Design Process

CS 695 / SWE 699, Fall 2023

Programming Tools

GEORGE MASON UNIVERSITY

Today

- Part 1 (Lecture)(~1 hr)
  - Design process: what are the steps in a developer-centered approach to designing developer tools?
    - Exploratory study: what challenges does a developer face?
    - Sketching & prototyping: how might a new tool better address these challenges?
    - Experiments: does your tool help developers work more effectively than they were before?
- Break!
- Part 2 (In-Class Activity)(~45 mins)
  - Conducting an observational exploratory study
- Project time in groups
  - Work on project in groups
  - Time to talk to me about projects

Logistics

- 2 weeks: HW1 — 9/13 — lit review + revised tool idea
- 2 weeks: HW2 — 9/27 — observational study
- 2 weeks: HW3 — 10/11 — sketches of tool interaction
- 7 weeks: HW4 - 11/29 — tool + small evaluation study

Exploratory studies

- Field observations / ethnography / lab observations
  Observe developers at work
- Surveys
  Ask **many** developers specific questions
- Interviews
  Ask a **few** developers **open-ended** questions
- Contextual inquiry
  Ask **questions** while developers do work
- Indirect observations (artifact studies)
  Study artifacts (e.g., code, code history, bugs, emails, ...)

Exploratory studies: goals

- Understand the process that developers use to tackle a programming problem
  - What questions do developers ask?
  - What strategies do they use to answer these questions?
  - Identify steps that are time consuming
  - Identify barriers that prevent developers from making progress
  - Identify breakdowns, where developers' mental model diverges from system (e.g., inserting defects)
  - In what ways do tools support or not support?

Controlled experiment

- Only way to argue **causality** - change in var x causes change in var y
  - Often used to test impact of a tool
  - Does change in programming tool cause change in {time, success, ...}

- Manipulate **independent** variables
  - Creates "conditions" that are being compared
  - Can have >1, but # conditions usually exponential in # ind. variables

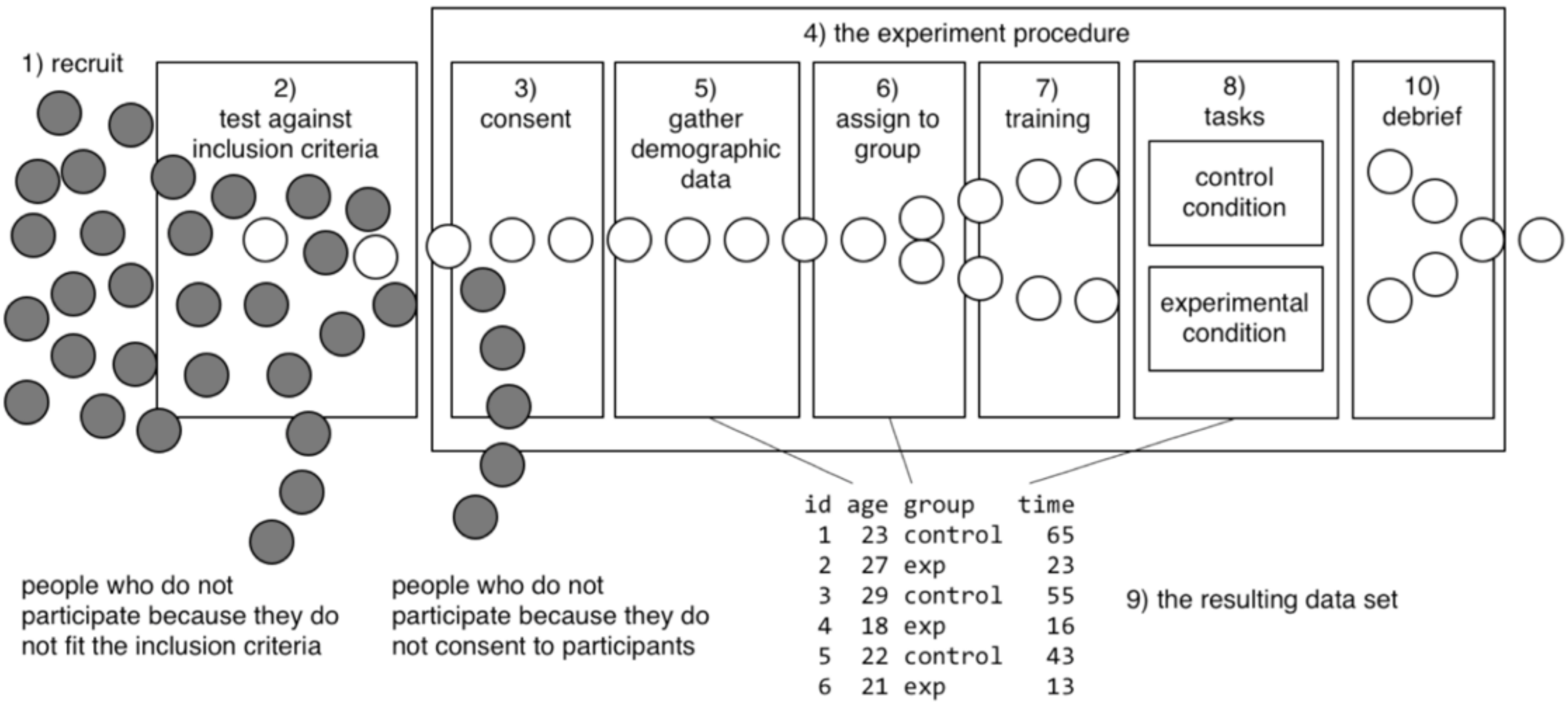
- Measure dependent variables (a.k.a measures)
  - Quantitative variable you calculate from collected data
  - E.g., time, # questions, # steps, ...

- **Randomly** assign participants to condition
  - Ensure that participants only differ in condition
  - Not different in other **confounding** variables

- Test hypotheses
  - Change in independent variable causes dependent variable change
  - e.g., t-test, ANOVA, other statistical techniques

Study design

Anatomy of a user study

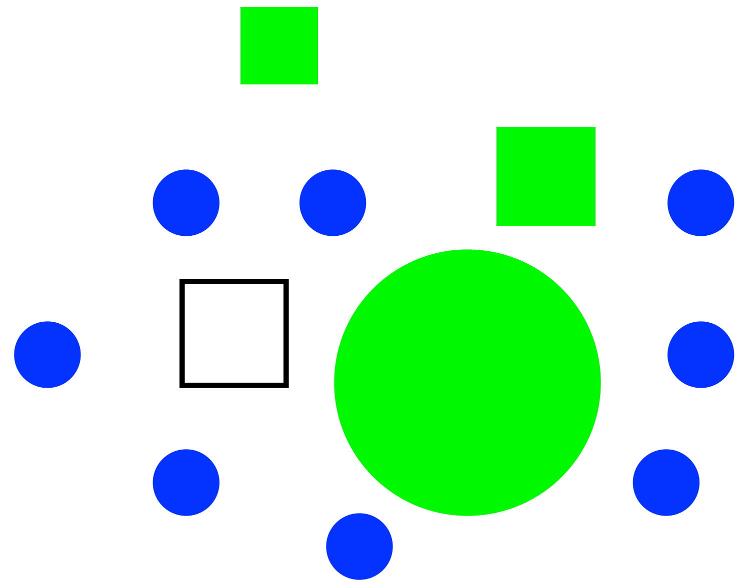


Terminology

- “Tool” — any **intervention** manipulating a software developer’s work environment
    - e.g., programming language, programming language feature, software development environment feature, build system tool, API design, documentation technique, …
- Data — what you collected in study
- Unit of analysis — individual **item** of data
- Population — **all** members that exist
- Construct — some **property** about member
- Measure — **approximation** of construct computed from data

Example — Study of shapes

Real world

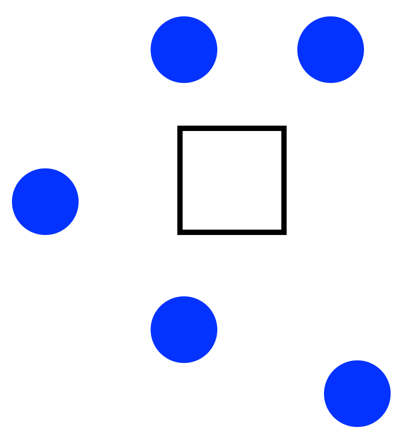


Population

shape
size
filled / empty
color

Constructs

Study



Sample of population

is blue?

size >10 or size < 10

Measure

(Some) types of validity

- **Validity** = should you believe a result
- **Construct** validity
  - Does measure correspond to construct or something else?
- **External** validity
  - Do results generalize from participants to population?
- **Internal** validity (experiments only)
  - Are the differences between conditions caused only by experimental manipulation and not other variables? (confounds)

Example: Typed vs. untyped languages

S. Hanenberg. (2009). What is the impact of static type systems on programming time? In the *PLATEAU workshop, OOPSLA 09*.

