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# Toward an Ecological Science of Teaching

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The need for a primary emphasis on teaching is a necessary, and as yet unfulfilled, goal of psychological science. We argue that an ecological model focused specifically upon understanding and optimizing teaching practice must incorporate the necessary complexity inherent to the teaching and learning process. To do so, we must expand our scope beyond the simple exploration of main effects under controlled conditions to the exploration of dynamic interactions, including the identification of boundary conditions, and the assessment of potential side-effects across relevant variables and contexts. To do so, foci on internal and external validity must be re-balanced in a manner more productive for practical inferences and applications. With an eye on educational practice, we point out that statistically insignificant results, under certain circumstances, can yield very useful strategies for teaching. Therefore, researchers interested in practical applications for teachers should be encouraged to use active control groups in their studies when feasible. We also argue that practical significance must include context-relevant information, for example, a ratio between the degree to which the findings can be used in context without upsetting other learning objectives and the amount of benefit given the costs (both time and energy) of the intervention, as an essential component to evaluating the potential utility of teaching research. Thus, statistically significant results must be weighed with respect to both effect-size and the practicality of implementation by teachers in authentic educational contexts before being considered a candidate for use in the classroom.

***Public Significance Statement***
We have a Science of Learning. Why don't we have a Science of Teaching? While Psychological Science has a great deal to offer with respect to the nature and characteristics of the learner, we argue that it can do better to inform and impact educational practice. We articulate the need and parameters for an ecological Science of Teaching to point and design findings from Psychological Science toward usable knowledge for teaching.

*Keywords:* scholarship of teaching and learning, teaching, learning, science of learning education

Teachers, across many fields, are looking to psychology to improve their impact. And, rightly so. We are the science that focuses on what goes on within the human mind, where learning, meaning-making, and processing occur. We study the motivation, emotion, tools, characteristics, and capabilities of the learner. The interaction of biology, context, and intention is integral to many of our models as psychologists (Fischer et al., 2007). Yet, as eminent historian of psychology Ben Benjamin so eloquently pointed out, psychology has done relatively little to improve the quality of *educational practice* since its inception (Benjamin, 2010). Whether it be K-12, university, or adult education, he posed as a fundamental challenge to our field: "We are the science of education, so why aren't we acting like it?" (Benjamin, 2010, 2:58)

A science of education is a multifaceted effort. Mayer described it as comprised of at least three interacting components: The sciences of learning, the science of assessment, and the science of instruction (Mayer, 2011). Mayer describes the sciences of learning as "aimed at understanding how people learn. In particular, learning is a change in the learner's knowledge that is attributable to experience" (Mayer, 2008, p.761). The science of assessment is described as the scientific study of how to determine what people know (Mayer, 2018, p. 174). Mayer describes the science of instruction as a science " . . . aimed at understanding how to *help* people learn" (Italics by authors, Mayer, 2008, p. 762). As the term "instruction" is sometimes regarded as limiting education to cognitive goals and/or a specific pedagogical approach, we would propose to rebrand this to the *science of teaching*.

## Looking Further: the Science of Learning and the Scholarship of Teaching and Learning

Whether it be in research or in practice, a focus on how people learn does not, necessarily, lead to better teaching. Biesta (2015) described how educational thinking has shifted its focus from teaching to learning, putting a bigger emphasis on the learner rather

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than the teacher, a shift also described by Meijer (2013) and Masschelein and Simons (2013). This recurring perspective in education and education-relevant research is sometimes at odds with other developmental theories that emphasize a more reciprocal and interactive perspective of teaching and learning with a stronger emphasis on the teacher influencing the learner in both formal and informal educational contexts across the life-span (e.g., Fischer & Bidell, 2006; Vygotsky, 1978). In this article, we reassert the need to consider the role of the teacher in facilitating the learner to do the work of learning. We further argue that, for knowledge about learning to be useable for those who teach, it must be interpreted, designed, and demonstrated to do so.

