Designing HCI Experiments

Chaklam Silpasuwanchai

Asian Institute of Technology

chaklam@ait.asia

Overview

Sources

- Mackenzie, Chapter 4-5, **Scientific Foundations, Designing HCI Experiments**, Human Computer Interaction: An Empirical Research Perspective, 1st ed. (2013)
- Zhao, **How to Design Controlled Experiments in HCI?** `https://www.slideshare.net/shilman/controlled-experiments-shengdong-zhao`

Research Methods

- In HCI research, the most accepted method is **experimental method**.
- **Golden rule** is 70% quantitative (verification of effects) and 30% qualitative (tell us why)
- In experimental research, **comparative evaluation** is often done, where **proposed solution** is pit against (1) **state-of-the art** technique and (2) **baseline** technique.
  - Baseline allows comparison of results with past studies. State-of-art allows comparison of proposed solution against the "best"

Research Question

- How does **pie menu** - our proposed solution - compared to **linear menu** in terms of performance?

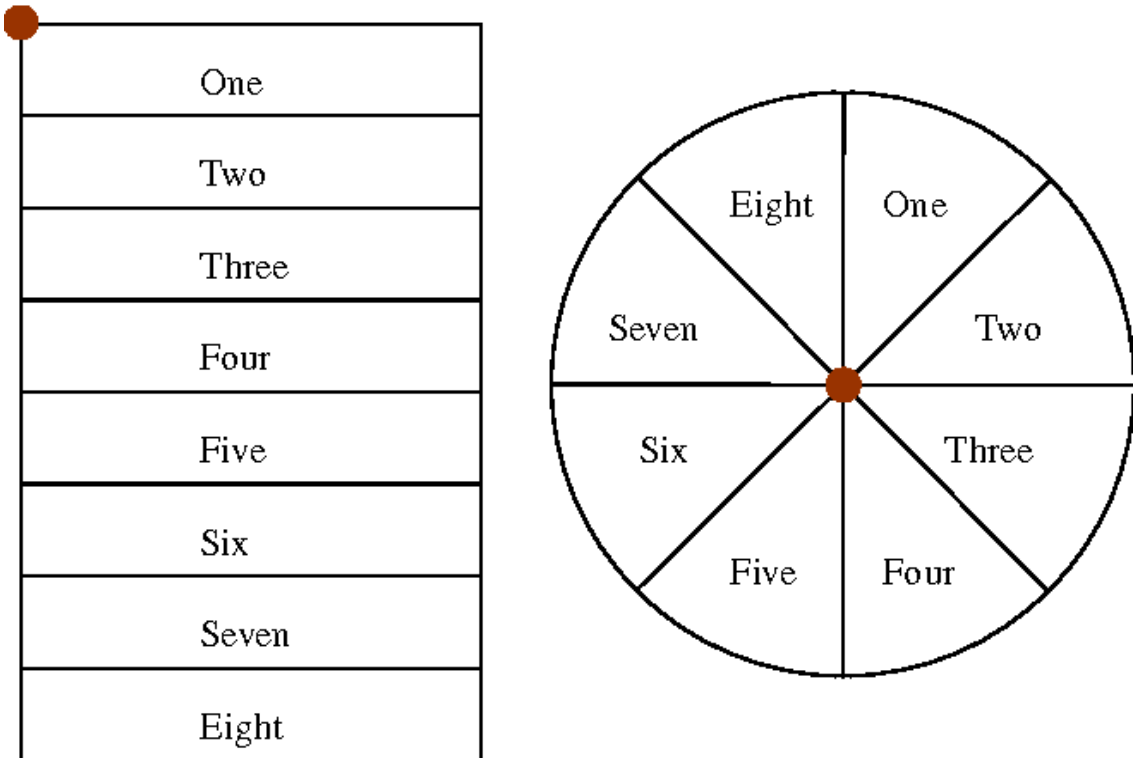

Figure: Linear menu vs. pie menu

Participants

Who should we pick?

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- Since everyone are users, we can pick anyone. But generally, pick **target population**
- For statistical analysis, we will pick at least 12 participants. A good number is around 12-15 participants. We can also use **power analysis** or **read papers**.

