PUTTING RESEARCH INTO PRACTICE: APPLYING EVIDENCE-BASED PRINCIPLES TO FOSTER STUDENT LEARNING IN STATISTICS AND DATA SCIENCE

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How can we apply evidence from research to best foster learning in our students? Inspired by the conference theme, a panel discussion at the IASE 2023 Satellite Meeting gave insight into the practical application of research-based learning principles to the teaching of Statistics and Data Science. The discussion was guided by the eight principles described in Lovett et al. (2023). These principles are grounded in learning theory and pedagogy and backed by empirical evidence. Panellists shared illustrative examples of how the principles are enacted in their teaching and participants had the opportunity to reflect on their own strategies for supporting learning through following these principles.

INTRODUCTION

This article is a summary and partial transcription (edited for length and clarity) of the plenary panel session "*Putting Research into Practice: Applying Evidence-based Principles to Foster Student Learning in Statistics and Data Science"* at the International Association for Statistics Education - (IASE) 2023 Satellite Meeting held in Toronto, Ontario, Canada. Inspired by the conference theme *"Fostering Learning of Statistics and Data Science,"* panellists were asked to provide examples demonstrating how evidence from learning science research is enacted in their teaching. The discussion was structured by the eight principles from the 2nd edition of the book *How Learning Works: Eight Research-based Principles for Smart Teaching* by Lovett et al. (2023).

The panellists represented a variety of teaching countries and teaching contexts. Sam Caetano (SC) teaches primarily large (> 200 students) undergraduate courses in the Department of Statistical Sciences at the University of Toronto, Canada. Many of her students are enrolled in or intend to study statistics as one of their undergraduate programs of study. Bruno de Sousa (BdS) teaches in the Faculty of Psychology and Educational Sciences at the University of Coimbra in Portugal. His students are primarily graduate students taking a mandatory statistics course to support their research in another area, with class sizes between 15 and 40 students. Anna Fergusson (AF) teaches in the Department of Statistics at the University of Auckland, New Zealand. She teaches both an undergraduate introductory course that has about 5,000 students a year and a 2nd course in Data Technologies that has about 250 students. Laura Le (LL) teaches biostatistics in the School of Public Health at the University of Minnesota, USA. Her students are primarily master's students in public health, many of whom are working professionals, and she teaches primarily asynchronous online courses with about 75 students per course.

The session started with the definition of learning. Learning creates a change that has a lasting impact on our students, and that happens in response to their experiences. While we cannot measure this change directly, students can demonstrate their learning in a variety of ways, through their actions, performances, or products. *How Learning Works* defines learning in three ways (Lovett et al., p. 3):

1. Learning is a process, not a product.
2. Learning involves change in knowledge, beliefs, behaviours, or attitudes.
3. Learning is not something done to students, but rather something students themselves do.

For each of the eight principles in the book, two panellists provided examples from their statistics and data science teaching practice, illustrating applications of the principle to support learning that lasts.

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EIGHT RESEARCH-BASED PRINCIPLES TO SUPPORT LEARNING

Principle 1

> Students differ from each other on multiple dimensions – for example, in their identities, stages of development, and personal histories – and these differences influence how they experience the world and, in turn, their learning and performance. (Lovett et al., 2023, p. 13)

Encapsulating the differences among our students is complex, as we consider the intersections of our students' identities and backgrounds and, consequently, what they bring to the learning environment. The panellists gave examples describing how their students' experiences have affected the learning experiences planned. This sometimes leads to unintended outcomes, but these can lead to alternative but equally rich learning. And we can structure our courses to allow our students the flexibility they need to balance the course requirements with their other demands and interests. Both panellists expressed the belief that all their students are capable of success, and their belief in the importance of creating structures to allow this success.

[AF]: My example is both a learning activity for myself as well as for my students. I had designed an activity where I had printed out several movie posters and the students were given a sample of 200 movie posters from all the movie posters I could find. My intent for the activity was that students would work in small groups, examine their sample of posters, and think of things that they could test as a feature that is dominant in movie posters. I thought they were going to notice features like the number of people pictured on the movie poster, the genders pictured, or the fonts and colours that are used. However, that was not the conversations that my students were having. They were saying "I see lots of blonde hair" and "I see lots of white skin." The point of the activity was for them to think about inference and about generalizing from samples to populations. But these 200 movies posters were almost exclusively white people. When I planned the activity, I did not consider that my students were predominantly Indigenous students, Māori students, and Pasifika students from the Pacific Islands.

When we talk about what students bring to their learning and we think about what data are and how students' experiences in the world shape what they see, it can completely change what we planned to teach. This activity became something completely different. Instead of a lesson on inference, it became an activity about representation. It was a space where it was okay to leave the statistics behind. There was no need to make an inference, the people pictured were nearly all white, and we would talk about something else instead. This was a learning experience for me as well, as it reminded me that we need to make spaces in our teaching that allow for what our students bring and recognize what they see in the data is as valid as what we might have planned.