## The Science of Learning

Daniel and Chew (2013, but also Nuthall, 2007) addressed important limitations to much of the Science of Learning literature with respect to leveraging it to guide teaching practice. These limitations tend to cluster around a few key areas. First, the design and testing of an intervention with the goal of determining a theoretically interesting and statistically significant difference often require different outcomes, designs, and controls, relative to developing and testing an ecologically valid, usable, and sustainable teaching intervention for general use. In the first case, the design is often heavily influenced by a quest for high levels of internal validity, may require high levels of support or expertise to implement, and may not target or assess issues directly relevant to practitioners, instead focusing on extension or issues of theoretical or methodological import.

Secondly, proposed interventions from the Science of Learning literature, while interesting and important, are seldom designed to be implemented by typically resourced teachers in representative teaching and learning contexts. Relatedly, many Science of Learning recommendations do not include the teacher or context (or student, for that matter) as a relevant variable, instead adopting the view of teacher as a mere delivery system. Yet, individual difference in teachers, students and contexts are a very real part of the teaching and learning interaction (e.g., Hardin, 2007; Hattie 2003; Huang & Moon, 2009; Wayne & Youngs, 2003).

Finally, the failure to consider "peripheral" contributors' interactions (e.g., motivation, emotion, arousal, etc.), side-effects, boundary conditions, and, in general, complexity limits the potential to apply findings from the Science of learning directly to teaching practice in complex and authentic contexts. Such limitations are a necessary result of scope and disciplinary boundaries inherent to research within a specific orientation, rather than neglect: As an extension of cognitive science, the Science of Learning is, first and foremost, a scientific exploration of the nature, mechanisms, and potentials of the human learner. Areas such as motivation or developmental level may not be core to this pursuit. Thus, the movement away from such specific focus on target variables toward the design of inclusive ecologically valid and evidence-based interventions for teachers derived from that knowledge may introduce a level of complexity that diverts from the primary goals of a science to explore the nature, mechanisms, and potentials of learning. In addition, ecologically valid designs require a skillset related to curricular design and knowledge of context beyond the training of many in this important field.

## The Scholarship of Teaching and Learning

The Scholarship of Teaching and Learning (SoTL) literature, on the other hand, offers designed and usually successful interventions that, although often hyper-contextualized to a specific instructor, topic and class configuration, may be generalized to similar classrooms with some careful adaptation. However, SoTL research rarely explicitly links findings to relevant psychological constructs and findings as the source of their successful interventions (Daniel & Chew, 2013), limiting our ability to extend or situate the findings in relevant the psychological literature. Further, a teacher interested in replicating the impact found in SoTL research in a different course or context needs to know more than procedures, as those procedures may need to be adapted to new contexts. Rather, they need to identify the essential components and constructs necessary for the desired impact so as to implement the adaptation with a degree of fidelity. Not identifying the core constructs and mechanisms responsible for a successful intervention risks the potential for subverting the desired impacts when adapting across contexts, teachers, and learners. Without such knowledge, practitioners may not be aware which components to protect and which are amenable to change.

## Teacher Is an Interaction

Unquestionably, studying the learner and the impact of particular practices are both necessary and worthy endeavors. However, we also need to know how a teacher can structure and activate learning in educational contexts. Neither a Science of Learning nor an SoTL perspective focuses much attention on the more complex and dynamic aspects of the teaching and learning interaction. In fact, neither elucidates the very important role of the teacher as a participant with agency and impact in this process, nor do they incorporate the recognition of the interacting social-emotional, structural, or contextual contributions teachers make to the teaching and learning process in their models, if present.

Hattie (2003), as well as many others, have described the important role of the teacher to make the difference in the classroom. For example, Hardin (2007) evaluated the introduction of presentation software across eight sections and four instructors. The results indicated an interaction between teacher and modality of presentation (with or without Powerpoint); incorporating presentation software enhanced the teaching of some teachers, harmed others, and had no impact for most. It is clear from studies like this that the teacher is, indeed, a variable to be reckoned with. The role of the teacher is an important component of the ecology of the learning process, that we must submit this role to legitimate and specific scientific inquiry that goes further than description (e.g., the influence of gender, age, experience, collective teacher efficacy), but focuses on teaching in context as a core variable.