Participants 26 undergrads **Task** write a parser 27 hrs

Setup new OO language 16 hr instructions

Conditions type system vs. no type system

found errors at compile time errors detected at runtime

RESULTS

Developers with untyped version significantly faster completing task to same quality level (unit tests).

Example: Study validity

- **Construct** validity
  Does measure correspond to construct or something else?

- **External** validity
  Do results generalize from participants to population?

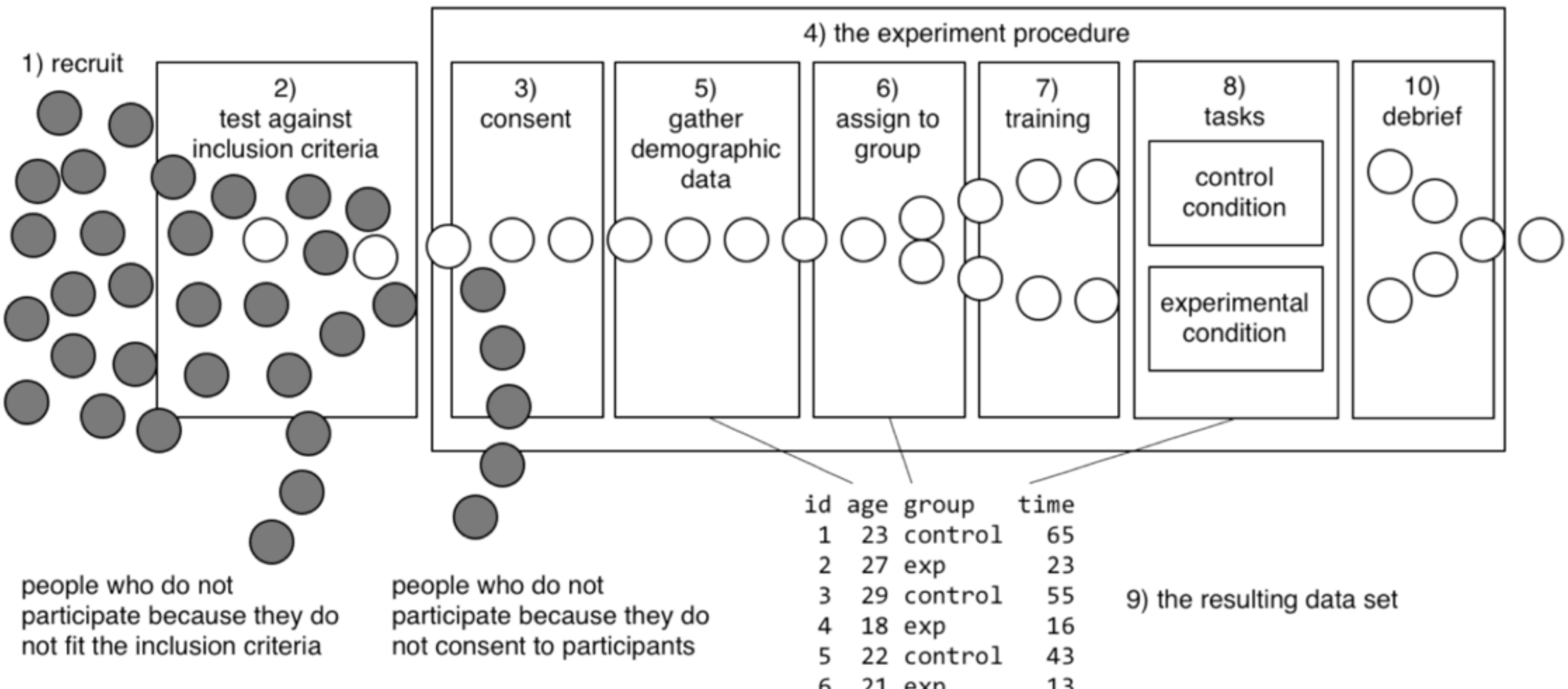
- **Internal** validity (experiments only)
  Are the differences between conditions caused only by experimental manipulation and not other variables? (confounds)

- **Other** reasons you're skeptical about results?

Good (not perfect) study designs

- Goals
  - Maximize **validity** - often requires more
    - more participants, data collected, measures
    - longer tasks
    - more realistic conditions
- Minimize **cost** - often requires
  - fewer participants, data collected, measures
  - shorter tasks
  - less realistic, easier to replicate conditions
- Studies are **not proofs** - results could always be invalid
  - don't sample all developers / tasks / situations
  - measures imperfect
- Goal is to find results that are
  - **interesting**
  - **relevant** to research questions
  - **valid enough** your target audience believes them

Overview


4) the experiment procedure
1) recruit
2) test against inclusion criteria
3) consent
5) gather demographic data
6) assign to group
7) training
8) tasks
control condition
experimental condition
10) debrief
id age group time
1 23 control 65
2 27 exp 23
3 29 control 55
4 18 exp 16
5 22 control 43
6 21 exp 13
9) the resulting data set
people who do not participate because they do not fit the inclusion criteria
people who do not participate because they do not consent to participants

Deciding who to recruit

- **Inclusion criterion**: attributes participants must have to be included in study
- Goal: reflect characteristics of those that researchers believe would benefit
- Example - Nimmer & Ernst (2002)
  - Support those w/ out experience w/ related analysis tools
  - Chose graduate students
  - Developed items to assess (1) did not have familiarity w/ tool (2) Java experience (3) experience writing code

Common inclusion criteria

- Experience w/ a programming language
  - Self-estimation of **expertise**; time
- Experience w/ related **technologies**
  - Important for learning new tool
- **Industry experience**
  - Indicator of skills & knowledge; could also ask directly
- (Natural) language proficiency

How many participants to recruit?

- More participants —> more statistical power
  - higher chance to observe **actual** differences
  - **power analysis** — given assumptions about expected effect size and variation, compute participants number
- Experiments recruited median **36** participants, median **18** per condition
  - Some studies smaller

Recruiting participants

- Marketing problem: how to attract participants meeting inclusion criteria
- Questions:
  - Where do such participants pay **attention**?
  - What **incentives** to offer for participation?

