Getting More Scientists to Revamp Teaching

By Quentin Vicens and Michael E. Caspersen

Despite extensive evidence in favor of student-centered teaching practices over traditional lecturing, most science faculty do not embrace these modes of instruction. Professional development efforts are plentiful, but they can lack in impact or scalability, or both. The factors that determine professional development quality within a research environment remain largely unidentified. However, findings from diffusion of innovation research suggest that science faculty will likely embrace alternatives to traditional lecturing according to their own perceptions and subjective evaluations of the new practices. The rapid diffusion of clickers at our university leads us to propose that faculty development strategies may gain in being explicitly informed by both the scientists' most immediate needs as teachers and the findings from diffusion of innovation research. Overall, a relatively hands-off approach to faculty development may be a gateway to instructional change at research universities.

In recent years, teaching improvement has become a priority at most research universities worldwide. To facilitate the change, research-based strategies that boost student learning abound (Handelsman, Miller, & Pfund, 2007; Mervis, 2013), and professional development efforts for science teachers are plentiful (Wilson, 2013). Yet, most science faculty members don't change their teaching accordingly, which in April, 2013, led the magazine *Science* to define as a grand challenge in science education the need to "identify the underlying mechanisms that make some teacher professional development programs more effective than others" (Wilson, 2013, p. 312). Our experience of facilitating teaching improvement efforts at the second largest university in Denmark incites us to suggest that similar to the "less is more" teaching approaches typically promoted by faculty developers, a less heavy-handed approach to professional development may be key in diffusing instructional change among science faculty. In that process, findings from diffusion of innovations research are instrumental in building a community of scientists who revisit their teaching.

Reassuringly, research on professional development has shown that factors for effective professional development are similar to those for effective teaching (Freeman, Marx, & Cimellaro, 2004). These principally include focusing on specific content, engaging participants in active learning that often involves inquiry, reaching out to all participants, aligning courses with one another and with actual practice, spending enough teaching time to ensure learning, and communicating at the participants' level (Handelsman et al., 2007; Wilson, 2013). Such training programs are successful for developing student-centered teaching communities made of both junior and senior faculty (Miller, Pfund, Pribbenow, & Handelsman, 2008).

Continuous support from science education experts is also critical in helping science faculty implement instructional change (Henderson & Dancy, 2008; Wieman, Perkins, & Gilbert, 2010). To that end, universities have hired "on the ground" faculty developers in most departments to specifically assist faculty members in transforming their courses according to scientific teaching principles (Chasteen, Perkins, Beale, Pollock, & Wieman, 2011; Wieman et al., 2010). Other institutions have fused science and teaching expertise by establishing appointments for scientists–educators that demand similar levels of expectations in teaching and research and that require a particular training in education (Bush et al., 2008; Cech, 2003). Such faculty can set an example and act as seeds for revisiting science teaching within their own departments. A crucial aspect to hiring either scientists–educators or science education experts is that they operate from within a department, so that departments and their associate scientists retain a sense of ownership of teaching improvement efforts.

Challenges to instructional change at research universities

Even though the many remarkable initiatives that exist to revamp teaching pay off within supportive or sympathetic environments that have more willingness to change and have sufficient funding, they don't easily scale up to reach the broader context of research universities worldwide, especially at times of scarce funding. Forty percent of scientists–educators at California State Universities consider leaving their job, mostly because they feel that their environment fails the promise of equally supporting teaching and research (Bush et al., 2008). In fact, a strong research program is emphasized over effective teaching for academic recognition, and scientists are conditioned to evolve in that environment from the early training stages of their PhD (Tagg, 2012). Consequently, they may not have time now to revise their courses (Dancy & Henderson, 2010), assuming they haven't already disregarded the need to change teaching altogether (T. R. Anderson, 2007).

