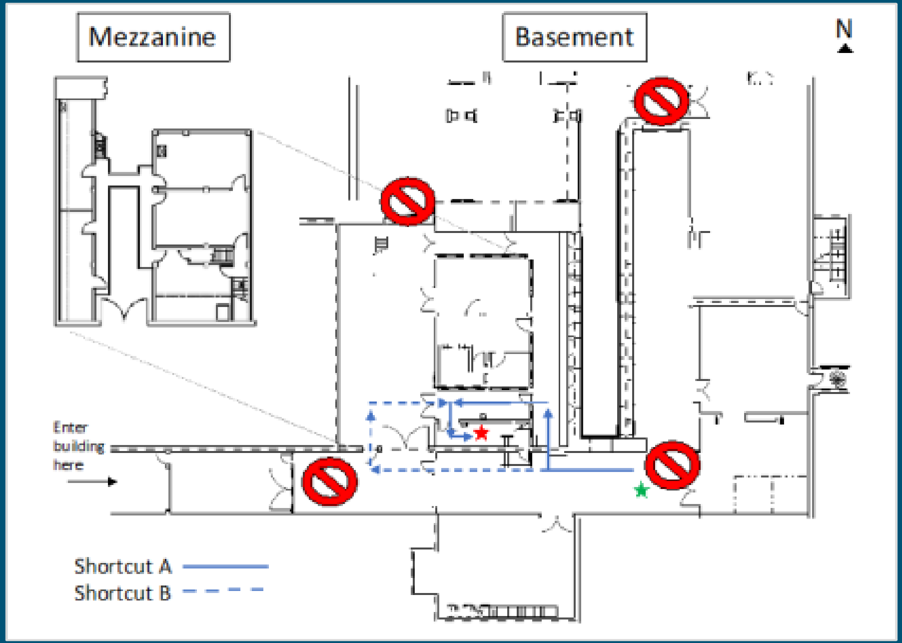




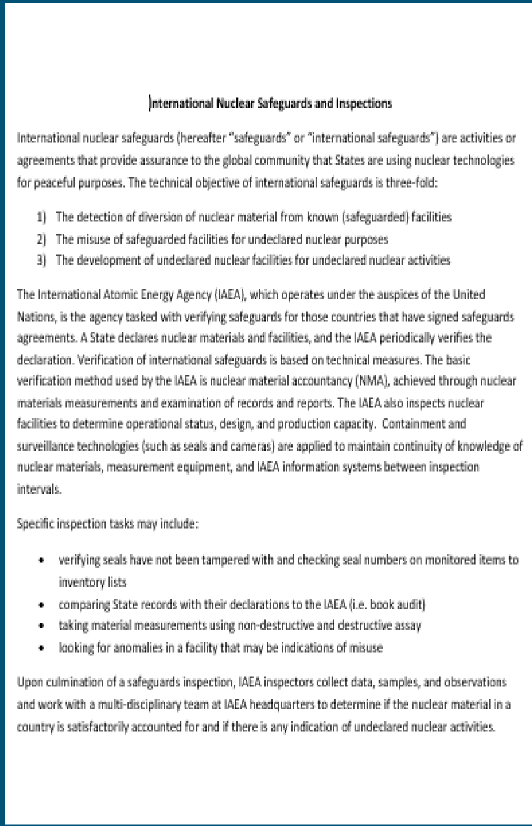
Tests of Spatial Learning

Survey knowledge: Ability to point to landmarks from the starting point of the route
Ability to find shortcuts between pairs of landmarks





Results



International Nuclear Safeguards and Inspections

International nuclear safeguards (hereafter "safeguards" or "international safeguards") are activities or agreements that provide assurance to the global community that States are using nuclear technologies for peaceful purposes. The technical objective of international safeguards is three-fold:

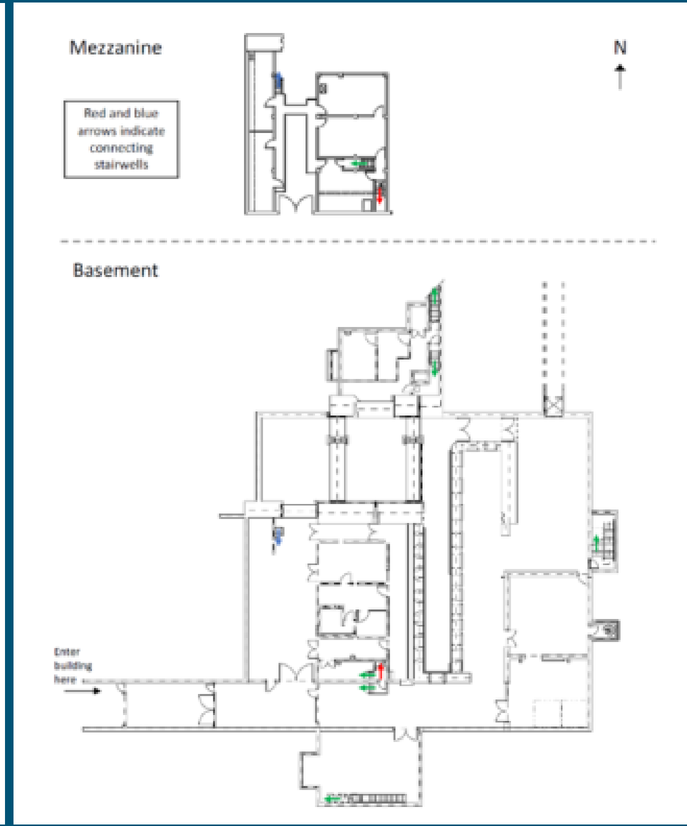
1) The detection of diversion of nuclear material from known (safeguarded) facilities
2) The misuse of safeguarded facilities for undeclared nuclear purposes
3) The development of undeclared nuclear facilities for undeclared nuclear activities