## A Science of (and for) Teaching

A Science of Teaching must begin with a few core assumptions. We offer, perhaps, the obvious proposition that teaching itself is worthy of investigation. Despite this seemingly indisputable statement, it is clear that the interactions central to teaching, beyond a teacher as a delivery-device perspective, have not been central to many areas of inquiry.

Relatedly, we propose that teaching and learning are often a complex interaction between the dynamic systems associated with

the teacher, context, material, and learner. Thus, a Science of Teaching must transcend the isolated main effects so prominent in the teaching and learning literature toward a richer and more complete model of the teaching process.

Models of the learner or recommendations for practice that do not take into account the interactive nature of cognition, emotion, etc. within the learner (e.g., Immordino-Yang & Damasio, 2007) can often encourage imbalanced models and side-effects in practice across domains (Immordino-Yang et al., 2019). For example, an intervention stressing a demanding cognitive task may increase learning, but reduce motivation or engagement. Another example is an intervention that positively impacts outcomes in foreign language learning may be ineffective in learning chemistry. Similarly, by recognizing that the necessary isolation of variables in laboratories and other controlled contexts may not be representative of the rich teaching and learning context, we can mitigate the risk of offering recommendations that subvert learning (Daniel & Poole, 2009), or, at least, do not encourage it (Brandmark, et al., 2020). The proposal to honor the interactive nature of teaching, context, and learner has implications for research and practice. How we move from controlled settings to more authentic ones (and back), including the need for translational models that allow for the gradual addition or subtraction of complexity (see Daniel, 2012 and Chew et al., 2010).

## What Does This Mean for Research on Teaching?

Every science, especially one focused on practice, must balance priorities. For example, to view internal and external validity on a continuum, one could easily err on one extreme or the other of the continuum, with significant costs, as well as benefits, depending upon the goals of that research. Similarly, determining what information is significant for a researcher's goals to be achieved and how to arrive at that significance is an important question a Science of Teaching would need to address. Below, we provide suggestions for a few of these issues as a starting point for a broader discussion on the parameters of a Science of Teaching.

### Validity

A Science of Teaching, we propose, would have to balance the goals of knowledge generation with practical import in a very different manner than, for example, a Science of Learning. Thus, a different balance of internal and external validity is necessary to move ideas toward promising practices (e.g., Kingstone et al., 2008). To do this, we must first acknowledge the complexity of the teaching and learning process. With that acknowledgment, high degrees of control (internal validity), with the goal of neatly isolating cause and effect, necessarily come at the expense of the potential for those findings to be useful in authentic educational contexts (external validity). In an ecological model, trade-offs between increasing control by decreasing complexity can compromise a true understanding of the interaction(s) and, important here, neutralize an ability to offer usable knowledge to teachers. Alternatively, a focus on ecological valid interventions and explanations would necessarily come at the expense of confident causal inferences. Thus, the encouragement of other mechanisms to develop an evidence base for such inferences, successive replications across contexts, for example, might be a strategy to offer additional explanatory power and thus should be encouraged by outlets and funders.

### Significance: When Non-Significant Is

The typical set-up in much of the pedagogical research is a treatment versus no treatment (or "business as usual") design. This design, while common, is rather limited in the conclusions one may reach. Something versus nothing, at best, can merely demonstrate that doing something is better than not doing something (or not) (Willingham & Daniel, 2021).

While an active control group, for example comparing the new intervention to one already known to have high impact, would yield much more useful information for teachers, many researchers may not want to gamble with such a design. It is too risky for many researchers if one of the goals is to publish: If the new technique is not significantly better than the active control, it would not be a good candidate for publication in many outlets. This approach erroneously assumes that a constrained number of "best practices" exist and that the goal of the literature is to find the singular "king of the mountain." But, what if we found ANOTHER great strategy that worked JUST as well in the classroom? This would be a wonderful addition to the literature. "Just as well" as something great can be a fantastic contribution to teaching, learning, and science. In this case, insignificance would be a valuable outcome.

As mentioned above, the demonstration of equivalence, albeit statistically insignificant, can be incredibly significant to teaching. For example, the non-statistically significant finding that technique X works, as well as the known to be successful technique Y adds breadth and flexibility to the teaching arsenal. Such an emphasis better serves the teaching community by providing alternatives from which to draw and adapt to teaching style, context, etc.