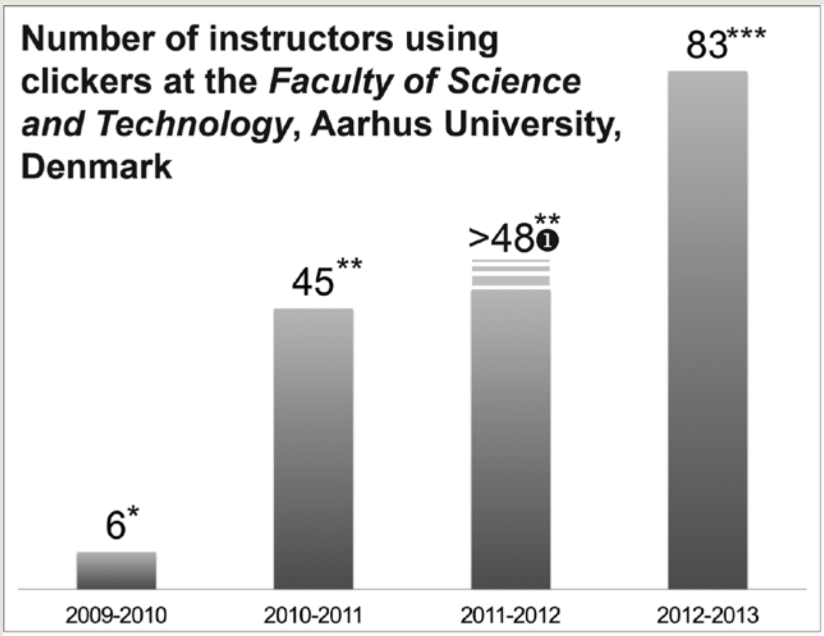
Even when scientists are well-informed and motivated to revise their courses, they may experience daunting situational or organizational constraints (Henderson & Dancy, 2007), such as configurations of auditoriums that conflict with group work or recitations that are scheduled before lectures for some groups. Without proper assistance (access to pools of qualified faculty developers varies widely across disciplines and locations), science faculty may also imperceptibly miss on implementing scientific teaching complete with all its technical, pedagogical, cognitive, and social components so that student learning will be promoted (Dancy & Henderson, 2010). In such situations of seemingly doing everything right, science faculty and their colleagues may view their experience as proof that active learning does not work (Andrews, Leonard, Colgrove, & Kalinowski, 2011; Research & Evaluation Team, Office of Technology, 2012).

Although this rough climate makes it tempting for faculty developers to lose hope or blame scientists, fortunately change remains possible because what fundamentally binds scientists in academia around the world is the desire to excel at what they do. Even when scientists don't see teaching as a priority, they would love for students to be more engaged, more articulate, and more reflective, and for teaching overall to be a more rewarding experience for everybody involved. Taking this important parameter into account more effectively in faculty development strategies could lead to instructional change.

A plain solution with a high potential for impact and sustainability is to provide adequate help for the few scientists who want to change something about their teaching through assisting them in reconfiguring only what they want to alter (Freeman et al., 2004). Scientists rarely complain about their teaching as being suboptimal. Hence, telling them that plenty of research-based evidence has shown that lecturing doesn't work is a counterproductive approach (Henderson & Dancy, 2007). What scientists complain about, however, is that students are not engaged, not motivated, and don't do their homework. Because these problems are what they experience directly

FIGURE 1

Adoption of clickers at the Faculty of Science and Technology, Aarhus University, Denmark, from 2009–2013.



* Departments of Physics, Mathematics, and Bioscience

** Departments of Physics, Mathematics, Bioscience, Molecular Biology, Computer Science, and Chemistry

*** All twelve departments at the Faculty

❶ Lower estimate: due to an insufficient number of clickers to meet the escalating demands, the first science faculty who had reserved clickers shared them with those who could not get any otherwise in the classroom, they are open to trying new strategies that will help them overcome these issues. Here, a valuable approach is to dilute out the principles of student-centered active learning so that scientists feel they get their most urgent needs met first. A few effective tips empower scientists and make them hungry for more and deeper adjustments to their teaching. This was the mission that we proposed to carry out via our Centre for Science Education, a teaching and learning center that was created in 2009 to promote excellence and scholarship in teaching by effective and efficient means within the 12 departments at our Faculty of Science and Technology.