Sources of participants

- Students
  - Class announcement, fliers, emailing lists
  - Incentives: small compensation & intrinsic interest
- Software professionals
  - Relationships w/ industry researchers
  - Studies by **interns** at companies
  - **Partnerships** or contracts with companies
  - **In-house** university software teams
  - **Meetup** developer groups, public mailing lists, FB groups
  - CS Alumni mailing lists, LinkedIn groups

Remote participants

- Online labor markets focused on or including developers (e.g., MTurk, oDesk, TopCoder)
- Pros
  - Can quickly recruit hundreds or **thousands** of participants
  - Use their own space & tools; work at own time
- Cons
  - May **misreport** levels of experience
  - Might leave task temporarily; more extraneous variation

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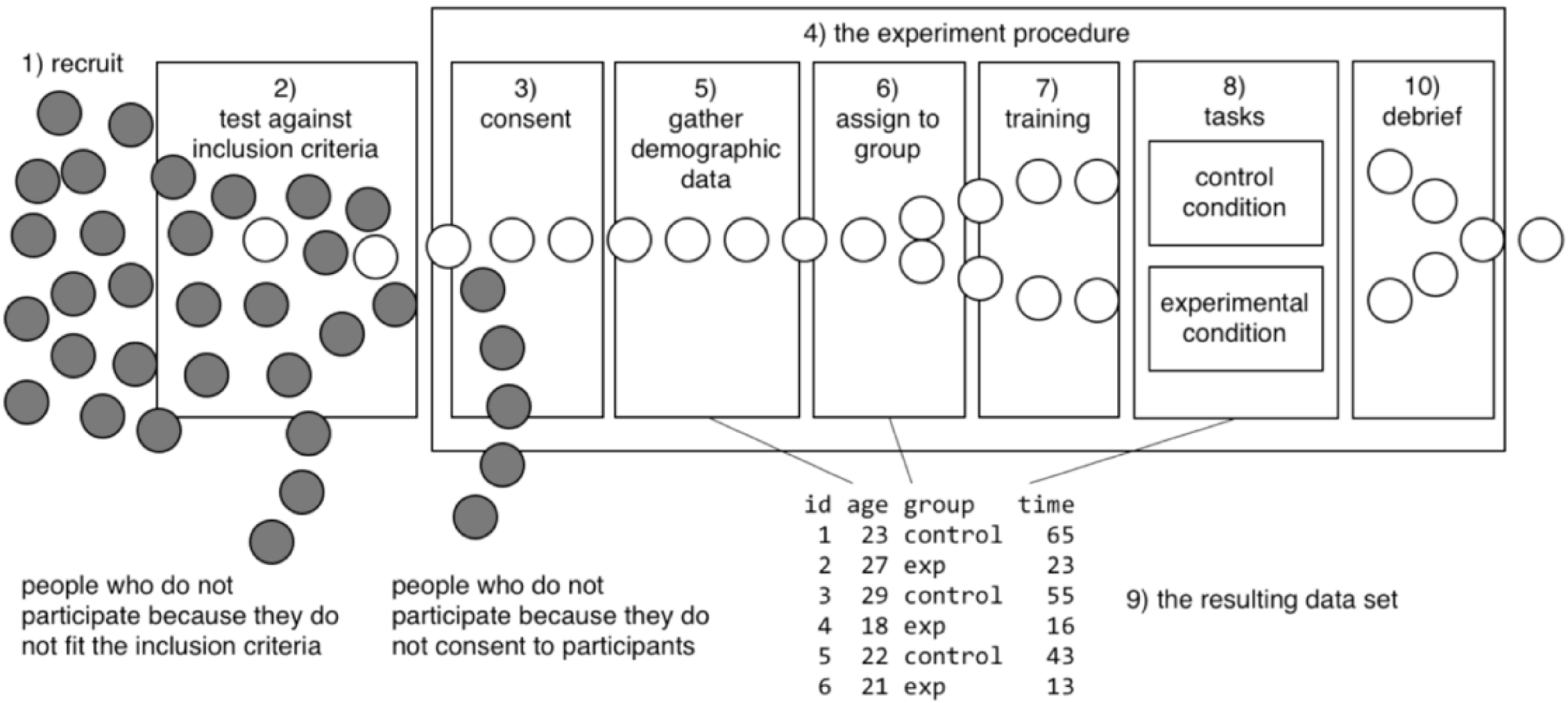

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Informed consent

- Enables participants to **decide** to participate with a few page document
- Key elements
  - Names & contact info for you and other experimenters
  - **Purpose** of the study
  - Brief (one or two sentence) high-level description of the types of work participants will be asked to do
  - Expected **length** of the study
  - A statement of any possible **benefits** or compensation
  - A statement of any possible **risks** or discomforts
  - Overview of the data you will collect (thinkaloud, screencast, survey questions, etc.)
  - Clear statement on **confidentiality** of data (who will have access?)

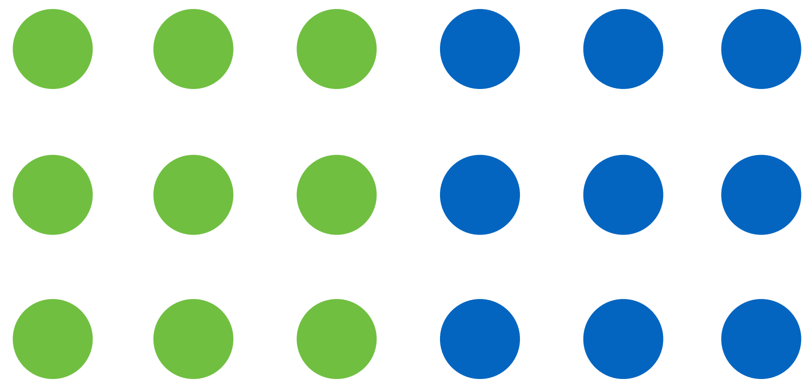
Collecting demographic data

- Goal: understand expertise, background, tool experience, …
- **Interviews** — potentially more comfortable
  - Before or after tasks
- **Surveys** — more consistent, can be used to test against inclusion criteria during recruiting

Assigning participants to an experimental condition

- Random assignment
  - distributes random **variation** in participant skills and behavior across all conditions
  - minimizes chance that observed difference is due to participant differences
- Used with a **between-subjects** experiment
- Are alternative designs that can reduce number of participants necessary to recruit

Within-subjects design



- All participants use all tools being compared one at a time across several tasks
  - e.g., participant uses tool in task 1 but not task 2
- **Learning effect** — doing first task may increase performance on second task
- —> **Counterbalancing** — randomize order of task & on which task participants use each tool
  - Latin Square design

Training participants

- Knowledge participants need includes
  - how to use **tools** in the environment provided
  - terminology & domain **knowledge** used in task
  - design of programs they will work with during task
- Can provide background and **tutorial** materials to ensure participants have knowledge.

To train or not to train?

- Key study design question, creating assumptions about context of use results generalize to
- Training
  - Ensures participants are **proficient** and **focused** on the task
- No training
  - Generalizes directly to new users who don't have training materials, but risks study being dominated by learning
- Studies often choose to provide training materials for tool

Design of training materials

- Goal: **teach** required concepts quickly & effectively
- Possible approaches
    - Background materials
    - Video instructions
    - Tutorial where participants complete example task w/ tool
    - Cheat sheets
- Can also include **assessment** to ensure learning
- Can be helpful for experimenter to answer participant questions

