Designcraft for experiments

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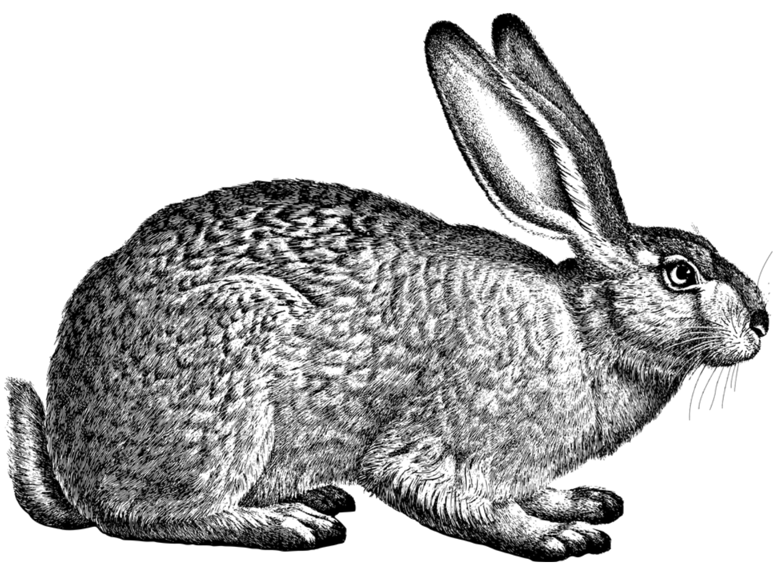
Chapter 1

Introduction



Welcome to experimental design. There are two sets of three exercises provided to explore principles for better experiments. This is a simple book to support the practical, at-home learning associated with experimental design. The text 'Experimental Design for the Life Sciences' underpins the design principles (Ruxton and Colgrave., 2018).

Life is an experiment. Individually and collectively. We experiment everyday. This is an opportunity to formalize some of those processes and make the learning from experimental design thinking a craft you can apply to all challenges. There are two primary modules to support this process.

(1) Field experiments comprises three outdoor experiments to explore sam-

pling heterogeneous, complex processes in natural systems. The purpose is to provide choice. You need to try each, briefly, as a pilot experiment only. Then, select one to pursue in depth and write up as a research article.

(2) The data experiments describe the opportunity to use design thinking to structure existing data that others have already collected. The same principles for better experiments still apply in how you reuse the data. There are also three examples provided. Select only one and write up as a note.

Both report formats supported by FACETS. It is the first and only open access science journal in Canada.

Lab outline

If you are electing to engage with this learning opportunity formally, please see the official course outline for specific details.

There are three summative assessments for the labs.

1. Dataset with meta-data for field experiment.
2. Field lab report.
3. Data-design lab report.

Big-picture steps to do labs

- Collect data outside individually or as teams on campus or anywhere.
- Write meta-data and enter data into spreadsheet and publish/submit for grading from any of the three outdoor labs proposed (try all three, but publish only ONE).
- Write up your fav data into a field lab report and submit for grading.
- Explore the datasets provided herein (data already collected and in Chapters 5-7).
- You explore them, think of an idea to do with one of them, and 'experiment' with data. Be creative.
- Write super short data-design report and submit for grading.

Part 1. Workflow for pilot and field experiment

1. Do all three field experiments in brief, pilot only, try each for a few hours.

2. Then, select one of the first three field experiments.

3. Do a deeper dive with your choice, i.e. fuller experiment wherein you structure observation by a key variable in the environment. Keep it observational.

4. Design the experiment; collect the field data.

5. Consider combining data from other students that examined the same system.
6. Publish your final field data with meta-data to figshare and also submit to teaching assistant via turnitin.com. Ensure you include the link to the figshare data in the pdf of work you submit to teaching assistant.

7. Write up the field experiment you completed for the deeper dive as a research article for the Canadian open science journal Facets.