[SC]: Like Anna, I also teach large classes. For an example related to this principle, I decided to describe multiple flexible policies that I have incorporated in my courses to universally accommodate many students in my class simultaneously, in a way that I can handle administratively and that is also favorable to the students. These policies include offering hybrid options for interacting with the material, makeup tests, extensions with no questions asked, and automatically taking the maximum of different grading schemes for each student. These policies allow the students to navigate the course as they need to, because they all have different things going on during the course. They may have competing deadlines for other courses, or they may have family emergencies, or they may have different interests, or they may want to take time to participate in a hackathon. In my course they have the capacity to make decisions based on the flexibility offered and incorporate their choice into how they navigate the course.

Principle 2

> Students' prior knowledge can help or hinder learning. (Lovett et al., 2023, p. 42)

Our students differ in the knowledge, beliefs, and attitudes that they bring to the classroom. For this principle, both panellists addressed the importance of knowing our students and anticipating anything that might hinder or that might help their learning. The panellists described how they set up their courses to help their students thrive and, as they're learning, help them connect new knowledge to what they have previously learned.

[LL]: My overall tip to address this principle is to be aware of, and design for, the (years of) prior knowledge and experience that students bring into the classroom. I consider years of prior

experience because there are a lot of working professionals in my classes. My students probably have some prior experience with data; maybe they've even had an undergraduate class in statistics, and they've definitely had exposure to math classes. I need to take their knowledge, their conceptions and their skills into account when I design my course to ensure that it is conducive to their learning. When I read this principle, I particularly thought about what could be hindering their learning.

These hindrances include lexical ambiguity as well as known sticking points. An example of lexical ambiguity is students using the word "correlation" in a colloquial sense rather than the specific meaning that we use in statistics. When it comes to known sticking points, I explicitly incorporate them into lecture and then make sure to have reinforcements in course activities for practice. I also put energy and effort into understanding *why* these topics are historically challenging for some students. For example, after years of teaching relative risk and odds ratio, I am keenly aware that these can be challenging topics for some students. In particular, the sticking point is not in the calculations of them but how to interpret a single value that is made up of two values (on the relative scale). There has been significant work in mathematics education on developing proportional reasoning, starting in primary school-aged children. Discovering this work and reading this literature gave me ideas for tackling this challenging concept with my adult learners.

Additional hindrances to learning may include the affective feelings students bring to the classroom. I find that many of my students have anxious feelings towards math and statistics, expressing sentiments like "I haven't done math in 20 years, and I'm really scared of this course," or "Math was so hard for me. I don't have a quantitative brain." And if they've previously only taken math courses and not statistics, they have pre-conceptions about statistics, thinking they will be applying a lot of formulas and that there is one right way to get the answer. To help improve student attitudes, I try to focus on the key objectives of the course. I'm very purposeful about articulating the course objectives and how all the unit or weekly objectives tie to them. And I share these objectives with my students so that they see clearly what they're doing and why they're doing it. The goal is to convince them they can be successful, and I will aid their success with my course design. Lastly, to address students' preconceptions about statistics, I provide opportunities for students to work collaboratively and explain their reasoning to support development of their understanding of what it means to think statistically.

[BdS]: The teaching context I'll speak about is a course in organizational psychology that I teach in English. It's part of the international Erasmus Mundus program with four participating universities. In my class, there were 16 students representing 12 nationalities. As you can imagine, all these 16 students have very different backgrounds in statistics. Some come to the class traumatized by their prior experiences with statistics, and this plays out in a few challenging ways. For example, this semester I was excited to begin with some of the initial classes introducing R commands that would allow them to carry out descriptive statistics in a new environment, because they have mostly previously used SPSS. But this semester my students had previous experiences with R that left them traumatized and not open to learning more R at the start of the course. And some of the students came from prior learning experiences in which statistics was treated as math. Others hadn't previously learned a lot about statistics, perhaps not advancing beyond t-tests. So my challenge was, how do you overcome such differences among students without some of them becoming bored and some of them becoming lost?

To overcome this, I go back and deconstruct the basic concepts. One of these concepts is p-values and unpacking what exactly p-values are. The students know some procedural rules, for example they know that if the p-value is less than or equal to alpha, the significance level, they reject the null hypothesis. But when they start writing their reports and their research results, they find this counterintuitive because typically the bigger the better. What I do is inspired by my mentor, Martha Aliaga. We talk about a one-sided test versus a two-sided test and the corresponding rejection region, decision rule, and p-value. To do that you don't need a lot of technology, just a whiteboard and a very simple example in which we work through the direction of the test that we have constructed, the decision that depends on alpha and where the observed value lies, and I include an example where the observed value is in the rejection region for one test construction and not for the other. And then we calculate the p-value to make the connection with its value relative to alpha and the corresponding decision, to develop an understanding of why the rule of decisions based on having the p-value less than or equal to

alpha leads to the rejection of the null hypothesis. In other words, I am showing the same concept in different ways. Some of the students may not have previously thought about p-values this way, others who came with a weaker background learn something new, and others develop a stronger understanding of what the concept really is. It takes a lot of time, patience, and creativity to present concepts in multiple ways and keep students engaged, regardless of their background.