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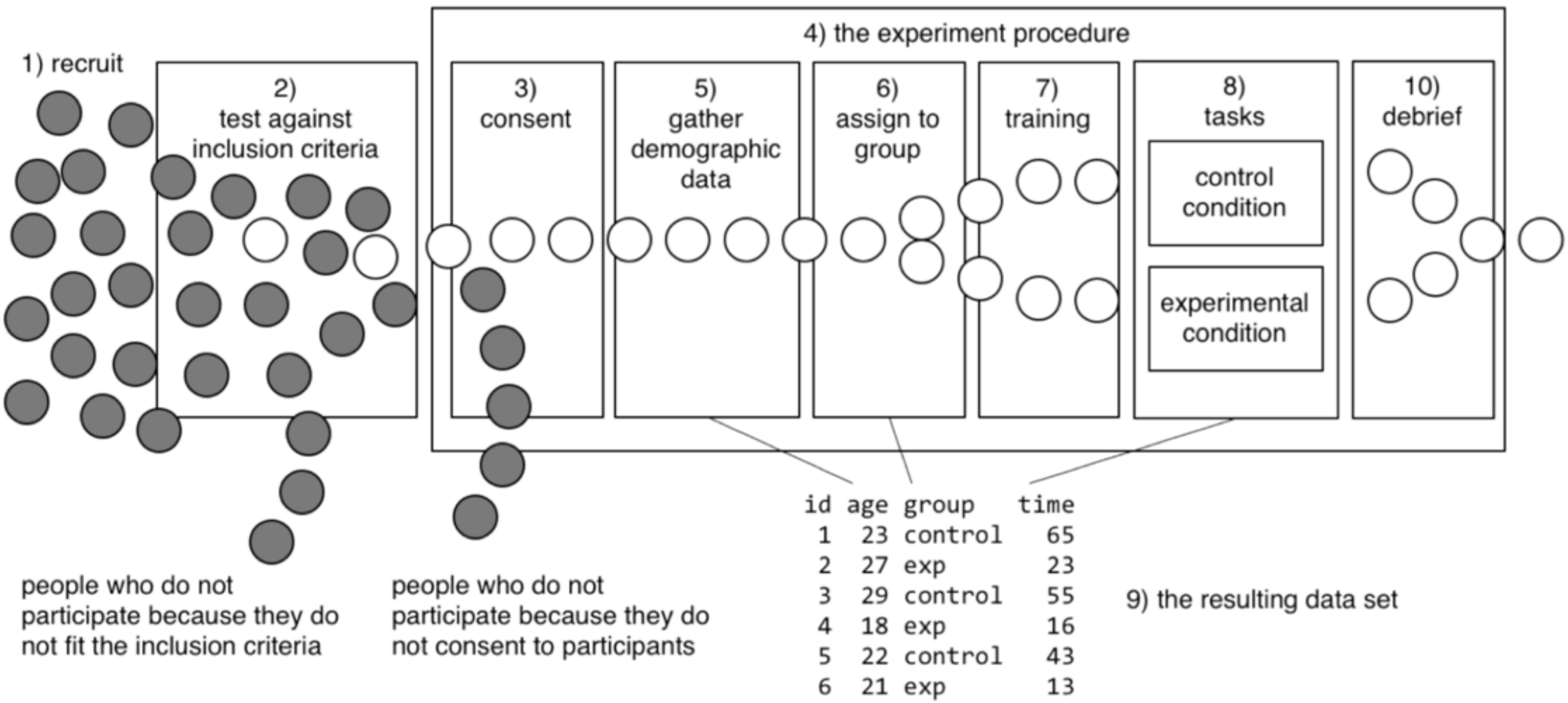
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Tasks

- Goal: design tasks that have **coverage** of work affected by tool
- Key tradeoff: realism vs. control
  - How are real, messy programming tasks **distilled** into brief, accessible, actionable activities?
- More realism —> messier, fewer controls
- More control —> cleaner, less realism
- Tradeoff often takes the form of tradeoff between bigger tasks vs. smaller tasks

Feature coverage

- Of all functionality and features of tool, which will receive **focus** in tasks?
- More features —> more to learn, more variation in performance, higher risk of undue negative results
- Fewer features —> less to learn, less ecological validity, more likely to observe differences

Experimental setting

- Experiments can be conduct in lab or in developer's actual workspace
- Experiments most often conducted in **lab** (86%)
  - Enables **control** over environment
  - Can minimize distractions
  - But less realism, as may have different computer, software, … from participants' normal setting

Task origin

- **Found** task — task from real project (15%)
  - e.g., bug fix task from an OSS project
  - More **ecologically** valid
  - May not exist for new tools
  - Can be hard to determine what feature usage found task will lead to
- **Synthetic** task — designed task (85%)
  - Can be easier to tailor for effective feature **coverage**
  - Must compare synthetic task to real tasks

Task duration

- **Unlimited** time to work on a task
  - Allow either participant or experimenter to determine when task is complete
  - Hard to find participants willing to work for longer time periods
- **Fixed** time limit
  - More **control** over how participants allocate time across tasks
  - Can introduce **floor effect** in time measures, where no one can complete task in time
- Typical length of **1 - 2** hours

Measuring outcomes

- Wide range of possible measures
    - Task completion, time on task, mistakes
    - Failure detection, search effort
    - Accuracy, precision, correctness, quality
    - Program comprehension, confidence
- Most frequent: **success** on task, **time** on task, tool **usefulness**

Piloting

- Most **important** step in ensuring useful results!
- (1) Run study on **small** (1 - 4) number of participants
- (2) Fix **problems** with study design
  - Was the tool tutorial sufficient?
  - Did tasks use your tool? Enough?
  - Did they understand your materials?
  - Did you collect the right data?
  - Are your measures correct?

  (3) Fix **usability** problems
  - Are developers doing the “real” task, or messing with tool?
  - Are users confused by terminology in tool?
  - Do supported commands match commands users expect?
- (4) **Repeat** 1, 2, and 3 until no more (serious) problems

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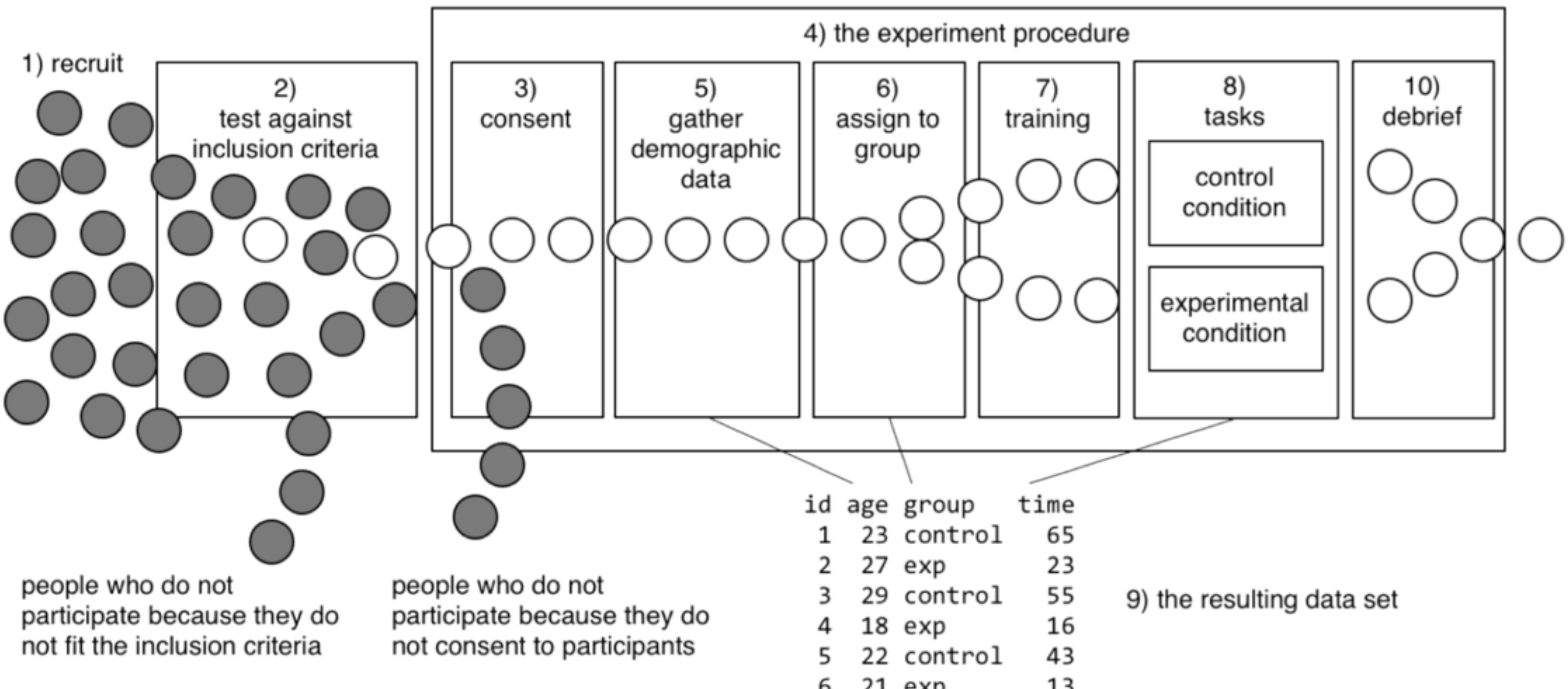