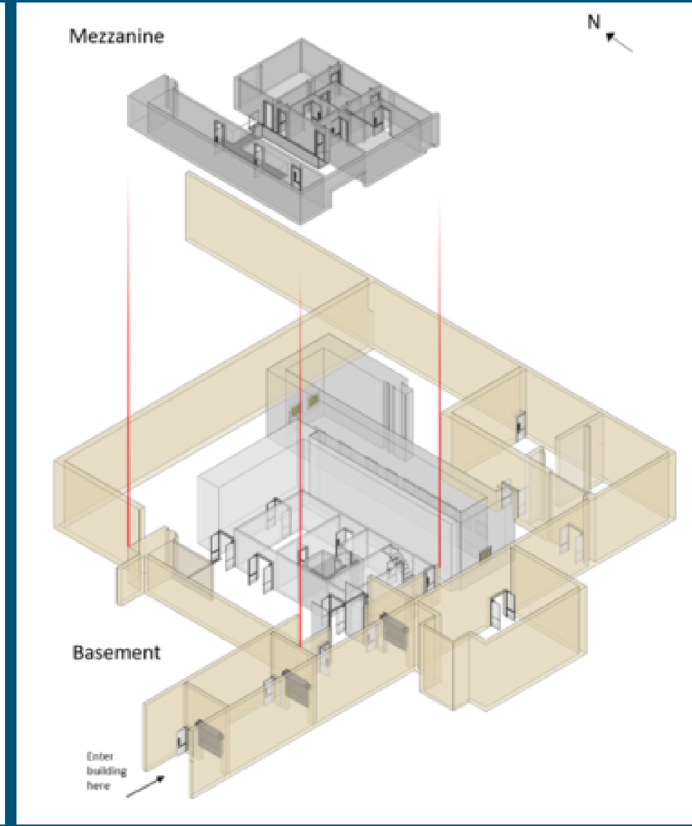
The International Atomic Energy Agency (IAEA), which operates under the auspices of the United Nations, is the agency tasked with verifying safeguards for those countries that have signed safeguards agreements. A State declares nuclear materials and facilities, and the IAEA periodically verifies the declaration. Verification of international safeguards is based on technical measures. The basic verification method used by the IAEA is nuclear material accountancy (NMA), achieved through nuclear materials measurements and examination of records and reports. The IAEA also inspects nuclear facilities to determine operational status, design, and production capacity. Containment and surveillance technologies (such as seals and cameras) are applied to maintain continuity of knowledge of nuclear materials, measurement equipment, and IAEA information systems between inspection intervals.

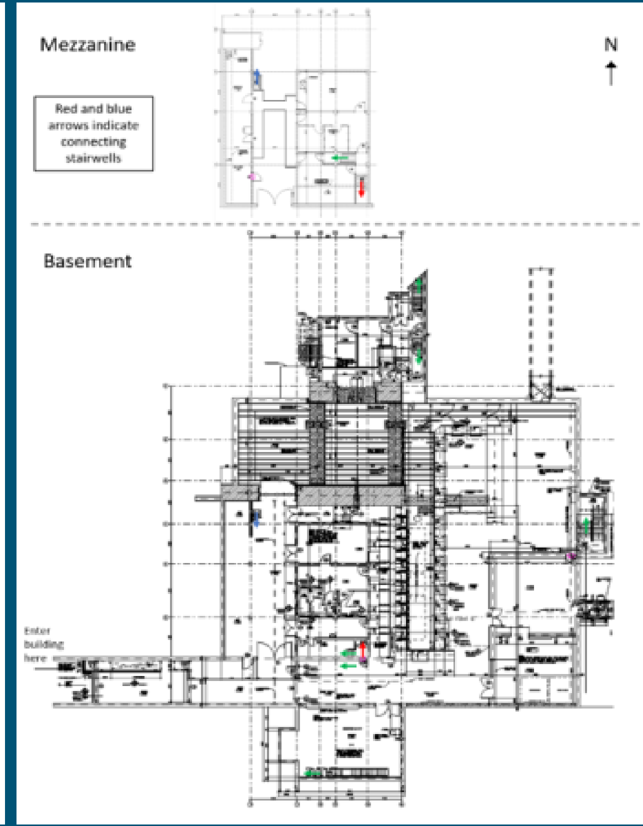
Specific inspection tasks may include:

- verifying seals have not been tampered with and checking seal numbers on monitored items to inventory lists
- comparing State records with their declarations to the IAEA (i.e. book audit)
- taking material measurements using non-destructive and destructive assay
- looking for anomalies in a facility that may be indications of misuse

Upon culmination of a safeguards inspection, IAEA inspectors collect data, samples, and observations and work with a multi-disciplinary team at IAEA headquarters to determine if the nuclear material in a country is satisfactorily accounted for and if there is any indication of undeclared nuclear activities.