Independent Variables

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- IV are variables we **manipulate**. Also called **factor**. What should be our IV?
- Our first IV is the **menu type** which has two **levels**: pie menu and linear menu
- To increase our research generalizability, we can further adds more IV, for example:
  - Second IV: **menu breadth** with 3 levels: 4, 8, 12
  - Third IV: **menu depth** with 3 levels: 1, 2, 3
  - Fourth IV: **usage** with 2 levels: mobile and stationary

Thus our work is a **2 x 3 x 3 x 2 factorial design**

Independent Variables

- Levels are sometimes called **conditions**.
- Other common IV such as feedback modality, selection technique, and so on...It is **recommended to choose between 2-3 IVs** for any experiment.
- Having too many IVs are impossible to interpret. For example, a design with one IV has *main effect* but no *interaction effect*. Two IV has two *main effects* and one *interaction effect*. Three IVs - there will be seven effects!

Independent variables	Effects					Total
	Main	2-way	3-way	4-way	5-way	
1	1	-	-	-	-	1
2	2	1	-	-	-	3
3	3	3	1	-	-	7
4	4	6	3	1	-	14
5	5	10	6	3	1	25

Figure: Source: Fg. 5.2 (Mackenzie)

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- For our case study:
  - **Speed**: measured as completion time
  - **Accuracy**: measured as error rate
  - **Learning**: measured speed and accuracy improvements change over time
- Good DVs are usually **numbers in continuous scale**
- Recommended to have **2-4 DVs**. Why not too little or too much?

Dependent Variables

- In HCI, the most common DV is **speed** (reported in task completion time) and **accuracy** (reported in error rate)
- Others include preparation time, action time, throughput, gaze shifts, mouse-to-keyboard hand transitions, preses of BACKSPACE, target re-entries, retries, key actions, gaze shifts
- Also some creative: count of negative facial expressions, number of times users shift their gaze from on-screen keyboard to the typed text.
- When reporting, it is important to see the **common units used in earlier work**, so your work can be compared

Other Variables

- Other variables are **noise** variables that we want to either control (**Control** Variables), allow to vary (**Random** Variables), or do our best to mitigate (**Confounding** Variables).
- Note that a variable can be either Control, Random or Confounding, depends on how you look at them.

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For our case study:

- **Control** variables for our experiment are computers, mouse, monitor, experimental time, environment, instructions, etc. which **should be** controlled as constant across participants

Random Variables

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- Our study?

For our case study:

- **Random** variables are participants' age, gender, background which we cannot control, but a well-designed experiment will help. At least, we need to record these info.

Confounding Variables

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For our case study:

- **Confounding** variables are **learning effect**, **individual differences**, and **implementation of pie menu and linear menus**

Within- and between-subjects

- Should we test all conditions with all participants?
- Or each condition with each group of participants?

Within- and between-subjects

- **Within-subjects** is when each participant is tested on each levels. Is also called *repeated measures*
- **Between-subjects** is when each participant is tested on only one level.

(a)

Participant	Test Condition		
1	A	B	C
2	A	B	C

(b)

Participant	Test Condition
1	A
2	A
3	B
4	B
5	C
6	C

Figure: Source: Fg. 5.6 (Mackenzie). a) Within-subject, b) Between subject

Within- and between-subjects

- **Within-subjects** uses **less** participants, prone to **practice effect** and thus require more **testing**. Usually preferred.
- **Between-subjects** uses **more** participants, prone to **effect of individual differences** and thus require effort to **balance** all groups. However, certain experiments require between-subject such as drug experiment or gender experiment
- **Mixed-design** uses both within-subject and between-subject in one design. For example, the experiment has two factors: block is within-subjects with perhaps 10 levels (block 1, block 2...) and handedness is between-subjects with two levels (left, right)

Within- and between-subjects

In our study, within-subject is the clear choice. Choosing between-subject will **require lots of participants** in order to balance out the effect of individual differences. The more factors (subsequently the conditions), the more participants we are required which is costly. On the other hand, within-subject is prone to **practice/learning effect** which can be easily fixed by administering **block design.**

Order Effects

Do you think the order of IV conditions matters?

If yes, how we should best order it?

Order Effects - Latin Square

- Order of conditions may affect the results, e.g., **fatigue**, **learning effects**. Thus it is necessary to *counterbalance* the order of conditions across participants
- **Latin Square** is a common method for counterbalancing.