For example, rather than comparing a new technique to business as usual, Jakobsen and Daniel (2019) recently compared a fairly well-documented college-level teaching strategy, team-based learning, with a "new" technique. The new technique worked just as well as the highly supported strategy. Such a finding can offer confidence to teachers that moving to the new technique has potential to be at least equivalent to their current practice, a level of confidence that a "something v. nothing" study cannot offer. In fact, if the new strategy fits their style or context better, it may even offer benefits beyond mere equivalence. Imagine that a comparison of online learning and offline learning yields a non-significant difference. This finding could mean that these approaches are equivalent in certain circumstances, making the next question: For what topics, in which circumstances, for which kind of pupils are there differences? Unfortunately, the use of active control groups in education research is fairly rare (e.g., Willingham & Daniel, 2021).

Rather than asserting statistical supremacy, a common-sense criteria for replacing pedagogical strategies and tools should be that the replacement be *at least* as effective with few, if any, subversive side-effects, when compared to its proposed predecessor (Daniel & Willingham, 2012; Gurung, 2017). For example, were we to find that less expensive electronic-textbooks were equivalent to more expensive print textbooks that would be a finding with tangible benefits.

In fact, until equivalence criteria have been consistently demonstrated in representative contexts, we would urge all teachers to be skeptical of adopting the newest and shiniest methods, as it could

result in providing inferior, but less expensive, tools to our most vulnerable students, with potentially devastating consequences. For example, Gurung (2017) recently found that Open Educational Resource (OER) textbooks were less effective learning tools compared to publisher-provided textbooks, particularly for students with lower American College Testing (ACT) scores, a test administered to impending high school graduates designed to measure readiness for college or university, many coming from the exact lower-income population we are targeting a price-point argument. Without demonstrating equivalence to printed textbooks, the adoption of certain OER products potentially harms at least some students and subverts the efforts of good teachers. However, demonstrating equivalence would provide options for a teacher potentially improving the learning experience. Equivalence, rather than supremacy, gives us an invaluable opportunity to responsibly enrich teaching and learning while avoiding potential unintended consequences. Research outlets and funders interested in developing successful teaching practices should encourage well done studies using relevant active control groups to promote the development of options for teachers.

## Significance: When Statistically Significant Is Not Significant

Consistent, but relatively small differences can result in *statistical significance*, based on the concept of rejecting the null hypothesis (e.g., the results are likely not due to chance). So, for example, an educationally non-significant findings (1–2%) can be statistically significant but hold little potential impact for the classroom. Regardless of the *p* value, the costs for implementing an intervention with such small impact are often too high, impractical, or, in reality, a waste of time. As a teacher, I must be concerned with both whether the recommendation can be done in my context and with my resources as well as a general cost–benefit calculation when I entertain the idea of an intervention. The research may demonstrate statistical significance. But, are they *practically* significant with respect to implementation? Do our common measures of practical significance address such practical concerns for teachers?

## Practical Significance: Effect-Size

The concept of *practical significance* is particularly important in educational research, including SoTL. Arguments for practical significance often revolve around a measure of *effect size*, with the logic being that larger effect sizes signify a more desirable impact on relevant measures. In other words, the measure of effect size can help a teacher answer the question: "Is it worth it?" Thus, an educator can use effect size as a more appropriate indicator of an intervention's utility in their teaching than simple statistical significance. For example, if a strategy demonstrates statistical differences in a study, this could mean that it consistently differs by a small percentage from the control. While consistent, the difference may not be meaningful in the classroom. Or, say you have two class activities for the same concept, one takes 5 min and other takes 20. Both lead to a significant amount of learning, but the 20-min activity leads to a significant, yet small improvement over the 5 min. Would the difference be worth the additional class time spent?