No Map

2D Simple Map

3D Simple Map

2D Blueprint

People with good and poor senses of direction performed equally well

People with a good sense of direction performed better

People with a poor sense of direction performed worse

People with a good sense of direction performed worse

People with a poor sense of direction performed the same as in No Map

Results – Pointing Task

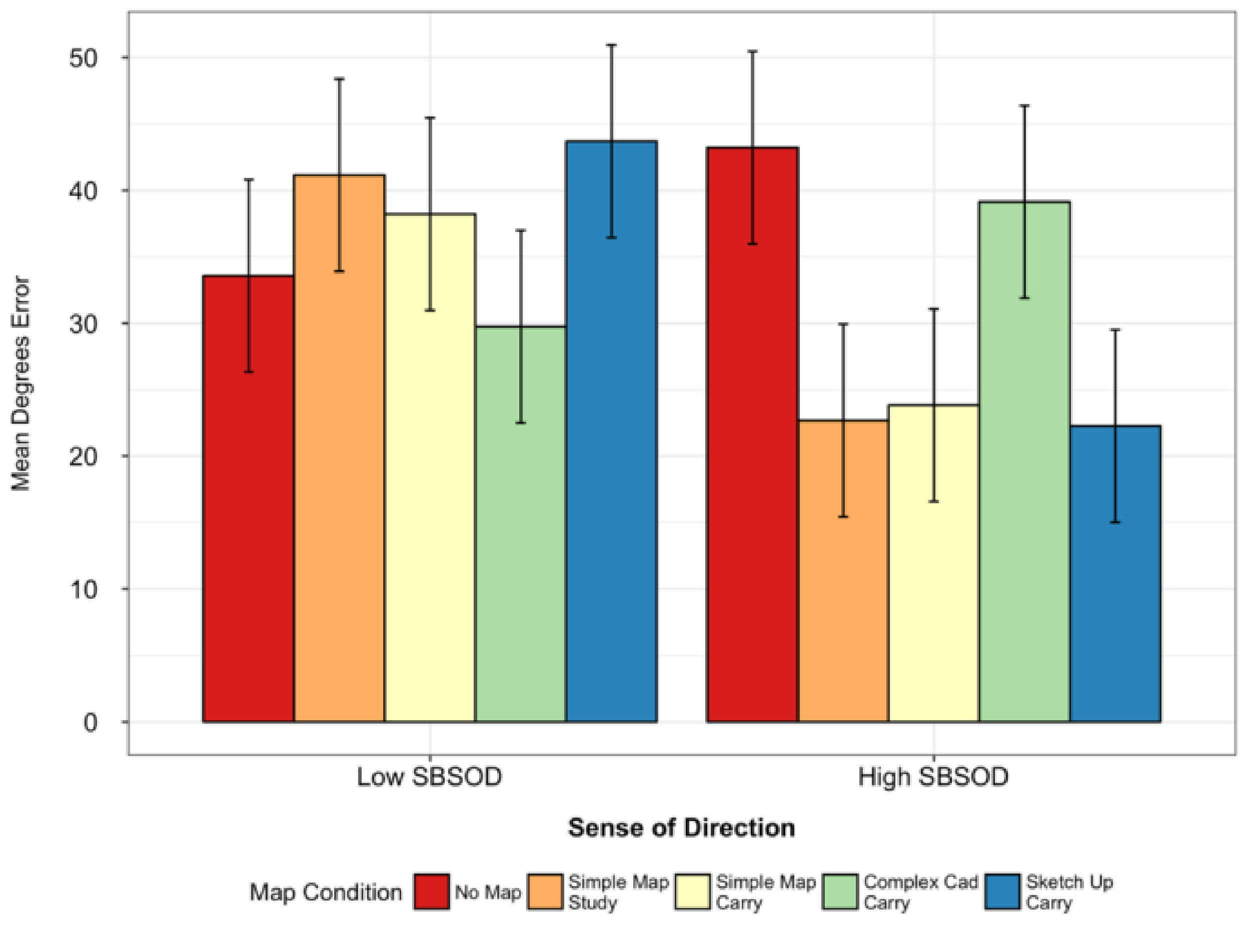
Higher error indicates worse survey knowledge

Low SBSOD

- higher error for the map conditions
- lowest for no map and complex cad

High SBSOD

- simple map (study and carry) and sketch-up maps were helpful
- Higher error with no map and complex map



Results – Shortcut Task

Higher error indicates worse survey knowledge

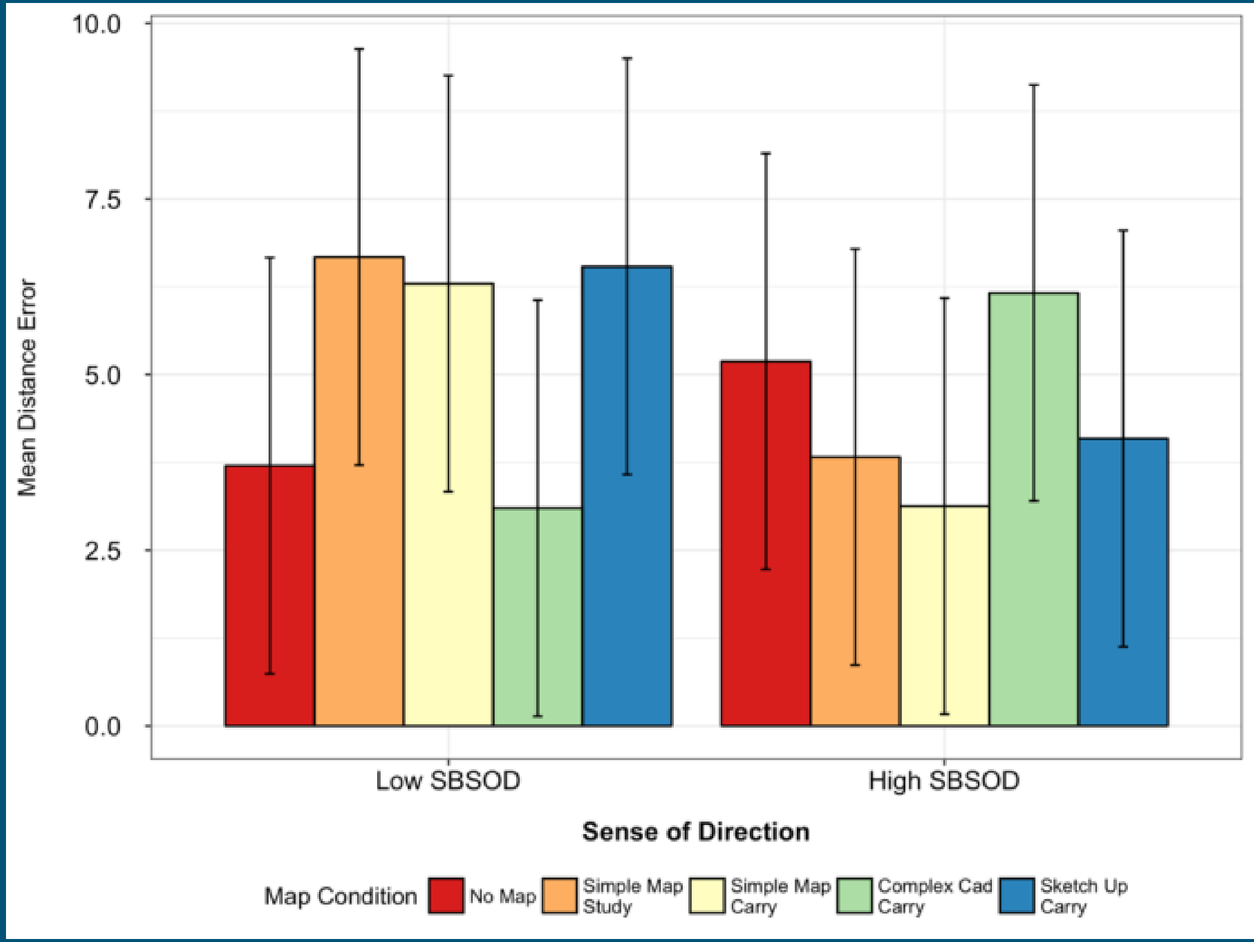
Same general pattern as the pointing task (but with greater error variance)