(a)

A	B
B	A

(b)

A	B	C
B	C	A
C	A	B

(c)

A	B	C	D
B	C	D	A
C	D	A	B
D	A	B	C

(d)

A	B	C	D	E
B	C	D	E	A
C	D	E	A	B
D	E	A	B	C
E	A	B	C	D

Figure: Source: Fg. 5.7 (Mackenzie). Here A, B, C, etc. represent conditions or combined conditions.

Order Effects - Balanced Latin Square

- A deficiency in Latin squares of order 3 and higher is that conditions precede and follow other conditions an **unequal** number of times. In the 4 *x* 4 Latin square, for example, B follows A three times, but A follows B only once
- **Balanced Latin-square** addresses this. The top row has the sequence A, B, *n*, C, *n-1*, D, *n-2*, etc. For following rows, simply add 1

(a)

A	B	D	C
B	C	A	D
C	D	B	A
D	A	C	B

(b)

A	B	F	C	E	D
B	C	A	D	F	E
C	D	B	E	A	F
D	E	C	F	B	A
E	F	D	A	C	B
F	A	E	B	D	C

Figure: Source: Fg. 5.8 (Mackenzie).

Order Effects - Full Latin Square

- The one drawback of balanced Latin squares is that it only works for **even** number of test conditions
- One may draw out all possible combinations (n!) (**full-counter balancing**) but would require more participants (here we could recruit 18 participants, each set with 3 participants).

A	B	C
A	C	B
B	C	A
B	A	C
C	A	B
C	B	A

Figure: Source: Fg. 5.11 (Mackenzie).

Order Effects - Randomization

- Another way to address this imbalance is to simply **randomize** the order of conditions. This is suitable when the task is **very brief**, there are many **repetitions** of the task, and there are **many test conditions**.
- Last, it is recommended to look at **earlier works**, to see the common acceptable counterbalancing method

Order Effects - Sequential

- Last way to address this imbalance is to use **sequential** order of conditions. This is suitable when the conditions you compared is of **increasing difficulty** by nature. For example, if you have two condition of a small and big width, it might be okay to always do small before big width since there is **no learning effect** anyway.
- Sequential is all about how you perceive the task whether it's an increasing difficulty task. I recommended to use this only if you are very sure.

Order Effects

How about our study?

Order Effects

- In our case, we have four IVs - menu type (MT) (2), breadth (B) (3), depth (D) (3), and usage (U) (2)
- The key here is to choose a reasonable order scheme that **minimize number of participants**, while reasonably mitigating learning effect.
- Since we have even number of conditions ($2 \times 3 \times 3 \times 2 = 36$), let's say we do **Balanced Latin Square**, we need a multiple of 36 participants, which is a lot!
- Can we further minimize participants.? Since **menu type** is our main factor, we don't want to compromise. **Usage** is only two level, so trying to do anything won't change much. **Breadth** and **Width** worth 9 conditions - since this is a lot, we can change to **Randomized** scheme or even **Sequential** scheme (since the complexity increases accordingly)
- Thus, we will have four conditions - MT1U1, MT1U2, MT2U1, and MT2U2. We will denote them as A, B, C, D. We can use balanced latin square which will give four sets: ABDC, BCAD, CDBA, DACB. Thus our number of participants will be multiples of 4; 16 and 20 are good numbers.

Task and Procedure

- It is highly recommended to use the **same task** (or with slight variations) as past work, so to promote comparison and advancement of the field. Also, they have already been well thought out.
- **Don't design your own procedure**, unless you have worked in the field for at least many years!

Task and Procedure

- What if user makes mistake?
  - use **trials**
- What if we want to monitor their learning rate
  - use **blocks** - a repeated section of an experiment that consists of multiple trials in randomized orders.
  - use **session** - which is simply composed of multiple blocks
- So how many trials and blocks? How about breaks?
  - More blocks and more breaktime are always desirable but based on **experimental time**. Why? **Reasonable duration is at max 1 hour.**

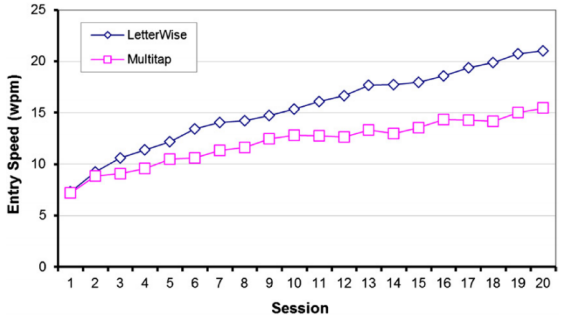

Figure: Source: Fg. 5.16 (Mackenzie). Two text-entry method were tested over 20 sessions; each session involved 30 minutes of text-entry.