8. Submit field experiment paper to teaching assistant via turnitin.com.

Field experiments gear

field lab	gear	purpose
birdwatching	lawn chair or balcony	a good spot to sit and observe birds
birdwatching	field guide or smartphone	support identification
birdwatching	binoculars, scope, smartphone	facilitate spotting and take pics (not critical)
bioblitz	practical shoes	good for thoroughly surveying your identified space
bioblitz	smartphone	iNaturalist app (not required but useful)
bioblitz	smartphone	take pics of animals
bioblitz	net	sweep and capture then release insects (not critical)
surveys	practical shoes	walking around your 50m outdoor space
surveys	measuring device for transect	tape, rope, phone with digital ruler, anything you can lay or run c
surveys	linear object for quadrat	bamboo, stick, pvc pipe, broom handle cut up, anything that is 0.

Part 2. Workflow for the data-design lab report

1. Explore each dataset.

2. Plan a variable to structure your design and analysis.

3. Reuse the data to explore your hypothesis and test your predictions.

4. Write a short research 'note' format paper suitable for publication in Facets journal.

5. Submit paper to teaching assistant via turnitin.com.

Data-design experiments gear

data lab	gear	purpose
all three data labs	access to computer or tablet	download dataset, explore data
all three data labs	R, Python, or any free stats app	plot data and do stats
all three data labs	internet access	to download data and submit note to teachin
all three data labs	Google Scholar or Web of Science	check literature on key topics
magic	a pack of cards	consider getting a pack to think over process
diversity	look for photographs online	explore how the data were collected visually
human	check out fitbits and trackers	check out watches, fitbit, trackers and explor

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Chapter 2

Balcony birdwatching

Bird observation, from a distance.

Learning outcomes

1. Identify common species of birds locally.

2. Collect a dataset.

3. Connect principles of experimental design to implementation.

4. Write clear and reusable meta-data.

5. Contribute to open science by publishing data and meta-data.

Steps

1. Scout out a location with more than a single species of birds and a frequency of a few different individuals of birds over a 5-10 minute duration.

2. Select a good spot to the observe birds at your designated location. It can be a balcony or quiet spot. Vegetation such as trees or shrubs can facilitate observation of birds by providing habitat.

3. Choose a distance that permits enough resolution to see plumage and what an individual bird is doing (depending on whether you are using binoculars, a spotting scope, or unassisted with your vision). There are considerable merits to observing birds more simply (Wilkinson et al., 2014). You are also welcome to address any visibility or spotting challenges using bird calls to record frequency of birds in a sampling region.

4. Specify a duration to sample, for instance, 60 minutes when you have observed the most birds in your scouting exercise. Remember, this is a pilot experiment. Take qualitative notes, sketch, and complete this datasheet.

5. Use your notes to complete a meta-data file, i.e. a description of how the data were collected, whether, when, and what each attribute in your dataset means.

6. Sign out a bird guide for your region from the library or university or try out a free app for now to support identification.

Data

Here is a sample datasheet for the pilot experiment. This is set up as species-level observations, i.e. each row or replicate is a species of bird you observe. This datasheet is for the pilot experiment, and it is a stepping stone for the deeper dive experiment if you choose to complete this experiment for your first report. A more detailed datasheet can consider duration or start and stop times of each individual bird, more details on the environment, or record interesting ecological or environmental variables that are present in the environment too - noise, disturbance, squirrels, other birds, etc.

Data can be organized in many different formats depending on the approach to collecting the data in the field or the lab, the instrument or method used, preference, or accepted standards within the domain of study. In many modern data science endeavours, data are also formatted according to the principles of 'tidy data' (Wickham, 2014). The following three rules define data as tidy (Grolemund and Wickham, 2016).

1. Each variable must have its own column.

2. Each observation must have its own row.

3. Each value must have its own cell.

Most scripting languages such as R or Python can resolve and tidy up data to adhere to these principles, but with a little planning, your data can be set up to facilitate this process and enable easier data visualization and models.

