System change: Engineering a lever for changing the teaching of science

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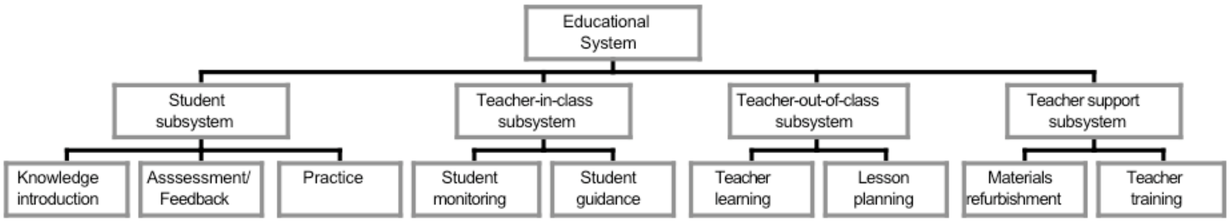
The elementary and secondary science instructional systems in the US are fundamentally broken: most teachers of elementary science and many teachers of secondary science have a weak mastery of the content they are teaching and do not use effective reform pedagogy (Ingersoll, 2003); US students spend less classroom time on science than students in many other countries (Martin *et al.*, 2000); most US textbooks used for science instruction bore the students or confuse the teachers (Vogel, 1996); most US students (and parents) do not value science as an epistemology or career (Chinn & Malhotra, 2002); and most US school districts have low quality and ineffectual professional development communities in science (Garet *et al.*, 2001).

Fundamentally improving this system is unlikely to succeed with a 'parts' perspective: only changing the textbooks, only changing the number of hours devoted to science, only changing the classroom pedagogy, only changing the content knowledge of teachers, or only improving the professional development techniques used in districts. The problem with the parts perspective is that science instructional system is a complex system of interacting and adapting parts that has settled into an equilibrium state, and thus is resistant to change. For example, textbooks with higher levels of cognitive demand are rejected by the existing system because the teachers are poorly prepared to use them, and efforts to reform teacher content knowledge are hampered by weak professional learning communities that are mostly volunteer based or with such little mandatory time as to be useless.

The magnitude and complexity of the problem does not, however, make it hopeless. For example, improving such a broken and complex system does not require addressing all of the broken elements simultaneously. In fact, even with much larger resources, attempting to address all the elements simultaneously is unlikely to work given the complex network of stakeholders that control the instructional system.

There is hope for the designer to instrument long-lasting and meaningful change by using a systems perspective to the design task and incrementally building change from that perspective. This paper outlines this methodology and presents an example from secondary science, based on my work with a wide variety of large urban school districts in the US, trying to produce significant improvements in student learning across the large districts. The insights reflect interactions with district officials, deputy superintendents, heads of science, lead science teachers, science education researchers, and scientists engaged in large amounts of outreach efforts. Some of the resulting programs led to rapid and widespread adoption of reform materials with significant, immediate changes in student learning (Mehalik, Doppelt, & Schunn, 2008). But lessons were also learned about how this systems change work could have been even more effective.

Step 1: Develop a model of the overall system to be changed. This step helps to ensure that the design includes all the critical elements (i.e., what subsystems are a critical element of the overall functioning system that needs to be changed). Note that the model of the system involves thinking in terms of subsystems rather than just parts. For example, individuals may play multiple roles within the same system but each role/function needs to be listed separately. There are often different ways of organizing a situation into subsystems. Here is one that I have found useful for thinking about science (Schunn, 2008).



In this model, the critical elements of the system involve what students do, what teachers do in the classroom to support students, what the teacher do outside of the classroom to prepare for the classroom, and how the system supports the teachers. In my analysis of large urban districts, all of the major subsystems are broken. First, feedback comes to late with respects to knowledge introduction and practice (i.e., poor instructional models). Second, teachers do little student monitoring, in part due to poor instructional models and in part due to weak content knowledge (i.e., poorly diagnosing student thinking because critical distinctions are not seen). Third, the district provides too little weekly time for teacher learning or effective lesson planning, and teachers lack the content knowledge and pedagogical knowledge to make significant improvements via lesson planning. Finally, the district and typical regional training partners lead very ineffective, irregular, and poorly attended professional development events, and science materials are decreasingly available in the classroom and very unevenly distributed across schools within the same school district or across school districts within the same region.