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Qualitative data

On the value of qualitative data

- Experiment may provide evidence that A is “better” than B
- But always generalizability questions about **why** and **when**
- Qualitative data offers possibility of explanation, making it possible to explain why result occurred.
- Can use **coding** to convert qualitative data to categorical data, which can be counted or associated with time to create quantitative data

Collecting qualitative data

- Screencasts
  - **Record** screen as participants do tasks
  - Many video recorders (e.g., SnagIt)
  - Offers insight into **what** participants did
    - What was time consuming
  - Permits quantitative analysis of **steps & actions**
    - Can code more fine-grained time data
  - Does not provide insight into why developers did what they did

Collecting qualitative data

- Think-aloud
  - Ask participants to **verbalize** what they are thinking as they work
  - **Prompt** participants when they stop talking for more than a minute or two
  - Offers insight into **why** participants are doing what they are doing
    - What barriers are preventing progress on task

Analyzing qualitative data

1. **open** coding - read through the text
   look for **interesting** things relevant to research questions
   add notes in the margin (or column of spreadsheet)
   add "**codes**" naming what you saw
   make up codes as you go, not systematic

2. **axial** coding - how are codes related to each other?
   look for **patterns**: causality, ordering, alternatives

3. **selective** coding - from initial codes, select interesting ones
   which codes found interesting things?
   from initial examples, build definition on when they are applied
   systematically reanalyze data and apply codes

4. **second** coder (optional)
   2nd person independently applies codes from definitions
   check for interrater **reliability** - if low, iterate defns & try again

Conducting an observational user study

Introduction

- Greet participants, introduce yourself, thank them
- Build rapport, socialize
- Introduce them to the setup
- Relieve anxiety and curiosity as much as possible
- Make clear evaluating design, not participant
- Let participants know you can’t answer questions about how to do task

Starting session

- Give participants description of task
- Start any video recording
- Start encouraging participant to think aloud
- Begin observing participants work on task

Interactions during the task

- Goal: listen, not talk
- Prompt participants to think aloud when necessary
  - e.g., What are you trying to do? What did you expect to happen?
- If show signs of stress / fatigue, let them take a break
- Keep participants at ease
  - If participants frustrated, reassure & calm participants
  - If so frustrated they want to quit, let them

Giving help

- If participants totally off track, small reminder of goal might help
- Should **not** give participants information about how to complete the task
- What if user asks for help?
  - Direct them to think through it or work it out for themselves

Collecting critical incidents

- *Any action that does not lead to progress in performing the desired task*
- May sometimes be related to a gulf of execution or gulf of evaluation
- Generally does not include
  - accessing help
  - random acts of curiosity or exploration
  - slips

Understanding a critical incident

- Important to understand in the moment what users goal is and what actions they are taking
- When a critical incident occurs, jot down
  - The time
  - What user was trying to do
  - What user did

Wrapping up the study session

- Provide questionnaire (if applicable) / conduct interview (if applicable)
- Answer any lingering questions the participant may have
- Thank the participant!!
- Provide any incentives (if applicable)

Reset study environment

- Make sure study environment is in the same state for all participants
  - Reset browser history / cache (if applicable)
  - Delete any user created content or materials