Sample data set
In this example, the field observations were coded as one species per behaviour per row. A compromise between tidiness and ease of collecting the tallies per species in the field.

rep	date	researcher	location	species	frequency	behaviou
1	15/9/2020	cl	High Park, Toronto	House sparrow	12	flying
2	15/9/2020	cl	High Park, Toronto	Blue jay	2	foraging
3	15/9/2020	cl	High Park, Toronto	Cedar waxwing	1	perching
4	15/9/2020	cl	High Park, Toronto	Cedar waxwing	3	foraging
5	15/9/2020	cl	High Park, Toronto	Dark-eyed junco	2	flying
6	15/9/2020	cl	High Park, Toronto	Black-capped Chickadee	3	foraging
7	15/9/2020	cl	High Park, Toronto	Black-capped Chickadee	2	posturin
8	15/9/2020	cl	High Park, Toronto	Black-capped Chickadee	3	interactin
9	15/9/2020	cl	High Park, Toronto	Black-capped Chickadee	2	sitting
10	15/9/2020	cl	High Park, Toronto	Wood thrush	2	flying
11	15/9/2020	cl	High Park, Toronto	Wood thrush	5	on groun
12	15/9/2020	cl	High Park, Toronto	Northern flicker	1	perching

Meta-data

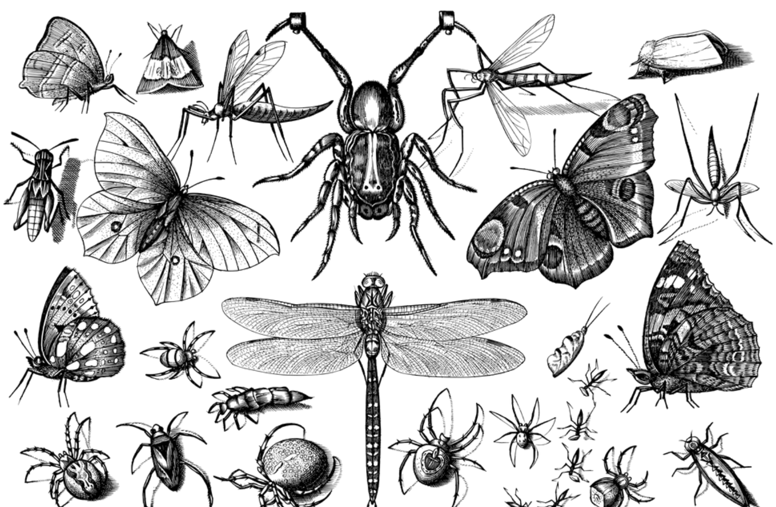
In many disciplines of science, meta-data are the descriptive elements of the dataset. They provide a clear means for discovery and reuse of data collected - by you in future and for others (Heidron, 2008; Reichman et al., 2011). For the purposes of our practical learning in experimental design here, describe what each column in our dataset means, describe the structure of your dataset (i.e. each row is a species-level observation, or plot, or transect), describe the duration of sampling, location, and provide a bit of guidance for someone to use in inspecting the dataset. It is very similar to the methods in conventional publications or standard reports, but it ensures each attribute in the dataset has a brief description. It is also superb preparation for the methods if you choose to write a report.

Deeper dive

If you choose this adventure, your goal is to experiment with the method of animal observation to test a hypothesis and predictions. The text ‘Experimental Design for the Life Sciences’ does an excellent job of explaining how to set up hypotheses and predictions (Ruxton and Colgrave., 2018). Pilot experiment first, think, explore your data and notes, then write your ideas down that you want to test. A hypothesis is a clear explanation of how a system works (LaPlaca et al., 2018; Bains, 2005). The predictions are logical and reasonable outcomes if the hypothesis is a good approximation of how the system works, i.e. the key variables that make it work. Predictions should be testable and read like simple sentences that describe results. The goal of the deeper-dive experiment is to take your pilot experiment, examine what worked and did not work so well in your experiment, and do a deeper and more thorough job of testing a key idea that you are interested in associated with bird communities in your backyard or neighbourhood. The goal should be to explore one key factor that describes how the species locally interact within one another, the environment or other species, or resources.

Chapter 3

Backyard bioblitz



A bioblitz is a biodiversity survey that is done rapidly for a specific place. National Geographic provides an excellent 'getting started' guide to the process.

Learning outcomes

1. Identify common species of animals locally.
2. Collect a dataset.
3. Connect principles of experimental design to implementation.
4. Write clear and reusable meta-data.

5. Contribute to open science by publishing data and meta-data.

Steps

1. Scout out a location that has a few species of animals. Vertebrate or invertebrate taxa - preferably both. A medium-size backyard, park, woodlot, or grassland is ideal.