Low SBSOD

- Lower error with no map and complex map

High SBSOD

- Higher error with no map and complex map



Results – Awareness of surroundings

Target Landmarks

Incidental Landmarks

Unseen Items

People who carried a simple map had a harder time recognizing incidental landmarks

- Trying to use the map distracted them from paying attention to their surroundings

Results – Memory Task (Target Discriminability)

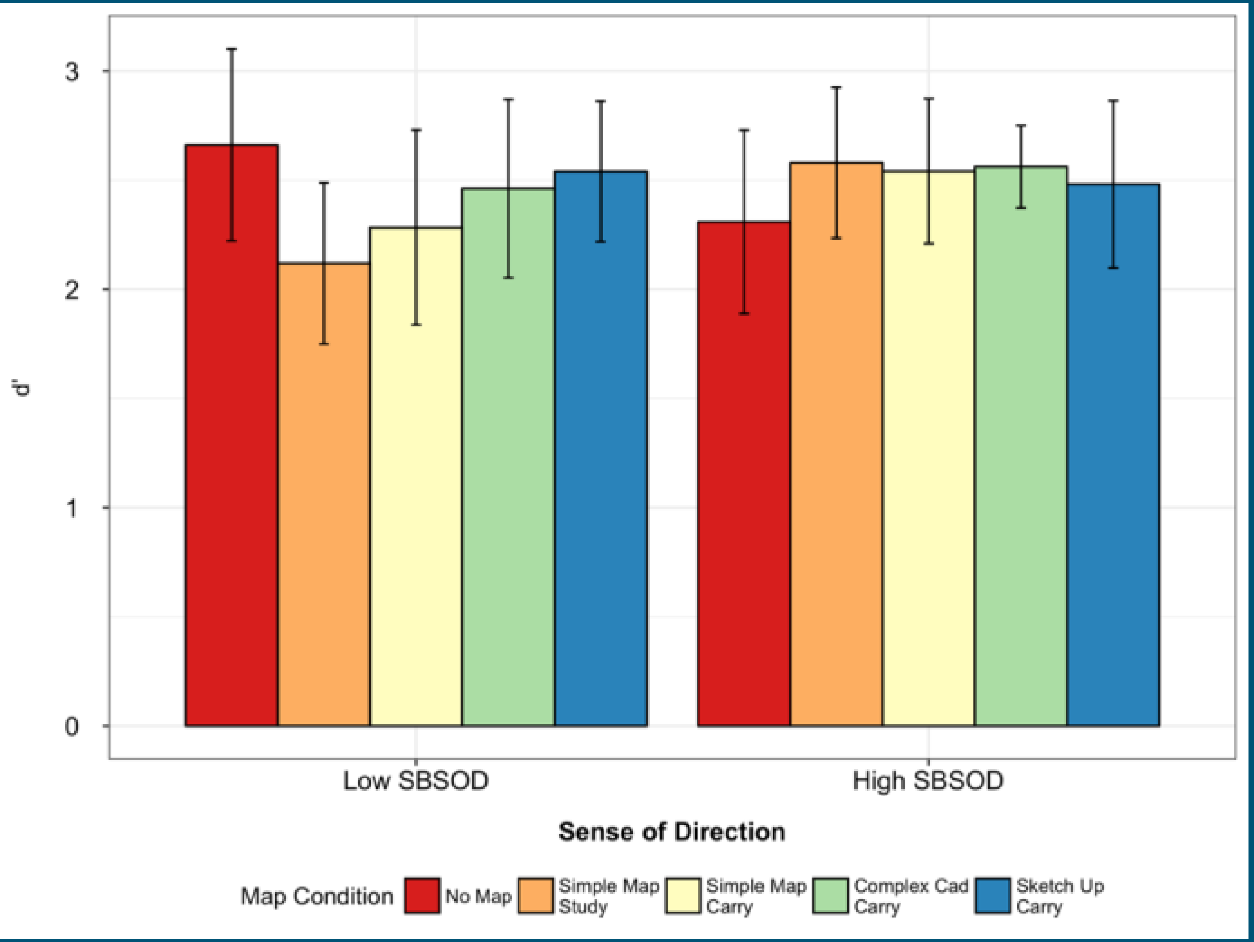
Higher score indicates better landmark knowledge

Only a marginal interaction between SBSOD and map condition

The low SBSOD group had the best landmark knowledge in the no map condition

Suggests that even trying to remember a previously studied map interferes with memory for landmarks

- Evidence against previous assumptions that landmark knowledge does not require attention