As the book tells us, research can guide us in what to do. This includes giving examples in different contexts so students can examine the differences and the similarities, assessing the prior knowledge that students have, discussing the conditions in which various methods apply, presenting abstract concepts in multiple ways including with and without formulas, reaching out to colleagues to share experiences and activities, and trying a new thing each time we teach a course to add to the different ways we can support our students' learning.

Principle 3

> How students organize knowledge influences how they learn and apply what they know.
> (Lovett et al., 2023, p. 67)

For this principle, both panellists talked about how they support their students in making connections among concepts. Their courses are carefully structured to guide students through the building of meaningful connections so that they will be able to effectively apply their knowledge later.

[BdS]: The example I will use for this principle comes from my experience with a master's level class in organizational psychology which has 16 students representing 12 nationalities. It is a very ambitious course, requiring students to write a paper by the end of the semester, based on their own research project that they've developed with their advisors. The course is in the second semester of their program, and they must have their data collected. By the end of the course, they conduct their data analyses and they write their paper, including methods, results, and discussion. Knowing they will need to do this, the first day that they arrive to my class they immediately want to do some analysis of their data, typically jumping straight to inference. I need to slow them down and instead I start with a simple task to see what they can do. I give them a very simple file in SPSS with data on work satisfaction. The file has only a few variables: gender, age, and level of education, and I ask them to tell me a story about this data set. Can you guess what most students do? They jump in and they start with t-tests. Why not start with descriptive statistics, draw some graphs, and then maybe carry out some t-tests if appropriate? The issue that I see is that the students tend to know the different parts of the statistics they have previously learned, such as descriptive statistics, correlation, t-tests, and linear regression, but they don't connect these different parts. They don't realize that a good descriptive study of their data sets can be helpful in determining the methods they are going to choose later. The main objective of this course is to identify students' needs for their research work, so every semester it's a different program. But I try to help them organize the content so that it makes sense for them in the context of the research they are carrying out. And I ensure that everything that I do in my classes, from the second class until the last class, is interconnected and has a clear purpose. I also work to engage them with topics beyond their research areas. For example, I tell them I might get to mixed models, which may not be a method they are using in their current research, but maybe next semester they'll meet their advisor and he or she will think then that it's a good idea to use mixed models. My goal is to keep the students engaged, understanding why they're learning, and understanding the interconnections.

[AF]: I'll about talk how we organize information for students at the course level, particularly for the very large introductory statistics course with around 5,000 students a year. I recently led the team that rewrote the course and one area of focus for us was to have the students come away from the course with more than a list of the types of tests that they could do, like a recipe list from which they can make choices such as "if I have one variable that's numeric, I'll do a one-sample t-test." In the middle of Figure 1, you can see the outline I wrote for other people on the team developing the new version of the course. You'll notice that there are three different modules that build from awareness to participation to production. We make this outline visible to the students and we explain to them that these are the three things we're working through. In Figure 1, the name under each of the modules indicates the content of each week. It is a focus rather than a method like a two-sample t-test or linear regression, that is, we organized the topics by what kind of things we were doing. For our students, we explain the structure by identifying the focus for that week, rather than a particular method. For our students' learning

process, we structured the course to keep building on earlier topics. At the beginning of every week, we refer to the week before and what we're building on, and explicitly connect that to the current week. As illustrated by the arrows, the idea is that over the course of the 12 weeks we're expanding their knowledge base regarding what they understand about learning from data. Around the outside of the diagram are five focuses, some of which come from my university's key priorities for what our graduates need to have shown that they can do by the time that they graduate. As an example, under "data + people" you can see that we have a commitment to ensure that Māori data sovereignty and Indigenous knowledge with data are recognized in our core structure. In our design of this course, we started with the key things are that we want students to think are important about statistics and organized the course around these things. And we wanted to make obvious to the students how their learning is progressing throughout the course, rather than just accumulating a collection of recipes or topics.