2. Do a bioblitz or intensive process of surveying a specific place for a short duration of time to estimate all the living species (excepting plants) locally.

3. For the purposes of this experiment, focus on on all animals you can spot.

4. Select a set of locations within the designated area to sample. This can include direct observation of species spots, a region, walking through a region repeatedly. Select the scale carefully that matches what you can observe. This can be relatively unstructured sampling process with the goal of documenting as many species as possible that reside in this place.

5. Record your data to your datasheet and also consider using the iNaturalist free app to record and share your observations globally.

Data

Here is a sample datasheet for the pilot experiment. This is set up as species-level observations, i.e. each row is replicate species you observe. This datasheet is not structured for frequency or density - simply a comprehensive list of all animal species you can spot during the pilot experiment.

Meta-data

Describe how you collected the data. Ensure that each attribute in the dataset has a brief description. This is like an abbreviated version of the methods section in peer-reviewed science publications. Report total sampling time and any relevant details that enable someone else to reuse these data or repeat the process of doing a bioblitz that collecting similar data in a different place.

Deeper dive

If you choose this adventure, your goal is to experiment with the method of measuring biodiversity locally. Innovate on the pilot experiment, simple biodiversity inventory methodology to test a hypothesis and predictions. The predictions should be logical and reasonable outcomes if the hypothesis is a good approximation of how the system works, i.e. the key variables that make it work. Predictions should be testable and read like simple sentences that describe results. The goal of the deeper-dive experiment is to take your pilot experiment, examine what worked and did not work so well in your experiment, and do a deeper and more thorough job of testing a key idea that you are interested in associated with biodiversity patterns locally. The goal should be to explore one key factor that describes why biodiversity varies locally - at the scale you define.

Chapter 4

Solo surveys

Distributed ecological networks often use surveys done by individuals or small-teams to compile data on species or communities. Transects and quadrats are typically used to structure these ‘walk-through’ surveys to estimate abundances and distributions of focal species. In this experiment, plants are examined.

Learning outcomes

1. Appreciate the complexity of plant communities.

2. Collect a dataset.

3. Connect principles of experimental design to implementation.

4. Write clear and reusable meta-data.

5. Contribute to open science by publishing data and meta-data.

Steps

1. Select a location that has at least 50m of space to walk a straight line unimpeded. This can be a forest, lot, disturbed area, grassland, or even a parking lot with enough cracks and permeable spots for plants to grow.

2. Run out a piece of string, rope, or just measure 1m and line it up visually for a total length of 50m.

3. Every meter, place a 0.5m quadrat or 0.5 by 0.5m square (string, ruler, cardboard, pvc pipe, measured piece of bamboo) on the ground.

4. Record the total number of different plant species present (i.e. species richness).

5. Estimate the total cover of all plants within the quadrat from 0 to 100% cover.

Data

Here is a sample datasheet for the pilot experiment. This is set up as plot-level observations, i.e. each row is replicate plot, one for each meter sampled on the 50m transect or line. This datasheet is structured very coarsely to estimate the total number of plant species and total cover of vegetation within the plots.

Meta-data

Describe how you collected the data. Ensure that each attribute in the dataset has a brief description. This is like an abbreviated version of the methods section in peer-reviewed science publications.

Deeper dive

If you choose this adventure, your goal is to experiment with the method of measuring plant communities. Innovate on the pilot experiment design and add more depth to your quantitative description of the plant community. These innovations can include deeper insights into the structure of the community (height of plants, density of all plants, or spatial patterns) or the composition (i.e. species identity, abundance per species per plot, flowering or not, native or invasive, or by plant functional groups). The predictions should be logical and reasonable outcomes if the hypothesis is a good approximation of how the system works, i.e. the key variables that make it work. Predictions should be testable and read like simple sentences that describe results. The goal of the deeper-dive experiment is to take your pilot experiment, examine what worked and did not work so well in your experiment, and do a deeper and more thorough job of testing a key idea that you are interested in associated with biodiversity patterns locally. The goal should be to explore one key factor that can be used to describe or predict plant community structure or composition for the specific habitat sampled.