Clickers as a Trojan Horse

The experience at our and other universities (Kolikant, Drane, & Calkins, 2010) is that clickers are an ideal Trojan Horse for generating a scientific teaching culture within a research environment. Since we first introduced clickers at our university 3 and a half years ago, almost all scientists who have approached us for instructional support have expressed the desire to use clickers. Unanimously, they had heard of clickers' potential to engage students, to make lectures more enjoyable and lively, and to enhance learning either from colleagues who were using them already—the few pioneers we had also assisted in getting set up—or from peer instruction's inventor Professor Eric Mazur from Harvard University who had "confessed" about transitioning from traditional to interactive lecturing at our university in 2009 (Mazur, 2012). Given that clickers can enhance learning, we were interested in ways of effectively diffusing that specific teaching innovation, together with associated pedagogies. More generally, we were interested in how any relevant teaching innovation could effectively and efficiently be diffused and become accepted by faculty members at a research university.

We provided scientists with robust and user-friendly clickers and clicker software similar to those used by Mazur, as well as with the basics of how to use them effectively in the classroom, through workshops and discussion groups during which we referred to some of the key online resources (in particular, resources from the Carl Wieman Science Education Initiative at the University of British Columbia, available at http://www.cwsei.ubc.ca/resources/clickers.htm) and more recently from Schell and Mazur (2012) and papers that document the effectiveness of clickers and peer instruction (see, e.g., Beatty, Gerace, Leonard, & Dufresne, 2006; Crouch, Watkins, Fagen, & Mazur, 2007; Knight & Wood, 2005; Perez et al., 2010; Smith et al., 2009). We did not provide any emphasis on complementary aspects suggested by scientific teaching (Chasteen et al., 2011; Handelsman et al., 2007; Mervis, 2013), such as creating or revising learning goals (to some extent this had been the focus of prior efforts; see Brabrand & Dahl, 2009), matching clicker questions to learning goals, and revisiting exam questions. We chose this relatively hands-off strategy because it had the advantage of being low budget when funding was only sufficient for one science education specialist position at two out of our 12 departments (Molecular Biology & Genetics and Computer Science).

After only 2 years, clickers had been used by 45 scientists from six departments and in more than 50 distinct courses. A survey conducted at that time indicated that all instructors had planned to continue using them in the future. Current statistics show that these instructors have indeed continued their use of clickers, and that more scientists from all 12 departments are becoming clicker users every year (see Figure 1). In their praise for clickers as great tools to get quality feedback from students, some scientists, for example, recognized how clicker questions would make them think about what the most important messages of their lectures were. Such reflections, combined with the observation that students' final grades did not improve on initial clicker use despite the visible increased engagement, prompted discussions about adjusting clicker questions so that they would be more about what the students should get from the course and more connected to the exam. As expected from interviews of scientists (Henderson & Dancy, 2008), from previous studies of the role of technology (Freeman et al., 2004), and as observed elsewhere (Kolikant et al., 2010), we found that exposure to clickers without much upfront pedagogical discourse led scientists to reflect about various aspects of their teaching, thus opening the door to progressively more substantial scientific teaching theory.

These observations suggest that at first, minimal guidance rather than in-depth workshops may be a clever strategy for ensuring sustainable change at research universities. At our university, only two science education specialists were sufficient to guide this massive clicker adoption and to initiate a similar motion at other faculties (Health and Arts). Constituting a critical mass of clicker users was possible through relatively hands-off support, along with our facilitation of various local, national, and international discussion groups and events in which clicker adopters would be invited to share their experience with their colleagues (e.g., our symposium in June, 2012, titled "Frontiers in Science Teaching Symposium: Clickers, Peer Instruction, and In-

TABLE 1

Outlook on strategies that help promote instructional change at universities and how they relate to findings from diffusion of innovations research.