Task and Procedure

For our case study:

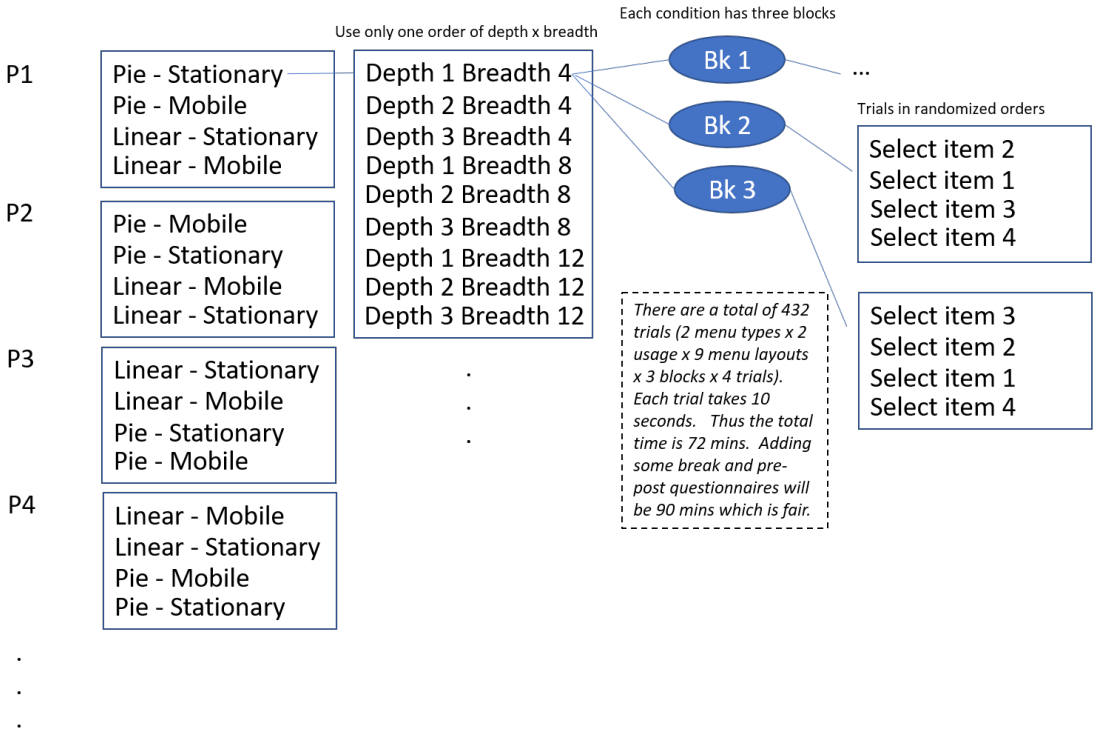

Figure: Possible experimental design

- **Trials**: 4 trials where each trial select certain menu item as fast and as accurate as possible
- **Blocks**: 3 blocks consists of multiple trials in randomized orders that repeated for each condition
- **Time**: 2 **input** methods x 2 **postures** x 3 **depth** x 3 **breadth** x 3 **blocks** x 4 **trials** x 2s $=$ 864s $=$ 14.4 mins $+$ 35 **breaks** x 1 min $=$ 49.4 mins
- How did I determine the break time or blocks?