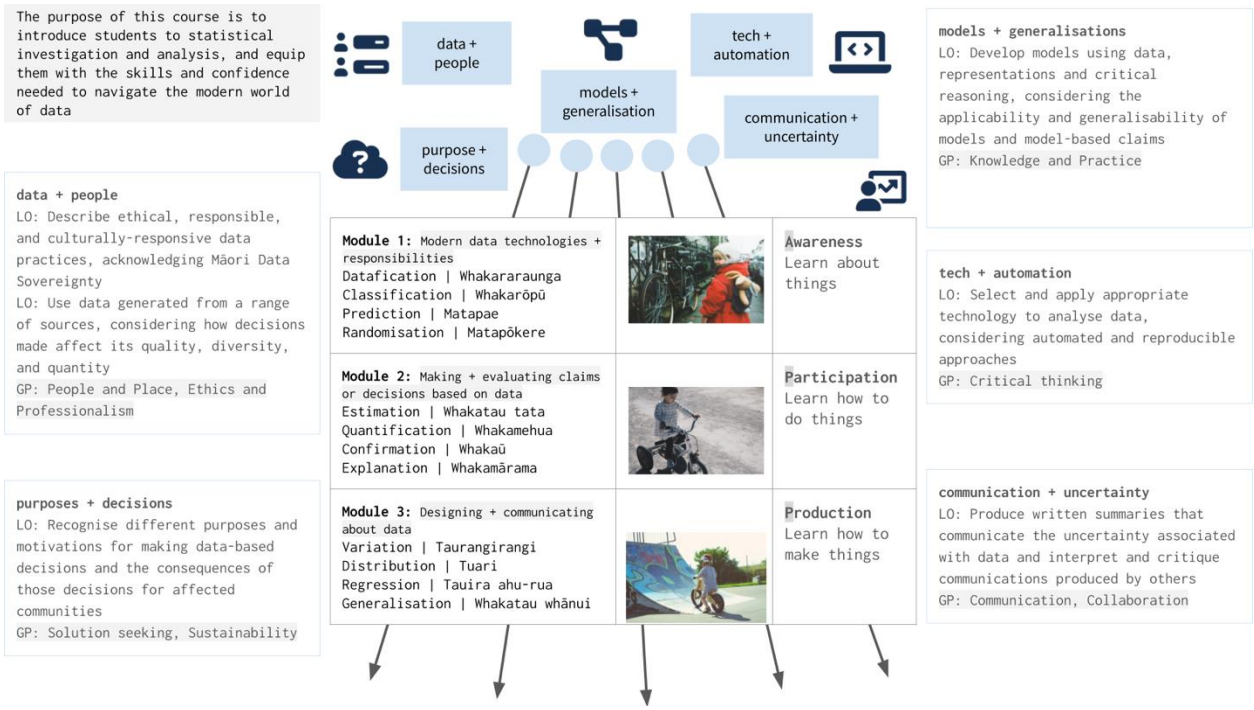

Figure 1. Structure of the University of Auckland introductory statistics course.

Principle 4

> Students' motivation generates, directs, and sustains what they do to learn.
> (Lovett et al., 2023, p. 86)

All the panellists teach in higher education, and students in higher education have considerable autonomy. Maintaining their motivation is critical to their intensity of effort, persistence, and the quality of their learning behavior. Teaching statistics and data science provides many opportunities for finding data to explore that would interest every student. To retain that motivation, the panellists described ways that they ensure that students perceive value in what they're doing, how they ensure that their students can expect to be successful, and how they create structure, so their students perceive that they're supported in their learning.

[LL]: While addressing the previous principle, Anna talked about the importance of telling students both what to do and why they are doing it. Similarly, my tip related to student motivation is to be intentional, transparent, and thoughtful in all our course components – learning materials, activities, practice opportunities, and assessments – so that we create an environment that supports student motivation. Like Anna, I also think a lot about course design and making sure that it's aligned with what I want my students to be able to do by the end of the course. Again, I have adult learners, so a lot of the discussion of intrinsic motivation in the chapter for this principle doesn't apply to my students. I instead thought about how value and expectation lead to motivation. I truly believe that we can design and

structure a course for student motivation and success, and that encompasses many aspects such as ensuring the presentation is at a level that everybody can understand, the questions we ask, and the assessments we give to help our students develop the skills and the knowledge that they need in order to be successful in what you want them to be able to do by the end of the course. It also encompasses instructor presence. Something that I'm very intentional about is creating learning objectives for every unit/topic/week and I share these with my students. This creates a roadmap for me as the instructor and sharing it with students helps them be responsible for their own learning. If they know where we want them to get to then they can consider whether they are on the right track. I often refer to the learning objectives when a student says they are struggling and that usually helps give them guidance on where they need to go. I also do this with my assessments. I always have a rubric that I share with students that makes it clear what I want them to be able to do and how I'm going to be assessing that so they have guidance on how they can be successful, and I've given them some responsibility in their learning. To practice the knowledge and skills before being assessed on their understanding, I use what we call "collaborative keys" or collaborative answer keys. These are collaborative documents that students work on either as a class or in small groups to come up with answers for any activity in which they are practicing their learning. The role of the instructor is to monitor the discussion in the documents and guide the students by posing follow-up questions. The collaborative keys encourage motivation by supporting the sense of autonomy as students feel they have control over their own learning, students develop competence through their interactions with their peers, and they get feedback on their learning. Feeling connected to other people is also important for motivation and, despite being an asynchronous course, my students say they feel they can connect with others in the virtual space in a way they never have in an in-person class because they are working together with a common goal.