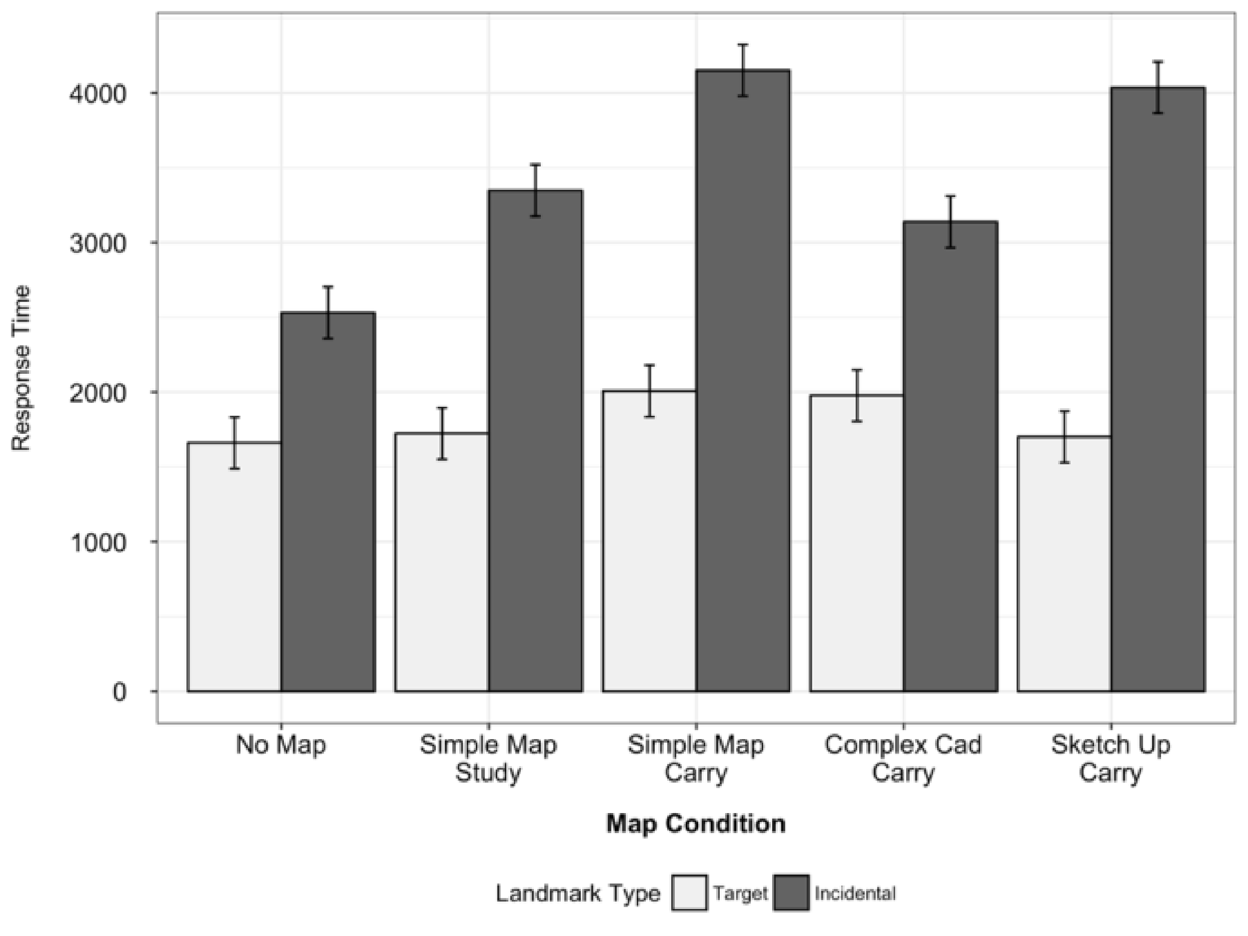
Results – Memory Task (Response Times)

Longer response times indicate difficulty in retrieving memory of item

No differences in response times for target landmarks (light bars)

Large differences in response times for incidental items (dark bars)

- Carrying a map draws attention away from environment--making retrieval of incidental items more difficult
- Even see these effects in simple map study condition – in which person could not physically use map in environment—so this effect is attentional



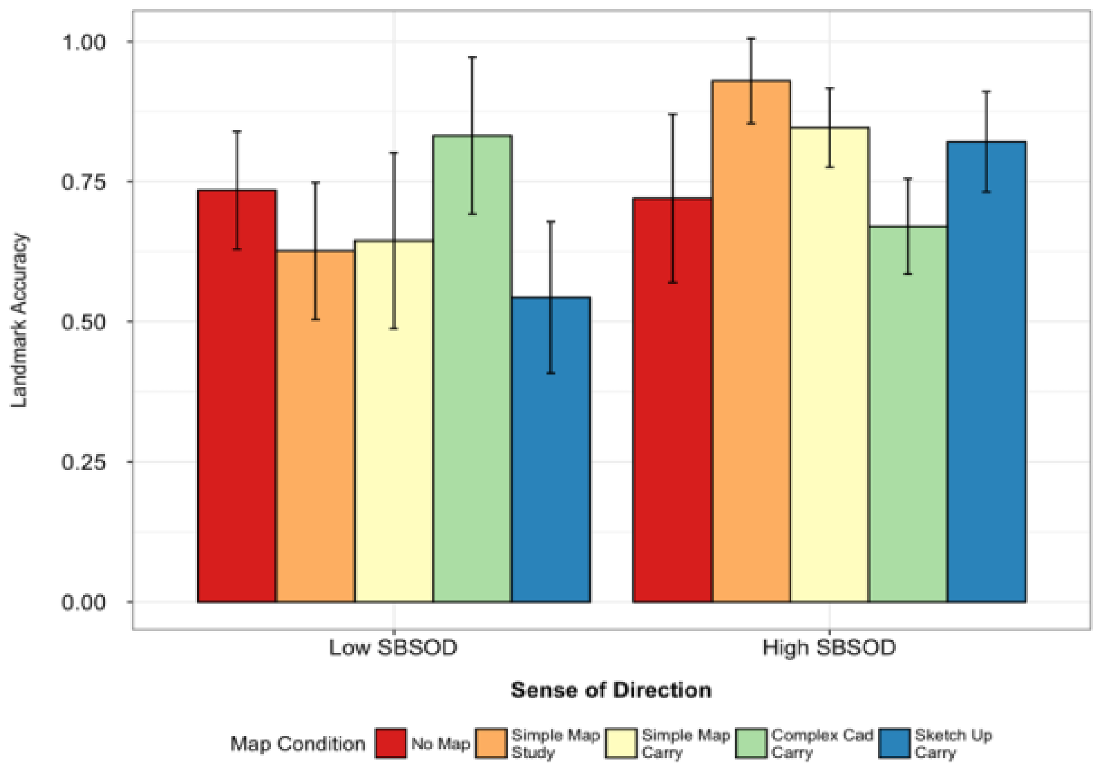
Results – Map Fill-In Task

Higher accuracy indicates better performance

Measures both landmark memory and placement

Using a map either before or during route learning helped the high SBSOD group be able to link their location in the building back to a physical rendering on a test map

The opposite was true for the low SBSOD group-- using maps made them perform worse than people who had never seen a map of the building before



Caveats and Directions for Future Research

We did not use real inspectors

- It's possible they have developed strategies—we might predict better performance from real inspectors

Our participants were unfamiliar with the building

- We predict our tasks would be easier with people who had visited the building before

Our study simplified the task – did not require multi-tasking, wearing PPE, working in foreign language, jet lag from traveling, etc.

- Our results might represent a best-case scenario—we predict spatial learning would be more difficult in the face of additional cognitive load (taking samples, using someone else's notes on the building, etc.)

Recommendations for spatial learning in complex environments

Know your abilities!