Chapter 5

Magic data

Magic: The Gathering is a popular collectible card game that includes strategy and chance. If you have not played, here is a great description. This is an excellent example of data collected that is appropriate for experimentation for several reasons. Many games have expansion packs and add-ons. Physical card collecting from sports to fantasy is a very popular activity in addition to a multi-million dollar economy and sales continue to grow. Consequently, these data are an opportunity to explore likelihood and consumer buying choices. It is also fun. Incidentally, the most valuable card reportedly sold for $250,000USD so understanding how frequently rare cards pops up is pretty interesting.

Learning outcomes

1. Work with an existing dataset and reuse it.
2. Design questions from data.
3. Connect principles of experimental design to implementation with data.
4. Write a clear hypothesis and predictions to explain or predict patterns in data.
5. Communicate data, design, and science succinctly.

Steps

1. Download the dataset.
2. Read the meta-data, and review what the game involves.
3. Explore likelihood topics, and prep a list of questions for the data.
4. Test one question with the data via a plot and a statistical test.
5. Decide if this is the dataset for you to write up as short research note.

Data

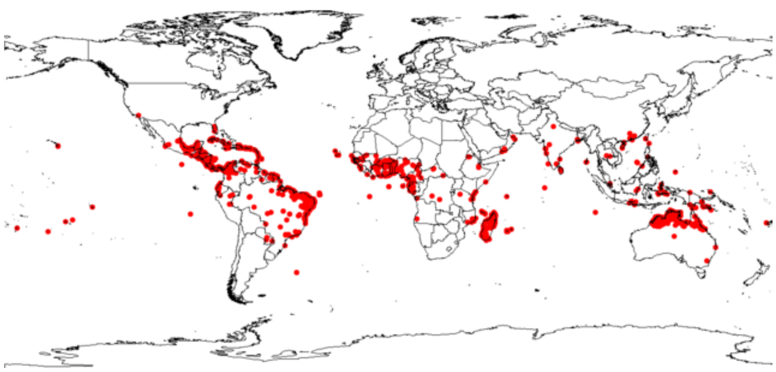
Here are the data collected by a researcher at York University. These data are the first of their kind and super fascinating.

Deeper dive

If you choose this adventure, your goal is to explore any component of the data to apply design principles. Informally, we are data mining (Hand et al., 2000). Data mining is a field of data science and many other disciplines that is exploding in capacity and application (Hooshyar et al., 2019; Aldowah et al., 2019). Typically, mining data includes seeking patterns and building models that either focus on description or on prediction. Experimental design principles are not always a component of data mining endeavours, and this is unfortunate. We can do better science and build better models with design thinking principles. It is still an experiment, but someone else (or you) collected data. Data can be used for the explicit purpose they were collected, re-purposed to explore another idea, or simply collected without a priori hypotheses and predictions that we derive later. This is where design thinking can make profound contributions. Select a variable from the data that you think can be a meaningful mechanism or explains patterns, describe differences, or predict outcomes. In this example, this design and experimentation process can include good thinking and data use to examine price prediction, likelihood of rares or other card categories, and pattern frequencies by various card attributes. Begin with one key variable that can be a factor or grouping variable and one key variable that is a response or outcome. Then, do some work, some thinking, try some designs with the data, and make the call if this is data-design lab you will write up.

Chapter 6

Diversity data



Diversity data from any citizen science project are profound resources for scientists, non-profits, individuals, managers, and stakeholders. Citizen science is a tool for conservation, data collection, and also policy (Cooper et al., 2007; McKinley et al., 2017). However, innovation through experimental design is not a component of many projects to date. The bioblitz model is common. We are citizens too as instructors and students, and we interact with a semi-natural, heterogeneous space when we can - campuses. There are at least two examples of data for campuses that can support and enable experimental design thinking. First, the trees on a campus are a viable ecological asset. Second, the biodiversity present on a campus - in addition to human animals.

Learning outcomes

1. Work with an existing dataset and reuse it.

2. Design questions from data about a university campuses.

3. Connect principles of experimental design to implementation with data.

4. Write a clear hypothesis and predictions to explain or predict patterns in data.

5. Communicate data, design, and science succinctly.

Steps

1. Download the dataset.

2. Read the meta-data.

3. Explore research on trees or biodiversity, and prep a list of questions for the data.
4. Test one question with the data via a plot and a statistical test.