[SC]: My comments for this principle connect back to my comments about the first principle. Flexible deadlines can help with student motivation, particularly when teaching the large courses that I do. I also recommend to any instructor using projects as assessments or any assessment requiring analysis of data, even if a small assignment, to include openness in the assessment. I've done this by having students design a survey or having them carry out a data analysis and letting them pick their own topic. Like Laura, I think a lot about this in the summer when I'm designing the course so it's very structured for all the assessments, rubrics, and grading. But I also integrate an opportunity for the students to be motivated by their own interests. It's very interesting to see what students choose to explore. The famous quote about statisticians being able to play in everyone's backyard is really evident when you have open projects. I've had students design surveys on different types of shoe wear because they were really into Nike, and I've had students survey the different trees on campus. If you can also have the students engage in some type of peer evaluation or just be able to see what each other is doing, it broadens this even more. Anytime you have a chance to let the students suggest a topic or be motivated by their own self-interest it's both selfishly fun, because you get to see what your students are interested in, but it also gives the instructor the opportunity to see that students who allow themselves to be driven by a passion project tend to experience success the course.

Principle 5

> To develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they have learned. (Lovett et al., 2023, p. 109)

The different teaching contexts of the panellists allowed the discussion to consider both the beginning and final stages of developing mastery. This development can be accomplished by first supporting the acquisition of component skills through lab assignments with specific tasks, which then get integrated into larger mini projects. For graduate students who will be carrying out research, supporting them in the final stage of developing mastery becomes helping them to put together the components of their prior knowledge. In discussion of this principle, the panellists also recognized that the book has a Western and undergraduate lens on teaching, which may not reflect every teaching context.

[AF]: I am also going to talk about projects and how I use them in my second-year data technologies course. A key objective of this course is to learn how to use R. The course is one of the only courses in which learning the programming language is a focus as opposed to using functions for carrying out analysis. In this course, I want the students to learn some programming concepts. But it's

only one of the three things that are important outcomes for this course. It's also important for them to learn how to communicate with the technologies and to build creativity.

Although mastery is not fully achieved by the end of the course, I approach the development of student mastery through weekly labs in which students work through some ideas about programming in R and then complete formative quizzes that have unlimited attempts to practice core skills from the labs. We start small and we gradually build and expand over the 12 weeks of the course. The weekly labs are contextualized within small application tasks. But every two weeks we have a larger mini project. These mini projects can't be completely open because I'm helping students to integrate some data thinking with some technology thinking and this is new to them. Rather than making the projects completely open, I give the students a "data landscape." An example of this is a project focussed on iTunes music. For this project, the students exercise some creativity because they can decide how to query the API. They can decide whether to query by the name of an artist or a genre or another category. The mini project requires them to make a playlist from a list of about 200 songs. The students come up with their own purpose for where this playlist is to be used, such as a party or a wedding. They then apply components of their R knowledge and data technology they've learned, such as how to use a package like dplyr where they can select, filter, group by, aggregate, etc., to create their playlist of 10 songs. The students need to think about how to use those techniques to manipulate the data and create an example of how that works based on their chosen criteria for their playlist. They then carry out some analysis to describe key features of the songs, such as how long they are on average or the main genre of these songs. These mini projects work well as a complement to the small weekly lab-based tasks and quizzes, requiring students to integrate new skills to solve a problem while providing an opportunity for creativity. The students feel like they have some choice, but the task is constrained enough that they still must think about how to put the particular skills we want then to develop into action to complete the project.

[BdS]: For this principle, I will again talk about the master's course on organizational psychology that I teach. In this course, students must acquire mastery because, by the end of the course, they are required to write an academic paper which can undergo the review and revision process. As we know, reviewers are sometimes not very kind and if the students want to be successful, they must produce something with a basis in the theory and methods that they apply. One of the challenges in teaching this course is that it is part of a program that involves four universities in Europe (Coimbra, Valencia, Barcelona, and Bologna) and there are many agents involved in this process. There is me, the coordinator of the course, and typically one or two home and host tutors. And we all need to agree, and sometimes we need to negotiate for all of us to be comfortable with the final product.

A point on which I didn't agree completely with the book is its suggestion that students typically go through a state in which they lack consciousness in what they don't know. My course has three major deliverables, including an oral presentation of each student's planned research at the beginning of the course, which allows me to situate what they're going to do and what their needs will be in terms of methods. My experience is that my students are very conscious that they don't know what they don't know and they're very conscious that they will need to do something to be able to carry out their data analysis for their research so they can accomplish the end result. So, in these oral presentations I get all the home and host tutors to evaluate their presentations and ask them questions about what they're going to do and identify the weakest and the strongest points. The class then moves on to learning the methods that I've collected from these beginning presentations and at a later point in the semester they hand in a written paper about their research including methods, objectives, and results. They get very detailed feedback from me on what they have done well and what was not well done and where they could have done more. And lastly, they have a final oral presentation of their research work during which I find they are much more relaxed because now they have the big picture, now they know what was required, and they are confident in the results.