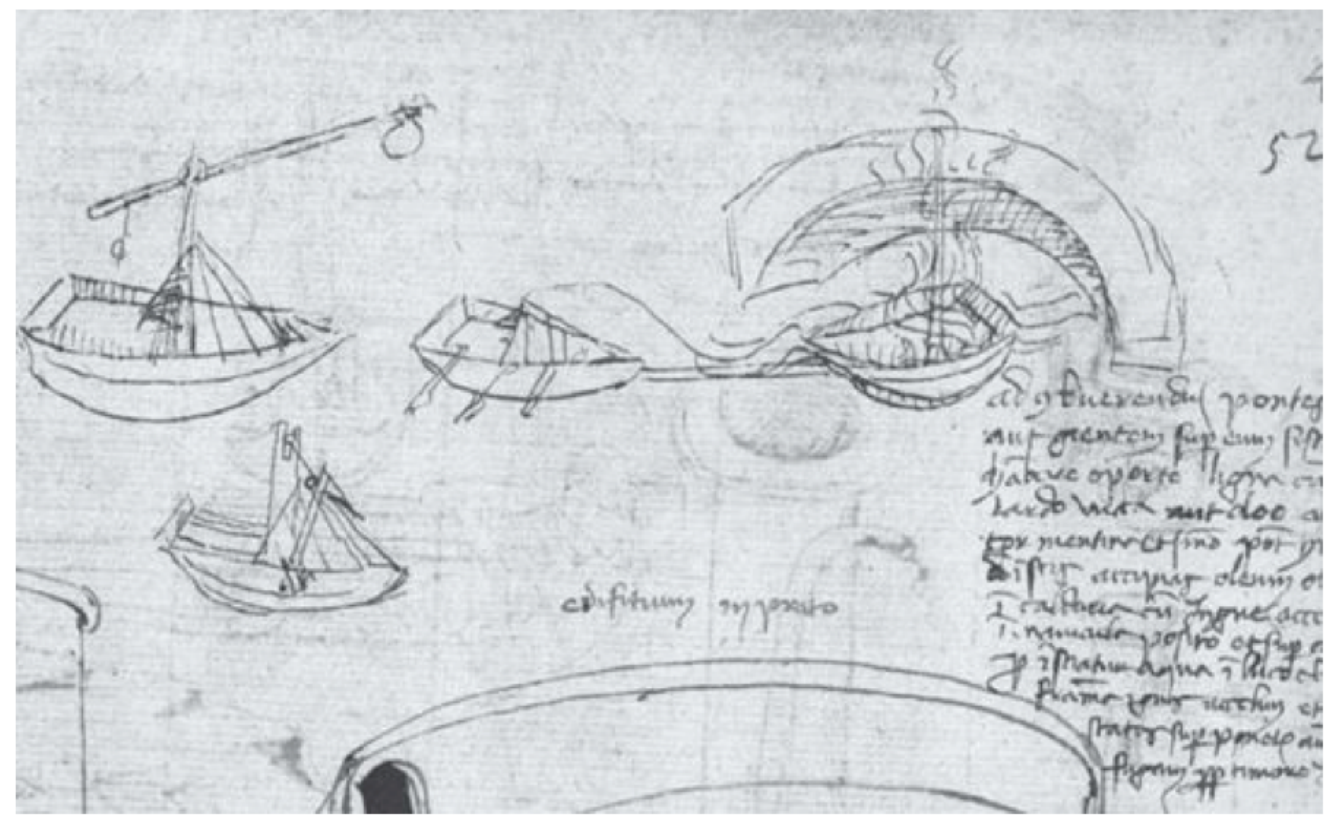
Transcript: example

				Uhh, so where did my StatusBar go?	
				So my StatusBar, I'm trying to figure out who calls updateCaretStatus	
		SwitchWindow	updateCaretStatus()+	Um, [rifling papers]	
				Um, the callers are CaretHandler, [writing]	
		ReferencesTo	View.CaretHandler.caretUpdate()+	um, caretUpdate, and that's on line 7251 ???	
				and I'm going to comment that out	
5:34		Edit	comments out updateCaretStatus() call	Ohh, it doesn't what me want to comment it out because it's the only thing	
		Edit	comments out guards	in here, so I'm going ???? Yeah, no ???	
				Next guy	
				No, no what are you complaining about?	[still errors in View class, but not in his metho
		ErrorTo	View.getViewConfig()+	[uses error on gutter to navigate]	
				[ViewConfig can't be resolved]	
				Now, I'm getting compile errors	
		BackTo	updateCaretStatus()+		
		SwitchWindow	View.getViewConfig()+		**Coding bug??**
				trying to edit the thing out, trying to comment the thing out	
		BackTo	View.CaretHandler.caretUpdate()+		
5:35		Edit	puts guards back, adds logging statement	Ok, he's still got an error, what's your error? Ok, he's gone	
		Critique		Boy, these files are so darn long they take an incremental compiler forever to	
				keep up. Another reason kids not to write files that are	
				2000 lines in them, uh	
				Ok, next is handleEditPaneUpdate, um	
		ReferencesTo	View.handleEditPaneUpdate()+	[writing]	
		Edit	comment out call to updateCaretStatus()	1671 and	
		ReferencesTo	View.setEditPane()+	33	
		Edit	comment out call to updateCaretStatus()		
5:36		ReferencesTo	StatusBar.handleMessage()+	Umm, this is	
				StatusBar	
		Edit	comment out call to updateCaretStatus()		**Breakdown?? - he's commenting out the call he just added**
		SwitchWindow	View.setEditPane()+	All right	
		Run jEdit		here goes nothing	
				There it is. Does it load up another file for me, no just one	
				?? [creates new buffer]	
		Hit breakpoint	updateCaretStatus()+		**This call is from scrolledVertically(), which didn't show up on updateCaretSt**
					Is this an Eclipse bug?????
					Or is it because there were errors in the file when the query was run?
	Got a wrong answer because			Mm, I didn't get all of them?	
5:37	of a tool breakdown	StackTo	View.ScrollHandler.scrolledVertically()+	What?	**Very baffled about this**
				Ok, so now this is baffling me, because what I did was that I asked Eclipse to	
				tell me all of the people that call updateCaretStatus(), and it gave me the list,	
				and I commented out all of these, and now I'm seeing scrollHandler is calling updateCaretStatu	
				and he doesn't appear on my list of people that allegedly for calling it	
				Um, so, what I'm going to do go back to StatusBar, and go to updateCaretStatus	
				and I'm going to call this darn thing again	

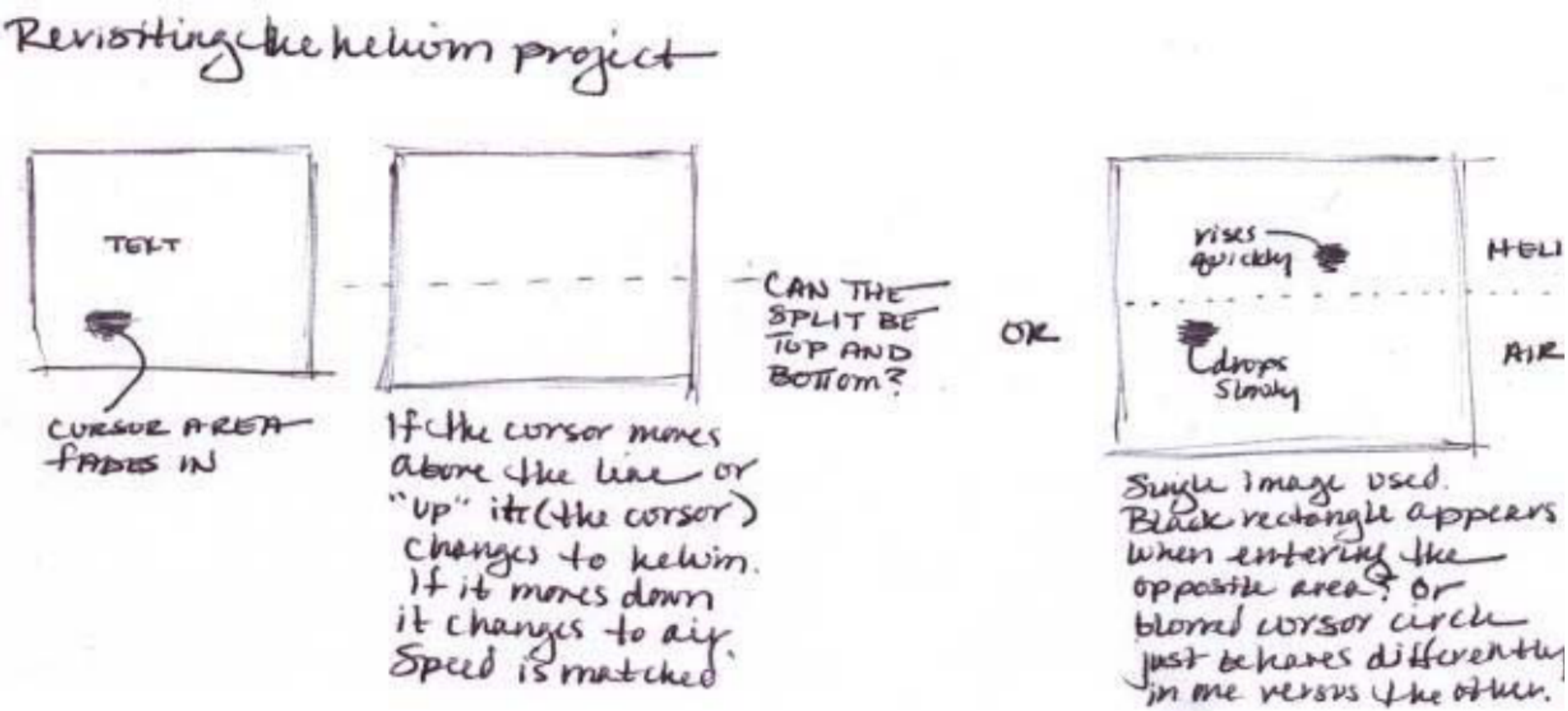
Sketching & Prototyping

Sketches are Sketchy

- Not mechanically correct and perfectly straight lines
- **Freehand**, open gestures
- Strokes may miss connections
- Resolution & detail **low** enough to suggest is concept
- Deliberately **ambiguous** & abstract, leaving “holes” for imagination