Determinants in the adoption of any innovation according to Rogers (2003)	Examples of considerations that pertain to the successful diffusion of student-centered, active learning strategies
1. **Perceived attributes of innovations**, divided in five subcategories: Is the innovation worth adopting?	Clicker-based peer instruction is an active learning strategy that helps students to be engaged in class and to assimilate concepts (Crouch, Watkins, Fagen, & Mazur, 2007; Knight & Wood, 2005; Smith et al., 2009)
1a. **Relative advantage** of the innovation over **existing** practices	• Clickers make it easier to engage all students one-on-one, at the same time, even in classes of >30 students
1b. **Compatibility** of the new idea with current values, socio-cultural norms, and **previously** introduced ideas	• Polling is a well-known technique as it is used in most surveys anywhere. • Instructors often pause their lecture to ask questions; with clickers, the number of students who get a chance to respond is just larger. • Because clickers automatically collect student's responses, they make it easier to organize students' responses than when counting from a show of hands or colored cards. • Clicker questions are similar in nature to multiple-choice questions students find on homework assignments or tests.
1c. **Complexity** of the innovation: The easier the **innovation** can be understood, the more likely it is to be adopted	• Clicker systems now exist that are plug-and-play for both instructors and students. • Simple but advanced clicker systems can be downloaded that run on smart phones or laptops (Vicens, 2013).
1d. Degree to which the innovation may be **tested** before adoption	• Upon installing clicker management software, instructors can quickly test clickers. • Students typically need only a few questions to figure out how to use a clicker or a clicker application.
1e. **Rapidity** with which a positive change can be noticed upon trial or adoption	• Student engagement as a response to clicker usage is immediately visible in the classroom to both instructors and students. • Instructors report how they have instantaneous feedback about the level of understanding in their class through the histogram of student responses.
2. **Type of innovation–decision**: Who decides to adopt? Is it an outside authority, the potential adopters, or both?	• Some form of institutional support is key for changing the culture of teaching at the level of the scientific departments (Wieman, Perkins, & Gilbert, 2010). • Scientists are more likely to adopt scientific teaching practices if they can "make them their own" by reinventing them some (Henderson & Dancy, 2008).
3. **Type of communication channels**: How is information about the innovation communicated to the adopters?	• For opinion, advice, and feedback on active learning strategies, scientists will go to colleagues who have been exposed to such practices. • Science faculty tend to rely more on internal than external science education specialists.
4. **Nature of the social system**: What are the norms of the system in which the adopters are now? How interconnected is that system?	• Good teaching ought to be better recognized/rewarded in research environments (W. A. Anderson et al., 2011; Antman & Olsson, 2007). • Rewards for good teaching may not be similar in nature to recognition of research quality. • Many institutions and their scientists don't view improving teaching as a priority (Wood & Gentile, 2003).
5. **Extent of change agents' promotion efforts:** How effective are the change agents, but also the early adopters at promoting change within their system?	• The power of workshops is often limited to raising awareness about student-centered practices. • Too much emphasis on showing research-based evidence that active learning works can kill any effort to promote its diffusion (Henderson & Dancy, 2008). • Scientists appreciate science education specialists who have a scientific background and can work with them as partners (Henderson & Dancy, 2008; Wieman, Perkins, & Gilbert, 2010). • Sustainable improvement of student-centered teaching practices occurs when the scientists who have been adopting these practices act as spokespersons for their adoption.

verted Classroom" (presentations available at http://cse.au.dk/en/frontiers/). Our clicker system was also relatively hassle-free, which meant minimal technical support. Wider adoption is now promoted through (a) sections of courses for new faculty recruits and events for all faculty that specifically emphasize scientific teaching and clickers, (b) clicker availability within each main auditorium on campus, and (c) the more senior clicker users acting as units of change within their departments and beyond. Not all clicker adopters are accomplished scientific teachers yet, but their experience with clickers has motivated them further to help students get better grades. Hence, although a hands-off approach may seem at first to not be high throughput, its benefits can quickly scale up.