Something I liked, but found intimidating, in this chapter of the book, was the many messages for educators. There are many suggestions for things we can and should do, and things we should not do, including breaking complex tasks into component small tasks that students can actually perform, not overestimating students' skills which require instructors to explain everything in multiple ways so that all students understand, providing personalized learning by teaching in different ways so that there is something that each student can identify with. There are other things that are difficult to implement in practice, particularly with graduate students. Graduate students can help us in identifying where we are clear and where they are having difficulty that we may not realize. And the context of this book

assumes the availability of resources that may not be the reality in every country, such as readily accessible textbooks, so addressing students' needs may require other solutions.

Principle 6

> Goal-directed practice coupled with targeted feedback are critical to learning. (Lovett et al., 2023, p. 133)

The assessment and feedback cycle is critical for student learning, and to be most valuable, it must be focused on the key knowledge and skills that we want our students to learn and it must be provided at a time when it matters. The panellists addressed how they do this in different contexts: large in-person classes and an asynchronous online class. They discussed the value of many small-stakes assessments and the importance of supporting graders in developing skills in providing effective feedback.

[SC]: For this principle, I am pulling from something I do in all my courses, which is having many small assessments with a variety of formats including quizzes, assignments, practice problems, in-class activities, weekly writing, ticket-out-the-door reflections, use of audience response systems with collaboration, and discussion. I use some combination of these in all my courses, while maintaining a balance between student workload and the value of encouraging students to keep up with the course every week. When students don't find the workload to be onerous, their feedback has been quite positive. They recognize that this helps them keep on track and accountable, and they appreciate that they are earning easy grades while doing so. And I maintain a flexible grading scheme. So, while there is something required every week, I can accommodate diverse student needs by only counting the best six out of eight or 10 out of 12 of these weekly assessments.

[LL]: My tip for this principle is to provide frequent and timely opportunities for students to receive formative and summative feedback. This could be done using any of the ways that Sam just proposed. I do this primarily in two ways.

Since I teach an asynchronous online class, feedback is critically important to help inform their learning since I can't peek over their shoulders or listen in on their conversations. Each week, students work on a learning activity in a collaborative document (my "collaborative keys") -a model drawn from the idea of interdependence in collaborative learning theory. The activity is tied to my specific objectives for that week. In the documents, I can see students helping each other and asking questions, creating a community of learners who are invested in wanting to understand and gain that week's knowledge and skills in a safe space where they are comfortable admitting they don't know how to answer a question and asking for help. And when they support each other, it makes my job much easier; the teaching team just needs to monitor the discussion in the documents to make sure they are converging towards a correct answer. Through these activities, students are getting timely and frequent feedback on their understanding while they're still practicing new concepts. They are not assessed on correctness, just that they have contributed. I also think a lot about how to give feedback on summative assessments in my asynchronous courses. My dissertation involved understanding experts versus novices and how to build more expert-like thinking in novices. What we know about novices is that if we simply give them the right answer, they may not be able to connect concepts well, which is essential for developing mastery. Instead, they see what they said and what their instructors said the answer should be, and they don't know how to fill in the gaps. In an in-person class, students can ask their instructor after class for help clarifying what the grader said. But in an asynchronous class with adult learners, the students are often so busy there's no way that I can efficiently communicate given my schedule. I try to relieve the burden of needing to ask for help in understanding grades and feedback by teaching my graders how to grade and how to give feedback. I coach my graders, giving them a template, sample feedback, and example answers so they know what they are looking for. As a result, my graders, who are graduate students in biostatistics, develop valuable communication skills.

Principle 7

> The classroom environment we create can profoundly affect students' learning, positively or negatively. (Lovett et al., 2023, p. 165)

The panellists teach in a variety of contexts, including large and small classes, in-person and online, and students who are majors and non-majors. Regardless of the context, what instructors do to create a positive environment has profound effects on student learning. This environment includes the physical or virtual space, in addition to intellectual, social and emotional dimensions. The panellists described how they have worked in their contexts to create a safe space so that all students can feel a sense of belonging and can thrive.

[BdS]: Of course, classroom environment matters. If you're in a classroom and your students don't get involved in discussions, it matters to their learning. Firstly, it's important to create an inclusive environment. Our classrooms must be welcoming to all students, whether they are men or women, straight or gay, religious or non-religious, black or white, and so on, and we must also recognize the internationalization of our students. We should consider topics that matter to students. In a course that I teach in the first semester, students must revise a paper. They can choose a paper on their own, with my approval, and the paper they choose could be a bad paper or a good paper. If they choose a bad paper, they will have a lot to criticize. The topic of the paper must relate to the course content, but they can choose a paper from an area they care about such as sustainability, green economy, social responsibility, multiculturalism, or global thinking. As a result, they are very engaged in what they are doing throughout the semester.