Task and Procedure: Example

- Procedure:
  1. Consent form and pre-experiment questionnaires
  2. Instructions
     - First, a menu item will be shown on display to indicate target
     - Second, user presses space-bar button to indicate "start"
     - Third, user select the target menu item as fast and as accurate as possible
     - Fourth, a moment of pause before going back to first
  3. Practice trials
  4. Main experiment with breaks
  5. Post-experiment questionnaires

Questionnaire Design

- Two purposes: (1) gather information on **demographics** (age, gender, etc.) and experience with related technology, (2) gather **opinions** at the **end of experiment**

Do you use a GPS device while driving? ☐ yes ☐ no

Which browser do you use?
☐ Mozilla *Firefox* ☐ Google *Chrome*
☐ Microsoft *IE* ☐ Other (_____)

Which browser do you use? _____

Please indicate your age:_____

Please indicate your age.
☐ < 20 ☐ 20-29 ☐ 30-39
☐ 40-49 ☐ 50-59 ☐ 60+

Questionnaire Design

- **Avoid creating your own questionnaires**. Making questionnaires requires some statistical proof so it's not easy. Follow the proven ones.
- Check with your past work what questionnaires they use. **Follow them.**

Validity Analysis

- Consider an experiment that compares **two gestures technique for TV**, which experimental design?
  1. Tested in a real-world environment - **large sofa** with a **large TV**. They can watch anything. They can also eat. No instructions given.
  2. Tested in a **controlled environment** - more-controlled - task, procedure, IV, DV.

Internal and External Validity

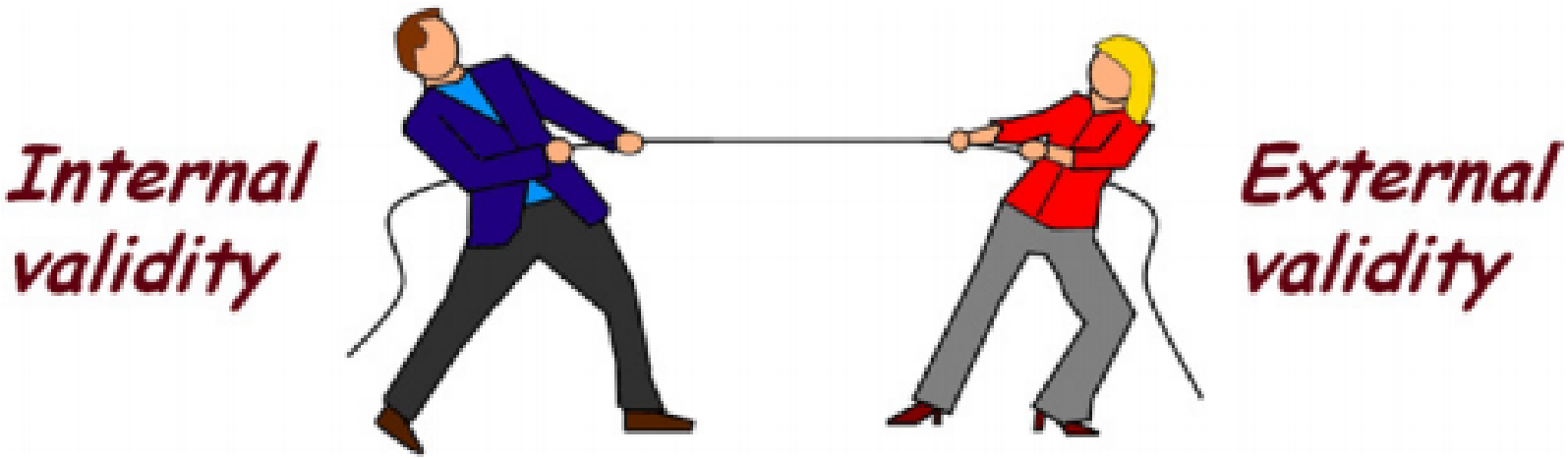

Figure: Source: Fg. 4.9 (Mackenzie)

Internal Validity

- **Internal Validity** is the extent to which an effect observed is due to test conditions
  - When you are comparing two conditions, did you make sure everything else is **equal** except what you are manipulating?
  - Did you correctly **order** the experimental conditions?
  - Did you assign users to different groups in a **randomized** way?
  - Did you take care **learning effects** by applying appropriate training before the experiment or applying block design?

External Validity

- **External Validity** is your result **generalized** across people and contexts
  - **Representative** participant?
  - **Representative** task?
  - **Representative** tool?