Considerations for a sustainable instructional change

Framing the process of faculty development at a research university as a process of diffusion of innovations is helpful to interpret the phenomena typically observed when promoting instructional change (see Table 1). Preferred teaching practices are innovations that faculty developers aim to spread among a population of academics. What leads individuals to adopt a practice different from their own is their subjective evaluation of that new approach, which is derived from their own experience, their perception, and peers' feedback. Significantly, awareness of a better way to do any task does not lead to its natural adoption (Rogers, 2003), an observation with obvious implications for scientists' use of improved instructional methods. Furthermore, the rate of adoption of any innovation is determined by only five variables (see Table 1), the perceived attributes of the innovation accounting for 50% of the variability between rates of adoption. Because these phenomena are part of the human nature, paying attention to them is essential to facilitate and not impede social change.

Providing user-friendly clickers to motivated instructors with minimal technical and pedagogical guidance proved to be key. Faculty had the opportunity to become familiar with clickers and their benefits, because the perceived attributes of clickers increased the chances that clickers would become adopted by users (see Table 1). To satisfy the senior clicker users, we then had to adjust our promotion strategy to include more substantial courses on pedagogies associated with clicker use, hereby noticing a synergy or cooperativity between the diffusion of clickers, peer instruction, and other active learning strategies. By that time, the culture at our faculty was primed for up-front scientific teaching courses for junior science faculty, further setting the ground for a sustainable improvement of the learning environment.

Even though clickers represent a gateway to sustainable teaching improvement, ultimately scientists still expect recognition for teaching excellence (Wieman, 2007). Recognition systems need to be put in place by universities or their departments that might include monetary incentives or some official academic recognition. Such systems should reward teaching skills, but also scholarly approaches to developing courses and choosing particular pedagogies (W. A. Anderson et al., 2011; Antman & Olsson, 2007). Scientists ought to be invited to take part in deciding how they would like to be recognized for good teaching and scholarship in teaching. To quote John Tagg (2012): "We need to not only design change for our institutions but redesign our institutions for change." We propose that a "less is more" approach to improving teaching quality as well as a recognition system are two of the major cornerstones in this process of institutional redesign that will sustainably upgrade the way we teach at universities worldwide. ■

Acknowledgments

We thank Stephanie Chasteen for insightful discussions and for critical reading of this manuscript; Eric Mazur and Chrysa Latrick for inspirational discussions and helpful comments on the manuscript; and our colleagues at the Centre for Science Education and at the Faculty of Science and Technology at Aarhus University for their ongoing support.

References

Anderson, T. R. (2007). Bridging the educational research-teaching practice gap: The importance of bridging the gap between science education research and its application in biochemistry teaching and learning: Barriers and strategies. *Biochemistry and Molecular Biology Education, 35,* 465–470.

Anderson, W. A., Banerjee, U., Drennan, C. L., Elgin, S. C., Epstein, I. R., Handelsman, J., . . . Warner, I. M. (2011). Changing the culture of science education at research universities. *Science, 331*(6014), 152–153.

Andrews, T. M., Leonard, M. J., Colgrove, C. A., & Kalinowski, S. T. (2011). Active learning not associated with student learning in a random sample of college biology courses. *CBE—Life Sciences Education, 10,* 394–405.

Antman, L., & Olsson, T. (2007). A two-dimensional matrix model for analysing scholarly approaches to teaching and learning. In C. Rust (Ed.), *Improving student learning through teaching* (pp. 54–72). Oxford, England: Oxford Centre for Staff and Learning Development.

Beatty, I. D., Gerace, W. J., Leonard, W. J., & Dufresne, R. J. (2006).

Designing effective questions for classroom response system teaching. *American Journal of Physics, 1,* 31–39.

Brabrand, C., & Dahl, B. (2009). Using the SOLO taxonomy to analyze competence progression of university science curricula. *Higher Education, 58,* 531–549.

Bush, S. D., Pelaez, N. J., Rudd, J. A., Stevens, M. T., Tanner, K. D., & Williams, K. S. (2008). Science faculty with education specialties. *Science, 322*(5909), 1795–1796.

Cech, T. R. (2003). Rebalancing teaching and research. *Science, 299*(5604), 165.