Even though statistical significance may not be practically significant to the teacher, this does not mean that small effects should be disregarded, for example, if the cost for implementing the intervention is also very low, or if the target population would meaningfully benefit. For the past 2 years there has been a lot of discussion about the effectiveness of growth mindset approaches with a large replication study by Yeager et al., (2019) and a double meta-analysis (Sisk et al., 2018) showing on average a rather small effect size. But this average effect size can hide both the fact that it can have negative effects for some students and that it can lead to a better result for a segment of the population (e.g., children from families with lower socioeconomic backgrounds in certain contexts). Further, it is likely that a number of strategically deployed, small impact, but easy to implement strategies, can, in concert with each other, provide significant learning impact. Thus, decisions based upon statistical measures of practical significance must be weighed with attention to nuance and context before confident implementation.

## Practical Significance: Beyond Measures of Effect-Size

While the concept of effect-size is important, it is not sufficient on its own to guide decisions for implementation, and not the sole measure of practical significance in a teaching context. There are other practical considerations that must be considered by a teacher before implementing evidence-inspired interventions: Those involved in a cost–benefit analysis related to deployment (Wiliam, 2018). Because of the need to demonstrate impact, a teacher has additional concerns when moving from the literature to the classroom. After all, teaching is, ultimately, a practical pursuit. Thus, a Science of Teaching must honor both the complexity of the process, as well as the impact of that interaction. These practical considerations go beyond the available statistics for a given study and should be areas of discussion for a Science of Teaching. For example, one must be concerned with:

1. How that intervention might interact with other variables and learning goals in a course; whether the intervention may amplify or subvert other important aspects of my course;
2. How large the potential effect may be relative to the amount of work needed to achieve it;
3. Whether one has the resources to implement the intervention correctly;
4. Whether will it likely work in the given context?

Effective teachers often ask these questions implicitly, a Science of Teaching should give them support to arrive at an accurate conclusion.

Significance is not significant if the requirements to implementation are overly arduous, too expensive, too time consuming, require expertise or equipment beyond that available in my classroom, etc. A teacher, should be concerned with all of these variables, and more, simultaneously interacting within the learner and the complex interaction of the learner (and teacher!) with the context. Thus, measures of statistical, or even practical, significance may not provide the information a teacher needs to decide which interventions hold promise for a given teaching and learning endeavor. Research on teaching and learning would hold more promise for guiding high quality teaching if studies addressed the full, or at least probable, range of practical concerns relevant to practice in their reports.

## The End of "Best Practices"

The goal of research on teaching should not, and could not, be a set of universal "best practices" that can be deployed across contexts, learners, and educators. An honoring of complexity and context also has deep implications for the practical goal of a Science of Teaching. If we acknowledge the dynamic and interactive nature of teaching and learning, the popular quest for "Best Practices" within a complex system becomes remarkably reductionistic. Such a "solutionistic" (i.e., Morozov, 2013) quest for an easy solution, or a small set of "Best Practices" within a complex system, though conceivable in a rich and mature literature, is ill-suited at this early stage of an ecological approach to understanding the process of teaching and possible applications derived from it.

The fact is, there is not, and cannot be, a single best way to teach (Daniel & Poole, 2009). Teachers are different, learners are different, contexts are different, and learning goals are different (and those differences all interact!). For example, feedback can be both effective and ineffective (Hattie & Timperley, 2007), and even if feedback has been given inspired by research, it does not necessarily mean that the pupils have actually learned (Wiliam, 2012). Active learning is good for some things, but not everything, and not for everyone at every moment (De Bruyckere et al., 2015; Holmes, 2016). The very fact that teachers who gravitate toward vastly different pedagogies remain effective in the classroom clearly demonstrates this quite clearly: Different things work differently for different people and "best" is not always "best." Or as De Bruyckere et al. (2019, p. 157) describe:

> . . . what works at 9 AM in one class may not work at 3 PM in another class. If that trouble-maker Peter is absent today, things may turn out differently than if he was present. For this reason, we must be constantly aware, as the designers of learning interventions, that if we use the available scientific evidence there is every possibility that what works in one context may not necessarily work in a different context (lesson, subject, age, school type, time of day, etc.).

Rather than an implausible set of "Best Practices," the practical goal of an ecological Science of Teaching would be to develop an *arsenal,* or *repertoire*, of effective techniques, approaches, and attitudes, in addition to the conditions under which they are optimally deployed (or avoided). Such an emphasis better serves the teaching community by providing alternatives from which to draw and adapt to teaching style, context, etc. It would also enrich and make more powerful theories and models related to the teacher and learner.