5. Decide if this is the dataset for you to write up as short research note.

Data

Here are the data collected by ecology students at York University and the University of Toronto Mississauga. Here are data for thousands of trees on York University, Keele Campus by a master gardener a number of years ago. In this both instances, click on the csv file to access the data but review the detailed meta-data to support reuse.

Deeper dive

If you choose this adventure, your goal is to explore any component of the data to apply design principles. In these examples, the design can include contrasts between different campuses or exploration of variation within a campus in terms of habitats. Do some work, some thinking, try some designs with the data, and make the call if this is data-design lab you will write up.

Chapter 7

Human data

Data associated with human life. The quantified self movement is a powerful (and moving) example of personal science and experimental design thinking. It is an experiment of one with trial and error and pre-post intervention thinking. Numerous trackers including smartwatches, phones, dedicated movement trackers such as Fitbits track steps, sleep, heart rate, and numerous other potential indicators of some components of life though big data (Swan, 2013). This is an opportunity to apply experimental designcraft to yourself and use these experiments to make evidence-informed decisions about exercise, sleep, and work patterns. Gamification is not so different from experimentation in this context and a compelling opportunity to have some fun with activities that you are already doing (Whitson, 2013).

Learning outcomes

1. Work with an existing dataset and reuse it.

2. Design questions from data about a single person walking and sleeping (but not sleepwalking).

3. Connect principles of experimental design to implementation with data.

4. Write a clear hypothesis and predictions to explain or predict patterns in data.

5. Communicate data, design, and science succinctly.

Steps

1. Download the dataset.

2. Read the meta-data.

3. Explore research on quantified self and human health, and prep a list of questions for the data.
4. Test one question with the data via a plot and a statistical test.

5. Decide if this is the dataset for you to write up as short research note.

Data

Here are the data collected by me. I wear a simple Fitbit tracker (old one) that tracks only steps and sleeps - not heart rate.

Deeper dive

If you choose this adventure, your goal is to explore any component of the data to apply design principles. In this example, the design and experimentation process can examine changes through time in one variable, relationships between variables, or make predictions about change and health and activity through time for this human being. Pattern and prediction are both possible with these data. Do some work, some thinking, try some designs with the data, and make the call if this is data-design lab you will write up.

Chapter 8

Rubrics

Experimental designcraft assessment framework

There are at least two primary modes of assessment (Kennedy et al., 2008). Formative assessment can happen during the learning process (Bennett, 2011). This active process of engagement with content and doing experiments is critical to becoming an effective life-long learner and successful scientist. In practicing experimental design and doing experiments professionally, this can take the of form of notes, sketches, photographs of the process or experiment at different steps, flowcharts, field and lab notebooks, code, and discussion with collaborators. This process of learning can include feedback from the team (in this course the teaching assistant, the instructor, or peers examining the same challenge). It can be enabled by testing how well one has advanced in achieving specific outcomes. For instance, share your meta-data with a peer and explore whether the individual can understand the meaning of the data and the process of experimentation that supported the collection or reuse of data. Summative assessment can happen at the end of key benchmarks in a learning cycle or at the completion of logical stopping points within the learning process that generated concrete products for review and grading (Taras, 2005). In this designcraft process of actively exploring experimental design, this can include production of data with meta-data, a lab report describing the deeper dive for one of the field experiments, and a lab report describing the design process of data reuse from one the examples provided. The process of formative asessment (steps along the way) and summative assessment (final products) should support one another to consolidate learning (Harlen and James, 1997).

A rubric is a scoring tool that enables fair, transparent and replicable grading in summative evaluation (Timmerman et al., 2011). Checklists are useful for formative self or peer assessment in the steps along the way to final products. In designcraft for experiments, this applies to the published data with meta-data and lab reports. In the formal offering of these labs for the course 'SC/BIOL

3250 4.00 Experimental design for environmental and evolutionary biology' at York University, the lab component is worth 50% of the final grade.

Rubrics

Formative = checklist for you to mentally tick of as you do work.
Summative = graded by educator to assess work and provide marks.