Internal vs. External Validity

- The idea is that in research, **internal validity** cannot be compromised. As for external validity, researchers have to do their best in a way that their work achieve the **highest external validity possible** and also **acknowledge the limitation** in their work.

Construct Validity

- is the extent to which you are **measuring things** based on what you claim
  - Measuring **happiness** but uses only interview or user preference
  - Measuring **typing performance** but ignore that people can type while walking
  - Talking about **habit** formation but collect data using only five days experiment

Practical suggestions

- **Reminders**: RQ → Hypothesis → Design and Implementation → Experimental Design → statistical analysis
- Always do a **pilot study.** It's almost 99% that your first experimental design will always be imperfect.
- There are **NOT only one experimental design solution; some decisions are arguable**. Of course, there are also many obviously wrong design.
- Try not to make your own task or questionnaires. **Follow papers**. This will make your work comparable, and also valid.
- **One hour** is just approximate. Some experiment is more tiring, so make sure your participants are fresh. If needed, split the experiment into several studies.
- I didn't talk much about **iterative experiment**, which is about having no clear IV, but instead iteratively explore your solution with your users directly. This is usually inefficient but only intended for people with no idea about their IV. **If you cannot think about what is your IV or hypothesis, usually because you don't understand enough.**

Link to project

- Any papers you read should be **experimental**, i.e., have clear IV and DV.
- You can attempt on any topic you want, but it should compose of experimental components, i.e., you should have clear, specific **research question**, **hypotheses**, and **experimental design**.
- Why Chaky emphasizes *experimental* papers, but does not encourage reading *exploratory* papers?

What's next

- Next coming week 3 workshops on experiment. Read and try the workshops before coming to class.

1st Workshop

Task

Given two baseline input methods: **QWERTY** and **T9**, and our proposed method: **Swiping Gestures** which we claim to be faster and more accurate. Design an experiment discussing:

- Research question
- Hypotheses
- Independent variables
- Dependent variables
- Any possible confounding/random/control variables
- Within or Between subject design
- Task
- Order
- Total experimental time

Discussion

2nd Workshop

Task

- **Research Question**:Which body parts are suitable for wearable vibration feedback in walking navigation for blind people?
- **Independent variables**: body parts (ears, neck, wrist, hand, chest, waist, ankle, front foot, mirrored on both sides), postures (standing, normal walking, fast walking), stimulus durations (700ms, 1000ms, 1500ms, 2000ms)
- **Dependent variables**: Perceivability and subjective perferences
- **Design the rest of the experiment**, including the task and procedure, the place of experiment, the participants, the order effects, number of trials and blocks, and last, calculate the total time of the experiment

Discussion

3rd Workshop

Task

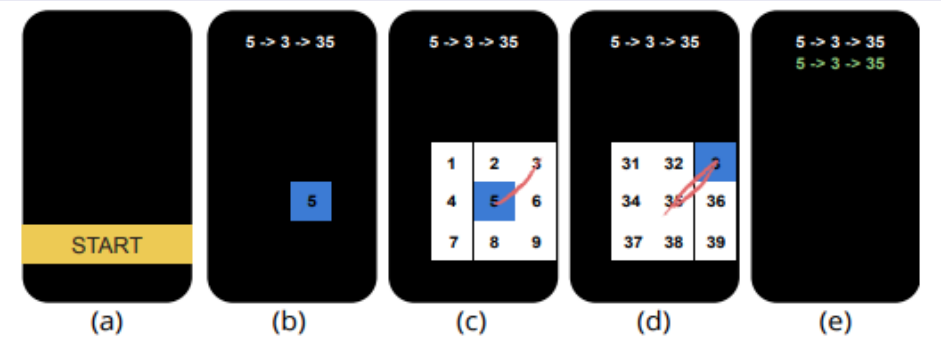

Figure: Source: Zheng et al. CHI 2018

- **Research Question**:We have proposed a gesture menu used in mobile phones - How does the newly proposed gesture menu compared to linear menu (baseline)?
- **Independent variables**: Input method (linear menu vs. gesture menu), Depth (1, 2, 3), Execution (guided, recall)
- **Dependent variables**: Time and error rates
- **Design the rest of the experiment**, including the task and procedure, the participants, the order effects, number of trials and blocks, and last, calculate the total time of the experiment

Discussion

Questions