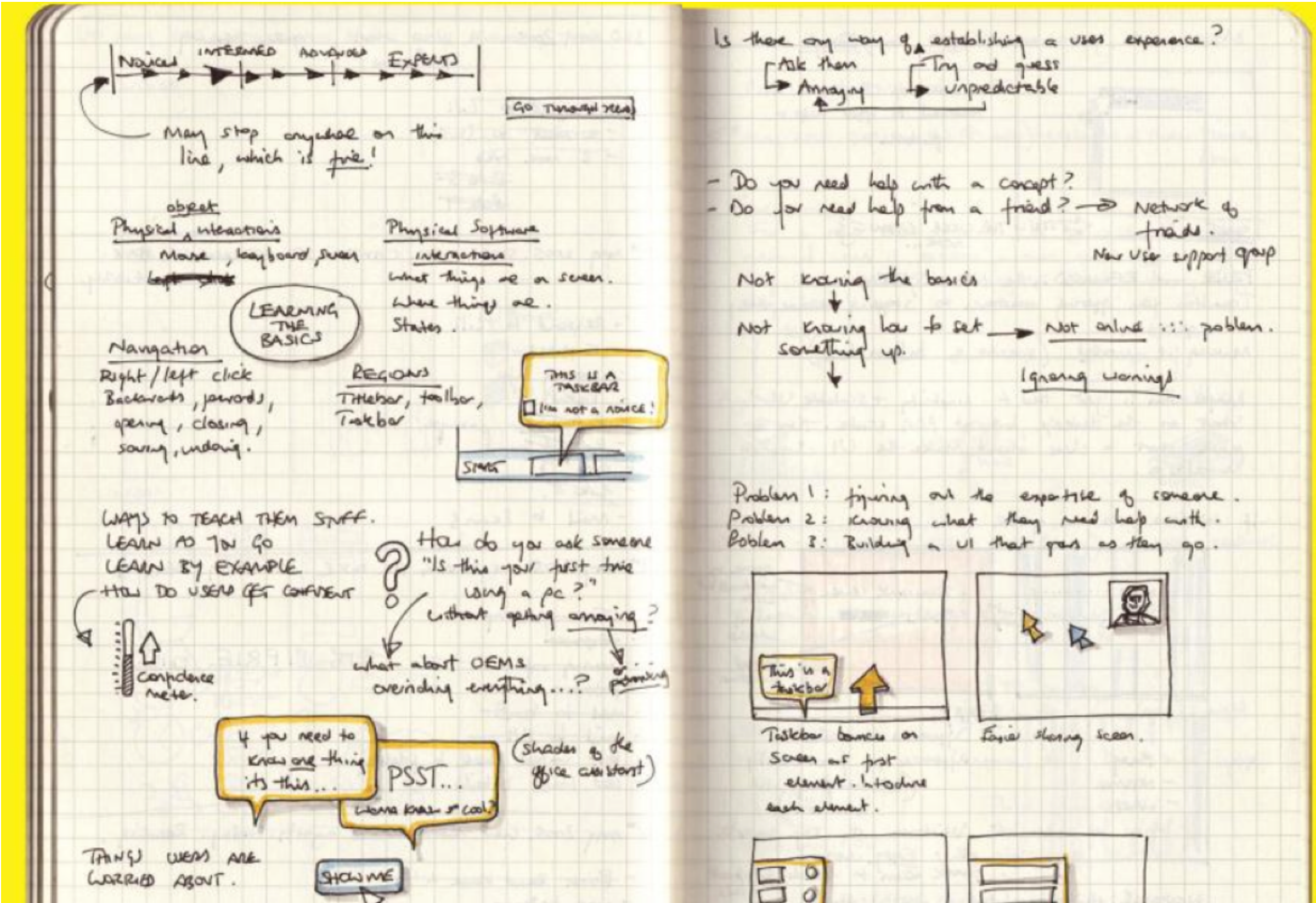
Sketches include annotations



Myers et al. (2008). How Designers Design and Program Interactive Behaviors. *VL/HCC 2008.*

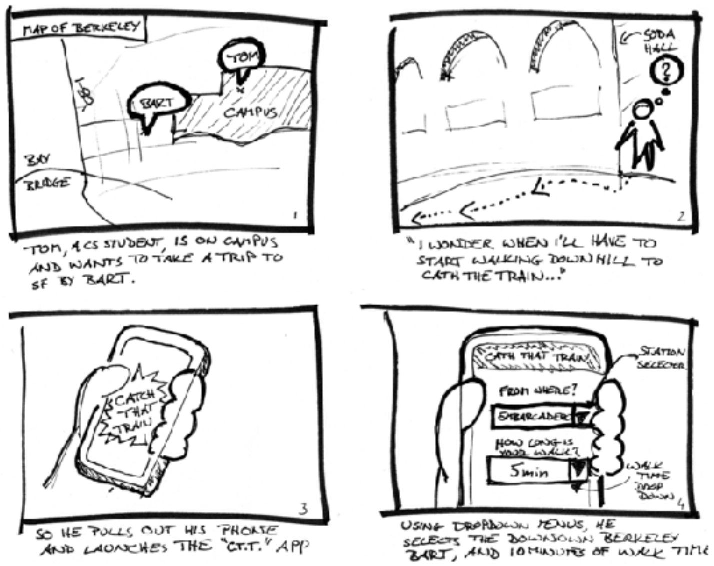
- Annotations explain what is going on in each part of sketch & how

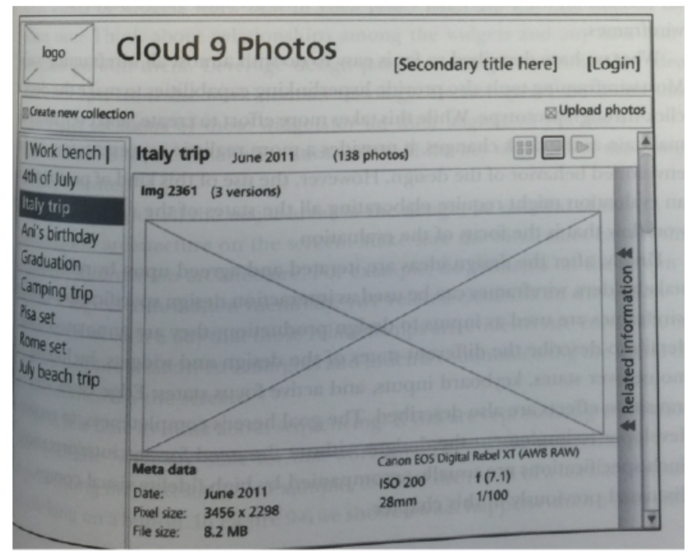
Sketches support design exploration

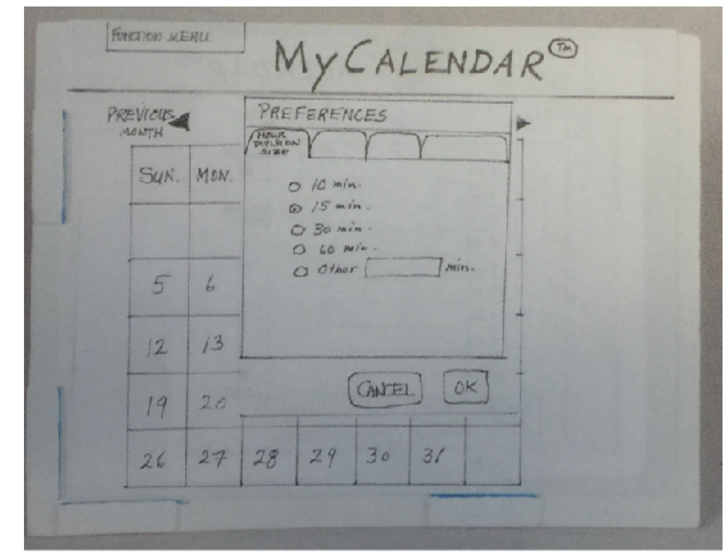


B. Buxton. Sketching User Experiences.

Fidelity of sketches & mockups







storyboard — wireframe — prototype

low ← fidelity → high

(many details left unspecified)

(more polished & detailed)

Storyboards for UI design

- Sequence of visual “frames” illustrating **interplay** between user & envisioned system
- Explains how app fits into a larger **context** through a single scenario / story
- Bring design to **life** in graphical clips - freeze frame sketches of user interactions
- “Comic-book” style **illustration** of a scenario, with actors, screens, interaction, & dialog