- If you have a poor sense of direction, a map might hurt more than it helps
- If you have a good sense of direction, an easy-to-read map is very helpful

Teamwork

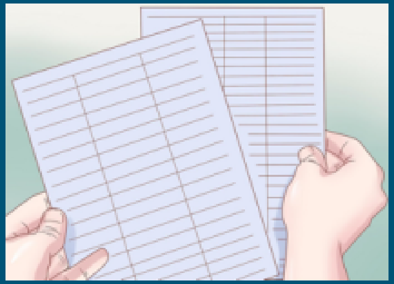
- When working in a team, only one person should track progress on th
- Others should pay attention to their surroundings

Simple is better

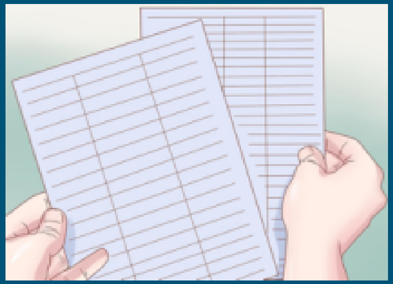
- Detailed blueprints were not helpful for spatial learning
- 3D maps did not provide additional benefit beyond 2D maps
- Studying a map before entering the building was just as effective as carrying the map along

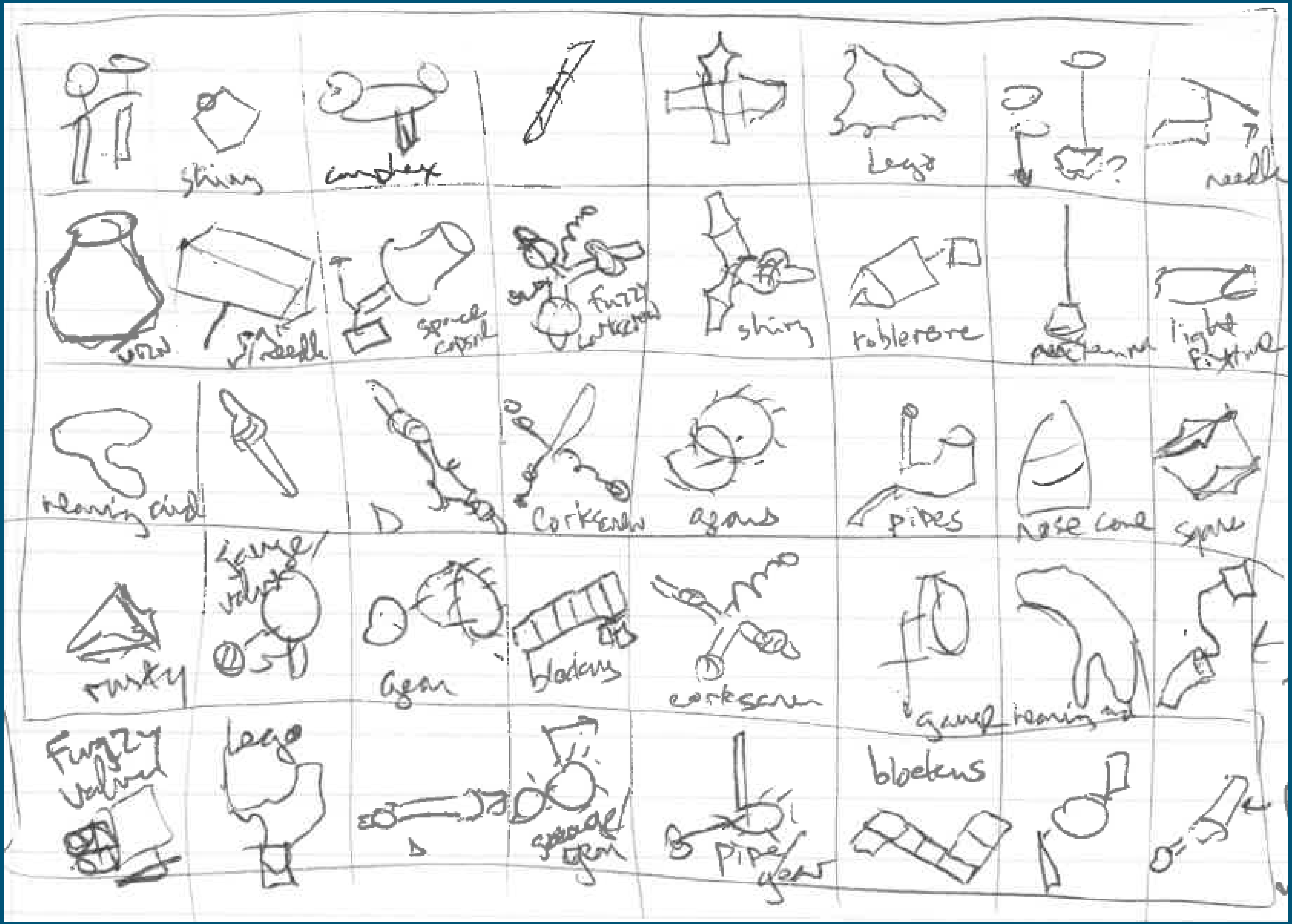
Once an inspection is completed...

What is the best way to record your observations so that you can make use of them several months later?

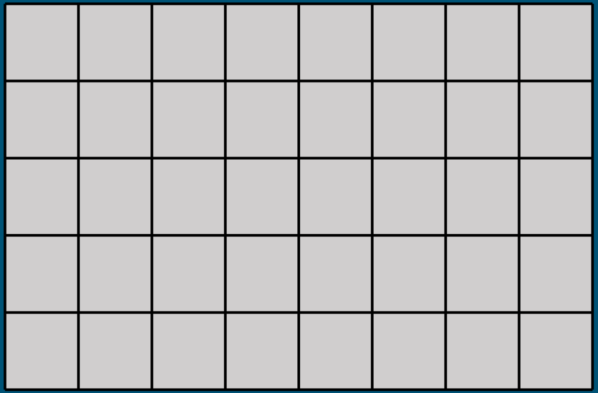


What is the best way to transfer this information to another team?