Chasteen, S. V., Perkins, K. K., Beale, P. D., Pollock, S. J., & Wieman, C. E. (2011). A thoughtful approach to instruction: Course transformation for the rest of us. *Journal of College Science Teaching, 40*(4), 24–30.

Crouch, C. H., Watkins, J., Fagen, A. P., & Mazur, E. (2007). Peer instruction: Engaging students one-on-one, all at once. In E. F. Redish & P. J. Cooney (Eds.), *Research-based reform of university physics* (Vol. 1). College Park, MD: American Association of Physics Teachers.

Dancy, M., & Henderson, C. (2010). Pedagogical practices and instructional change of physics faculty. *American Journal of Physics, 78,* 1056–1063.

Freeman, J. G., Marx, R. W., & Cimellaro, L. (2004). Emerging considerations for professional development institutes for science teachers. *Journal of Science Teacher Education, 15,* 111–131.

Handelsman, J., Miller, S., & Pfund, C. (2007). *Scientific teaching*. New York, NY: W. H. Freeman.

Henderson, C., & Dancy, M. H. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics—Physics Education Research, 3*(2), 02010201–02010214.

Henderson, C., & Dancy, M. H. (2008). Physics faculty and educational researchers: Divergent expectations as barriers to the diffusion of innovations. *American Journal of Physics, 76,* 79–91.

Knight, J. K., & Wood, W. B. (2005). Teaching more by lecturing less. *Cell Biology Education, 4,* 298–310.

Kolikant, Y.B.-D., Drane, D., & Calkins, S. (2010). “Clickers” as catalysts for transformation of teachers. *College Teaching, 58*(4), 127–135.

Mazur, E. (2012). *Confessions of a converted lecturer* [Video file]. Retrieved from http://youtu.be/ZpNjem3p0Ak

Mervis, J. (2013). Transformation is possible if a university really cares. *Science, 340*(6130), 292–296.

Miller, S., Pfund, C., Pribbenow, C. M., & Handelsman, J. (2008). Scientific teaching in practice. *Science, 322*(5906), 1329–1330.

Perez, K. E., Strauss, E. A., Downey, N., Galbraith, A., Jeanne, R., & Cooper, S. (2010). Does displaying the class results affect student discussion during peer instruction? *CBE—Life Sciences Education, 9,* 133–140.

Research & Evaluation Team, Office of Technology. (2012). *What do you mean active learning doesn’t work?!?* (Research brief). University of Minnesota. Retrieved from http://www.oit.umn.edu/research-evaluation/research-briefs/

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York, NY: Free Press.

Schell, J., & Mazur, E. (2012). *Turn to your neighbor: The official peer instruction blog*. Available at http://blog.peerinstruction.net/

Smith, M. K., Wood, W. B., Adams, W. K., Wieman, C., Knight, J. K., Guild, N., & Su, T. T. (2009). Why peer discussion improves student performance on in-class concept questions. *Science, 323*(5910), 122–124.

Tagg, J. (2012). Why does the faculty resist change? *Change, 44,* 6–15.

Vicens, Q. (2013). Building students’ knowledge one click at a time. *Laering og Medier,* 10, 1–28.

Wieman, C. (2007). Why not try a scientific approach to science education? *Change, 39*(5), 9–15.

Wieman, C., Perkins, K., & Gilbert, S. (2010). Transforming science education at large research universities: A case study in progress. *Change, 42*(2), 7–14.

Wilson, S. M. (2013). Professional development for science teachers. *Science, 340*(6130), 310–313.

Wood, W. B., & Gentile, J. M. (2003). Teaching in a research context. *Science, 302*(5650), 1510.

Quentin Vicens (quentin.vicens@gmail.com) *runs his own faculty development company from France* (http://quentinvicens.com) *and is a former science teaching and learning fellow in the Centre for Science Education, Department of Molecular Biology, at Aarhus University in Aarhus, Denmark.* ***Michael E. Caspersen*** *is director of the Centre for Science Education and associate professor in the Department of Computer Science at Aarhus University.*