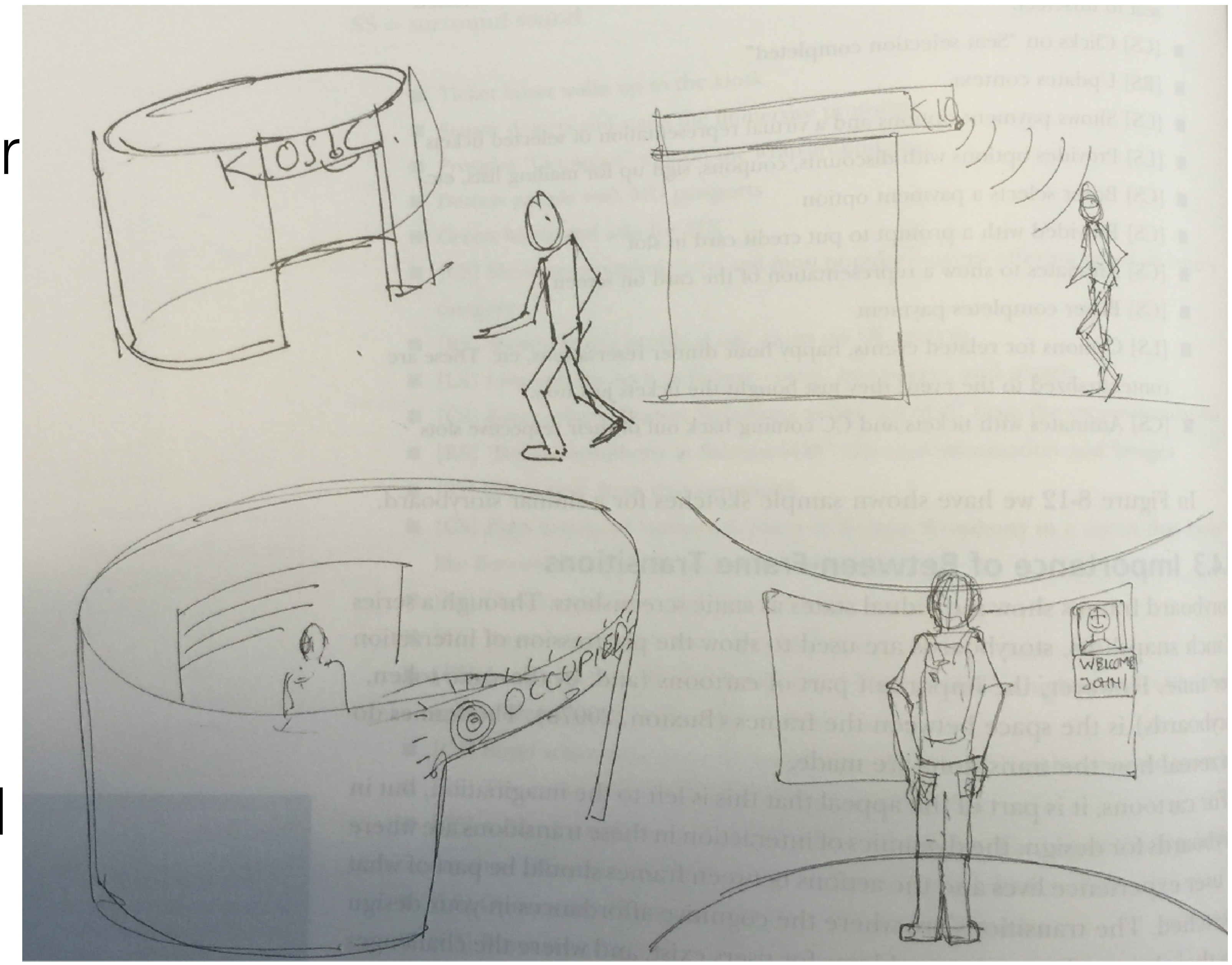
Crafting a storyboard

- Set the stage:
  - Who? What Where? Why? When?
- Show key interactions with application
- Show consequences of taking actions
- May also think about errors

Example: ticket kiosk

Ticket buyer walks up to the kiosk

Sensor detects user & starts immersive process



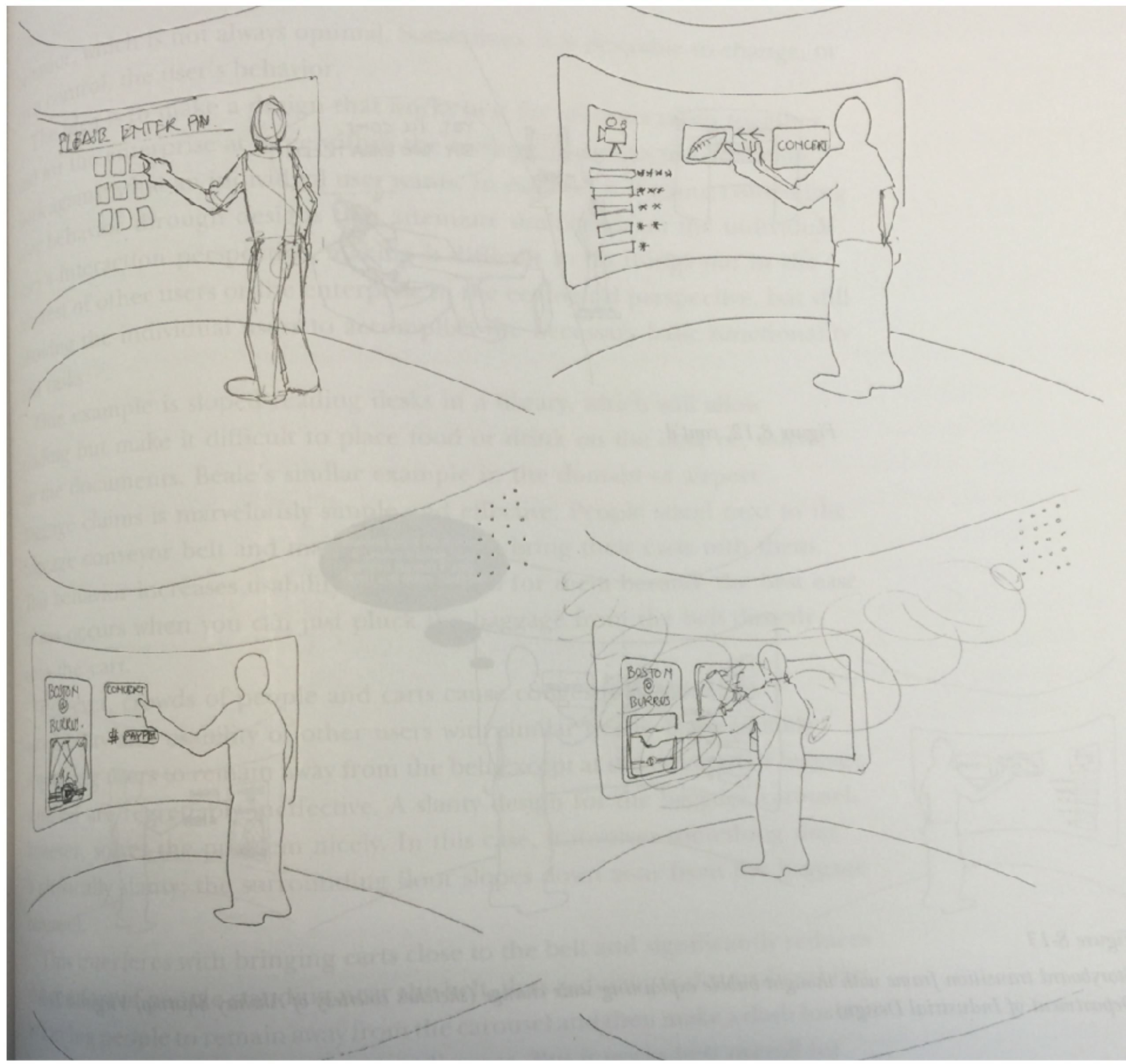
Displays "Occupied" sign on wraparound case

Detects people with ID card

Example: ticket kiosk

Greets buyer and asks for PIN

Shows recommendations & most popular categories



Buyer selects "Boston symphony at Burruss Hall"

Plays music from symphony, shows date & time picker

Frame transitions

- Transitions between frames particularly important
- What users think, how users choose actions
- Many problems can occur here (e.g., gulfs of execution & evaluation)
- Useful to think about how these work, can add thought bubbles to describe

In Class Activity

Think-Aloud Usability Study

- In groups of 2
  - Conduct a small think-aloud usability study.
  - One person will serve as participant. Other as observer.
  - Observer will ask participant to complete a short programming task while engaged in think-aloud.
    - If participants forgets to think-aloud, prompt them, e.g., "What are you working on now?"
  - Observer will take notes on activity, notes key steps and any critical incidents that occur.