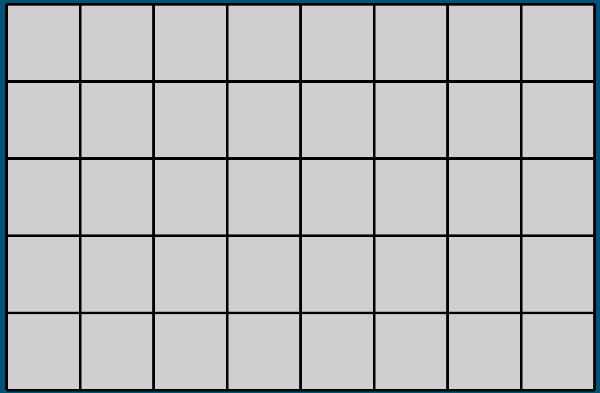




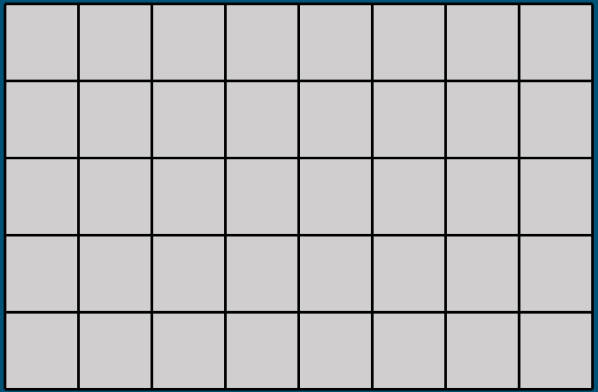
shiny
complex
lego
needle
urn
space capsul
fuzzy corkscrew
shiny
toblerone
light fixture
corkscrew
gears
pipes
nose cone
spare
rusty
gauge/valve
gear
blocks
corkscrew
Fuzzy valve
lego
pipe/gear
blocks



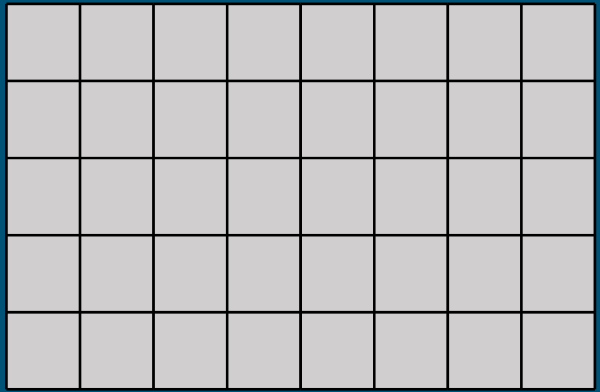
Written Notes



Camera



Camera + Written Notes



No Notes (Memory Only)

Participants had 12 minutes to study or take notes for each board

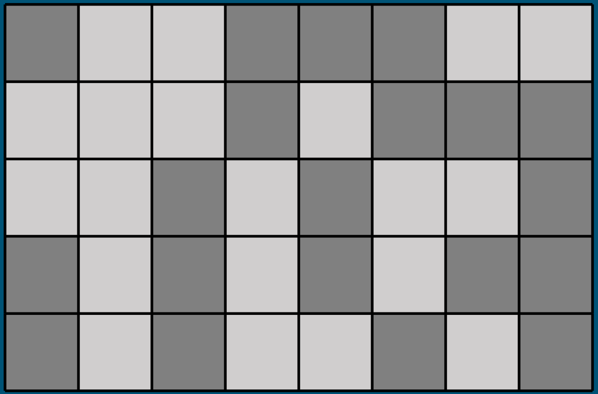
Order of note taking conditions was counterbalanced across participants

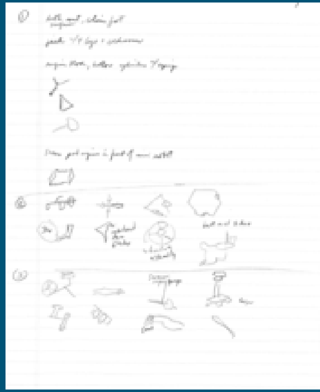
Three Experiments

Experiment 1:
- Participants returned 2 days later and tried to use their notes to detect changes in the image arrays
- 20 participants (7 female, mean age 44, range 24-68)

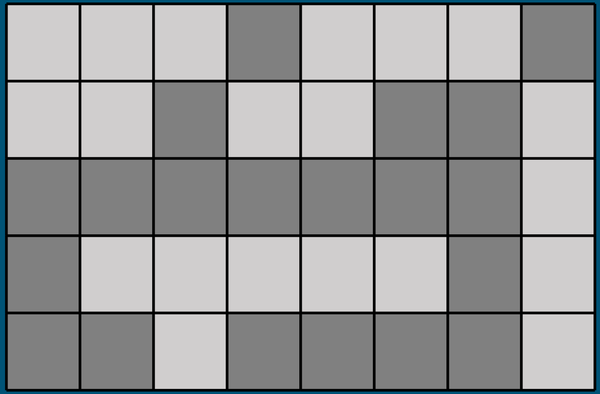
Experiment 2
- Participants from Experiment 1 returned 6-9 months later and tried to use their notes to detect changes
- 16 participants (6 female, mean age 42, range 24-68)

Experiment 3
- New participants used the notes from Experiment 1 to try to detect changes
- 18 participants (9 female, mean age 33, range 19-62)