Summative marking key for published datasets

This is the marking key you are looking for. This key is used for the field datasets to ensure that you can improve and learn from the process. Reminder, metadata are the 'data about the data' - i.e., the descriptions of what each column header means, a list of the key concepts, and a description of the terms within each specific variable. Sometimes, it is really useful to make a short **meta-data table** to describe the data and upload that file with the observational or experimental data too (Lortie et al., 2022).

item	description	criteria
1	data	tidy (rows and columns logical and organized), clear labels, no errors
2	data	observations meaningful, accuracy, sufficient (i.e. sufficient replication based on
3	meta-data	every variable or column clearly described for the reader, units not within cells,
4	meta-data	description ensures the process of observation be repeated by another, like a mi
5	open science	details sufficient for [open science](https://open-science-training-handbook.gitbo

Summative assessment marking key for field lab report

This is the marking key for the field lab report. Single or double spaced, 12 point font, at least 1 inch margins (the default). PDF format only. Lab reports must also be submitted to turnitin.com. We strongly prefer captions for the figure and figure at the end of the report.

Facets journal is Canada's first and only multidisciplinary open access science journal. Follow the instructions proposed for a research article for this journal. Please keep the length of your article between **2000 to 5000 words**.

page	concept	description
1	Title & abstract	Title of experiment (like you would see for a peer-reviewed scientific publica
2-3	Introduction	Sets the context, explains why study needs to be done, state hypothesis and
4	Methods	Described well enough for someone else to replicate design, explain the relev
5	Results	Clear text should be able to stand alone including description of statistics, c
6-7	Discussion	Restate findings in brief and then propose significance of the work and/or li
8	Literature cited	At least 5 recent papers (typically defined as published in a peer-reviewed jo
9	Figure legend	Figure legend describing what the figure shows, plus put at end of the repor
10	Figure	Figure at the end of report, on a single page, you need a plot (or table, we c

Summative assessment marking key for data-design lab report

This is the marking key for the data-design short report. Single spaced, 12 point font, at least 1 inch margins (the default). PDF format only. Lab reports must also be submitted to turnitin.com.

Facets journal is Canada's first and only multidisciplinary open access science journal. Follow the instructions proposed for a note for this journal. Please keep article at **1400 words or less**.

page	concept	description
1	Title	Title of experiment (like you would see for a peer-reviewed scientific publication, meaningfu
2	Introduction	Single paragraph stating background, hypothesis, and your prediction(s)
3	Results	Single brief paragraph stating findings and single figure with legend (legend and figure at th
4	Conclusions	Single paragraph stating conclusion and implications of what you tested with thes data
5	Lit cited	A total of 3 references, recent published within the last 5 years in a peer-reviewed journal

Chapter 9

Final notes

Experimental design is a rich field of research, thought, and meta-science. How we do better science and explore the processes that support discovery is one of the most critical and fundamental contributions to social good and society. Individually, it can improve how you make choices. It can also improve your critical thinking capacities. Likely all skills, practice is key. Design thinking and an experimental mindset are worth cultivating and preserving culturally. Simple rules that guide and inform decisions but that adapt is absolutely the space for designcraft to promote scientific literacy and novel forms of creativity. Collectively, these exercises provide only a snapshot of the opportunities to apply scientific design thinking. You will find many other ways to positively apply structured, iterative thinking to all the challenges you tackle.

Chapter 10

Recordings

Learning outcomes

1. Familiarize oneself with the structure of labs.
2. Highlight key points described in the designcraft manual.
3. Consolidate understanding of datasets provided.

Recorded exercises

Succinct tour of the key points articulated in the designcraft manual (and in some instances in slide decks supporting this guide).

topic	link
lab manual tour	https://youtu.be/kYrrLheYHM8
rubrics	https://youtu.be/1qPvuhLbzo4
birdwatching	https://youtu.be/ZH0PGxdpDes
bioblitz	https://youtu.be/yOXyrhuq5bY
solo surveys	https://youtu.be/9nItxjSRSDo
magic data	https://youtu.be/NelbIKuy4gA
magic the gathering game	https://youtu.be/qSqi3yLnTkU
diversity data	https://youtu.be/UlE0GmRxl3M
human health data	https://youtu.be/JlTwVTNPVVc

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