Regarding the physical classroom environment, the photos in the middle right of Figure 2 show a real classroom, as it looked in 1859 and as it looked in 2009, where the big difference is that the blackboard has moved from the left to the right side of the room. Moving beyond our current classrooms, in a perfect world we might have what is imagined in the picture below these. Our learning environment could be outside with spaces for discussion and spaces for having coffee. And although we are working on more innovative new spaces, the new spaces are sometimes built with the old format. They may have more comfortable seating, but the seats are still fixed in place and we're not able to move chairs to create the environment that we want in our classroom.

And as Laura described, a welcoming environment can also be created virtually for an online class. By working to create safe spaces for students to post their questions anonymously and by providing different ways of learning the same concepts and, as Sam talked about, having alternative methods of assessment, other than just written tests or essays, we may lower the level of anxiety and stress in students.

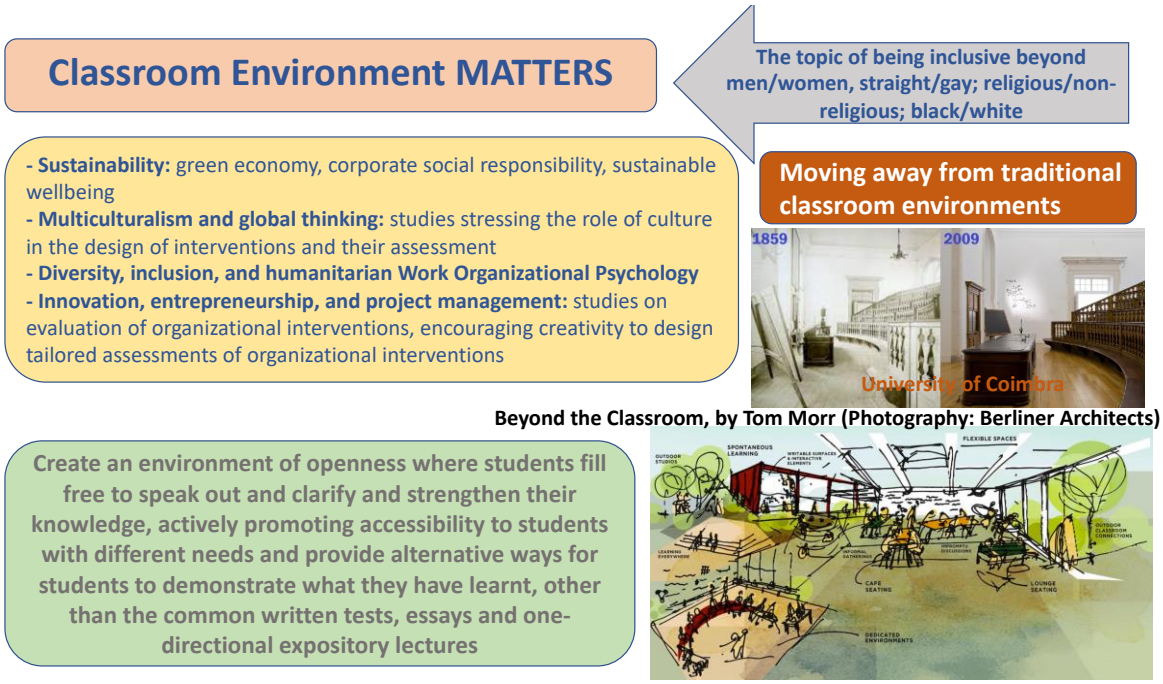

Figure 2: Classroom environment involves both physical space and an open and inclusive climate for learning.

[AF]: Regarding physical environments, I'll talk again about the large course I teach with up to 2,500 students per semester. The lecture theatres hold 600 students in one space. So you have hundreds of introductory-level statistics students, many of whom are not there by choice but because they need to take the course as part of their programs (e.g., psychology or business). A key outcome of the course is that students can write about the concepts, and it is a challenge to give valuable feedback on writing with so many students. To address this, I have developed a tool called "Quick Write." It's a very simple interface that asks students to quickly write something, as the name implies, in response to a prompt I give them in lecture. Their responses appear on screen in tiles, randomly shuffled, so students don't know if it will be their response that will be visible to the rest of the class. I can move the tiles around to pick examples to talk about. For example, I can unpack differences and similarities among how different students have responded to the same question. The responses are anonymous and editable, so we can tweak the written responses live in front of students to show how they can be improved.

We've also used the tool to capture student feedback on the course. A general theme of the feedback we've captured is that we've been able to create a positive learning environment, even in this massive space with hundreds of students, because the students felt like they could contribute, and they could be seen. Even if a student's answer is used for improvement, it is still a comfortable experience because it's anonymous and because all students are learning how to revise. To encourage engagement, we start with some trust activities, so students understand how the tool will be used, are comfortable with the anonymity, and understand the distraction of inappropriate responses, which the instructor can easily move off the screen.