## Conclusion

In this article, we proposed a new approach to the Science of Teaching. We build on an already a rich scientific literature that can be a powerful resource for rich teaching. While seldom a prescription for high quality practice, findings in the Science of Learning and SoTL literatures can erroneously be regarded as prescriptions for practice in a narrow vision of "evidence-based education" (De Bruyckere et al., 2019). Instead we argue that the present approach of science in this realm is not sufficiently powerful or synthetic to either encourage a useful model of the teaching and learning process, or to produce usable classroom practices that encourage fidelity and impact without unintended consequences.

The result of pedagogical research may (fingers-crossed) eventually provide guidance that incorporates the nuance inherent in the complex interactions involved in effective teaching. For now, teaching would benefit from removing a singular focus on *best practices*, instead turning its attention toward the development of a variety of evidence-backed strategies, or *promising practices*, that teachers can deploy across specified contexts, learners, goals, and styles. Researchers hoping to impact teaching practice should focus on identifying psychological principles that hold promise for practice (e.g., *promising principles)*, and designing from them *promising practices* that can be tested in authentic contexts (Daniel, 2012).

Rather than dogma, flexibility and experimentation are important tools for the responsible teacher to leverage the most appropriate evidence-backed strategies. A literature rich with possibilities is our best tool to inform this process. Therefore we strongly encourage journals and editors of outlets that include content with recommendations for educators to consider the value of often messier, but externally valid designs, active control groups and the result of statistical equivalence to an already demonstrated strategy as an important step in the evolution of a literature that serves both science and the classroom teacher.

Further, practical concerns, including measures of effect size and addressing the practical concerns of implementation should be considered essential components of studies that hope to influence teaching practice across the different interacting functions and contexts of education. Providing teachers with the tools and information needed to evaluate and implement *promising principles* is the core of what would make a Science of Teaching an inspirational source of truly innovative teaching and learning practice and the context to enrich theories and models of learning and development. This, we argue, can more effectively happen with attention to complexity within an ecological framework. In this way, a science *of* teaching would also become a science *for* teaching.


## Résumé

Il est nécessaire de faire de l'enseignement un objectif, qui reste à atteindre, de la science de la psychologie. Nous soutenons qu'un modèle écologique axé spécifiquement sur la compréhension et l'optimisation de la pratique de l'enseignement doit inclure la complexité intrinsèque de l'enseignement et du processus d'apprentissage. Pour y arriver, nous devons élargir notre portée au-delà de la simple exploration des principaux effets dans des conditions contrôlées pour inclure l'exploration des interactions dynamiques, y compris la détermination des conditions limites et l'évaluation d'éventuelles répercussions parmi les variables et les contextes pertinents. En outre, l'importance accordée à la validité interne et externe doit être rééquilibrée de façon plus productive afin d'obtenir des conclusions et des applications pratiques. Du point de vue de la pratique pédagogique, nous mettons en relief que des résultats non significatifs sur le plan statistique peuvent, dans certains contextes, mener à des stratégies très utiles pour l'enseignement. Ainsi, les chercheurs s'intéressant aux applications pratiques pour les enseignants doivent être encouragés, lorsque cela est possible, à utiliser des groupes témoins actifs dans le cadre de leurs études. De plus, nous soutenons que la portée pratique doit inclure l'information pertinente selon le contexte, par exemple, le rapport entre le degré auquel les résultats peuvent être utilisés en contexte sans nuire aux autres objectifs d'apprentissage et l'importance des coûts (en temps et en énergie) de l'intervention, en tant qu'élément essentiel pour l'évaluation de l'utilité potentielle d'une recherche sur

l'enseignement. Ainsi, les résultats statistiquement fiables doivent être pondérés quant à l'ampleur de l'effet et à l'aspect pratique de leur mise en œuvre par les enseignants dans un véritable contexte pédagogique avant d'envisager leur usage en classe.

*Mots-clés :* science de l'enseignement et de l'apprentissage, enseignement, apprentissage, science de la pédagogie

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