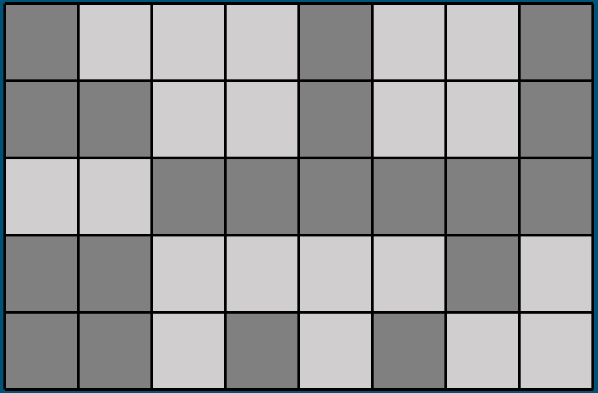




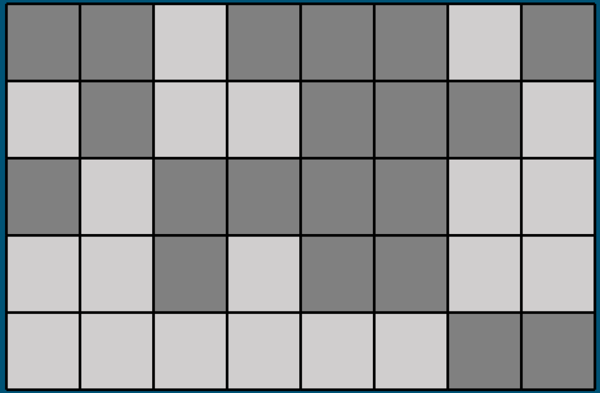
Written Notes



Camera



Camera + Written Notes



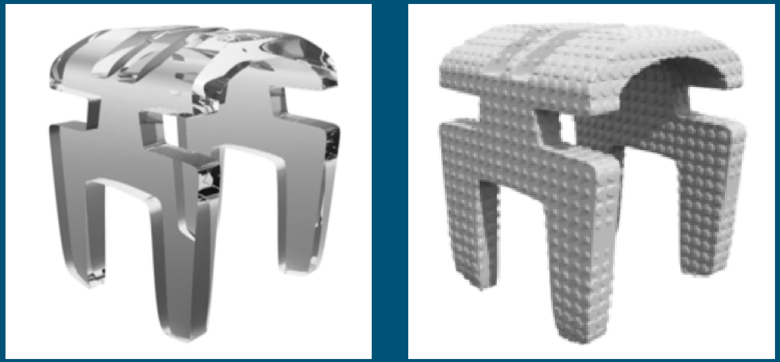
No Notes (Memory Only)

At test, half of the items had changed

Participants had 12 minutes per board to write down which items had changed, what kind of change, and how confident they were

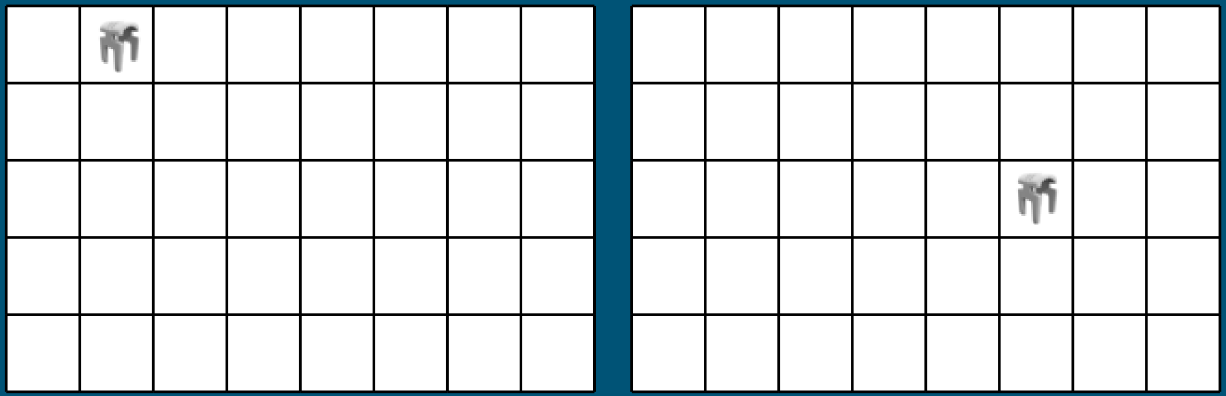
Four Change Types

Material Change (4)

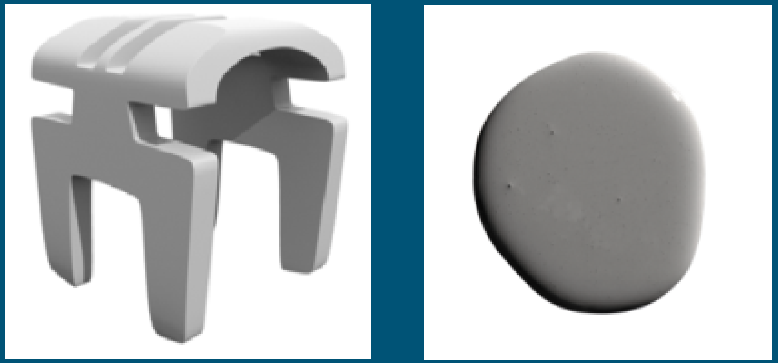


Orientation Change (4)

Location Change (6)



Replacement (6)



Our experiments in the safeguards domain:

- Identified gaps in the existing cognitive science literature
- Used carefully-designed experiments to test the impact of different information formats on human performance
- Produced recommendations that take the IAEA inspectors' constraints into account
- Contributed to the scientific literature
  - Spatial learning in complex indoor environments
  - Knowledge transfer outside of shift-handoff settings
  - Note taking outside of classroom settings

Acknowledgements

This work was funded by Sandia National Laboratories' Laboratory-Directed Research and Development (LDRD) program, through the Global Security Investment Area.

The research team wishes to thank:

- **Michael Trumbo, Siobhan Heiden,** and **Matt Windsor** for experimental support
- **Heidi Smartt** for her safeguards contributions to our experimental design
- **Greg Baum** for his facility engagement support
- 120+ Sandians for experimental participation!

For a full report of work:

Stites, M. C., Matzen, L. E., & Gastelum, Z. N. (2020). Where are we going and where have we been? Examining the effects of maps on spatial learning in an indoor guided navigation task. *Cognitive Research: Principles and Implications, 5*(13).

Gastelum, Z. N., Stites, M. C., & Matzen, L. E. (2019, May). The role of maps in site knowledge and wayfinding: A human performance evaluation for international nuclear safeguards inspections. In *Proceedings of the European Safeguards Research and Development Association Symposium 2019*

Stites, M. C., Matzen, L. E., Smartt, H. A., & Gastelum, Z. N. (2019, July). Effects of note taking method on knowledge transfer in inspection tasks. In *International Conference on Human-Computer Interaction* (pp. 594-612). Springer, Cham.

Gastelum, Z. N., Matzen, L. E., Stites, M. C., & Smartt, H. A. (2019, July). Human performance testing on observation capture methods for international nuclear safeguards inspections: Transferring knowledge from the field to headquarters and back. In *Proceedings of the Institute of Nuclear Materials Management Annual Meeting 2019*.