Audience response systems and large lectures are not new things, but often in these settings student engagement involves only multiple choice or true-false questions. Requiring students to write, even a small amount, allows us to capture what they're thinking and provide some personalized feedback to some students, from which all students can benefit.

Principle 8

> To become self-directed learners, students must learn to assess the demands of the task, evaluate their own knowledge and skills, plan their approach, monitor their progress, and adjust their strategies as needed. (Lovett et al., 2023, p. 189)

In discussion of the final principle, we returned to the conference opening talk given by Chris Wild, who addressed the need for students to develop new skills in the era of generative artificial intelligence. Chris identified several meta-skills that we need our students to develop including an open attitude, resilience, creativity, social intelligence, and metacognition. The panellists described several ways they develop skills in metacognition including peer review, pre- and post-assessment reflections, clearly articulated learning objectives, and the creation of a safe space for students to ask questions. Many of the practices that support other principles also support the development of self-directed learners.

[SC]: As part of the process of supporting my students to become self-directed learners, I've tried to mimic the peer review process in some of my courses, introducing how to provide feedback, how to reflect on it, and how to use it to improve. I have done this in a few courses in which students submit a draft or a proposal for a large project. At some point they will get some feedback from the instructor or the teaching assistants along with their grade. But I also like to have a peer feedback component so that students are exposed to other students' ideas and proposals. I give students a period of time during which they can reflect on the peer feedback they received, make edits, and then submit their final project or the required product if it's a scaffolded assessment. I have found that this has allowed students to reflect more on what they've done as well as giving them exposure to what other students in the class are doing and to what an instructor or teaching assistant, who has experience going through a similar kind of process, says about their work. And the editing step allows them to use this experience and feedback in their own learning process.

[LL]: My initial reaction to this principle was that it was not my favourite, because I don't feel like I do enough to develop students' metacognition as I should. But after reflecting on my practices, I discovered I do more than I give myself credit for. Much of what I do was not intentionally designed to develop metacognitive skills, but because all the eight principles we've discussed work together, practices for other principles also help students become self-directed learners. My tip is to create

moments for students to check and reflect on their learning, to check their understanding, which will both solidify their knowledge and self-evaluate their knowledge and skills. This can be done through group work on activities or quizzes, anything that will force students to talk aloud to somebody else which helps to solidify their understanding. Having readiness quizzes with multiple attempts helps students learn their weaknesses and where they need to review and this can help correct their misconceptions of the material while they are learning, rather than allowing the misconceptions to linger on.

Additionally, having clear learning objectives in rubrics allows students to assess their understanding of the task at hand and develop the metacognitive skills of asking themselves whether they are where they need to be and assessing whether they have completed the task sufficiently to be able to submit their work. I strongly believe that we need to explicitly write down what we want our students to be able to do.

I also assign a reflection assignment for large course projects in which I ask students to consider how the project aligns with the overall course learning objectives, how it will impact the skills that they may learn later in life, and how what they learned might be transferrable to a different context in their career or their program or their life more generally. This also encourages students to appreciate the value of the time spent on the project.

Finally, I try to be approachable, so students feel they can come to me for help, and I will bend over backwards to help them. Help-seeking behavior isn't natural for everybody, and I try to promote it by letting my students know I am here for them. In the online setting, I also feel it is very important to find ways to have students feel like there's a person behind the asynchronous words. I have a smile emoji in my email signature, I talk about my kids in course announcements, and I play songs to try to lighten the mood. And I have a mantra that there are no silly questions, only curious ones, to encourage students to be comfortable asking anything.

CONCLUSION

The final panellist who spoke began her comments about Principle 8 by saying that she recognizes that several of her teaching practices build metacognitive skills, but that she doesn't do these things intentionally for this purpose. But it was clear in all the comments on all principles from all panellists that there is intentionality in their teaching. And their teaching practices that support some of the principles, often also support others.

To conclude, we briefly considered the book's principles and the claim that they are domain-independent, experience-independent, and cross-culturally relevant. During the panel discussion, we described a variety of ways the principles apply to the teaching of statistics and data science. Through the various teaching contexts of the panellists, we saw the principles applied in higher education contexts for undergraduate and graduate students with various levels of experience, including students with significant professional backgrounds. The panel did not explore whether the principles may apply for younger students. Some tension was identified in the consideration of how and whether all the book's suggestions apply in the context of teaching graduate students, who bring maturity and autonomy to the learning environment. Finally, the book acknowledges that the research underlying the principles has been carried out primarily in Western settings, but it claims that the principles are relevant in all counties. The panel noted that some advice may not apply universally, and there is an opportunity to explore the contexts in which the research upon which the principles are based can be effectively and practically applied.

REFERENCES

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