Step 2: Determine output requirements associated with key decision makers, including the ones that are not currently being met. From the social psychology and organizational psychology literatures, a clear finding is that individuals and groups are much more open to change when it is clear that the current situation is perceived as unsuccessful and the new proposal addresses this perceived weakness. This step involves identifying more than just the relevant output dimensions, but also what target levels are required (e.g., which levels of student performance in what areas would be considered success).

For example, in the US, performance on state tests is very important to administrators in public school systems, but only in terms of the number of students meeting the ‘proficient’ bar (rather than average score or number of students meeting the ‘advanced’ bar). On the teacher front, in addition to some (but lesser) worries about student performance on state tests, there is considerable anxiety about overall student apathy/behavioral problems and low student performance on certain topic areas. Thus, the teachers AND the district administrators would be interested in changes that address critical topics in the existing curriculum that also appear prominently on the state tests and with which students are obviously struggling.

By contrast, none of the administrators and few of the teachers are interested in specialty topics like nanoscience or robotics, even though students might be very interested in those topics. In the school core curriculum, administrators and teachers control the topic choices, and thus their perspectives are especially important, whereas in informal learning settings or elective learning settings within schools, student interests dominate.

Step 3: Identify resources available for use. In addition to challenges or requirements, instructional systems also have resources (e.g., existing materials, regional partners, what budgets are available, according to what categories of expense, how much professional development time is actually available).

We also found that districts could require and organize 20 hours of teacher professional development over the course of a year, although this required focal attention of the administrators to declare it as a priority over competing plans for that time.

We also found that large districts do typically have a significant proportion (e.g., at least 10%) of science teachers who have good content knowledge and leadership capabilities, although they often are not yet acting as teacher leaders in the district and the central office people are often unaware of these talents.

Finally, we found that districts were willing and able to spend up to $10/student in upfront costs to acquire new instructional materials, not including photocopying costs, which appear to come from different budget categories.

Step 4: Develop a growth and sustainability model.

Because the systems change is typically much too large to be accomplished all it once, design for systems change will typically also require a growth model, which often is a capacity-building theory of action. However, the model also needs to have a sustainability component—new administrators, teachers, and competing forces for reform are constantly entering the system. Thus, leaving behind a knowledgeable, distributed leadership team may be critical to long-term success. Along these lines, some policy researchers have come to talk about interventions that are educative for the system players (e.g., for teachers or administrators) beyond the initial primary targets (i.e., students).

Replacement units as beginning systemwide, sustainable change.

The model of systemwide change that I have been pursuing involves 6-to-8-week replacement units, taking into account the typical problems and resources found in large US urban school districts regarding science education. The goals of the replacement unit are to 1) identify effective teacher leaders within the existing teacher pool so that they can help with further reform efforts, 2) change teacher beliefs about reform pedagogy so that all teachers will support later reform efforts, and 3) provide noticeable immediate change in student learning outcomes so that administrators will support further reform efforts of this style. The replacements units must, therefore, lead to improved student learning outcomes, but the most important functions are to make the overall instructional system more able to engage and sustain broader reform efforts.

The duration of the replacement units (6-to-8 weeks, or 20-to-30 hours of instruction) are strategically selected to be long enough for impact but short enough to be easily implemented. With rich instruction of that length, we have found that students can come to significantly better learning outcomes on major science topics (Mehalik et al., 2008). As a result, teachers change their minds about what levels of reasoning/cognitive demand their students are capable of reaching and the value of reform practices. This duration of reform curriculum is also short enough to be tried on a trial balloon basis, especially if the topic of the replacement unit is a core element of the curriculum not currently obtaining adequate student learning levels. For such topics, teachers are willing to try something new, especially if also encouraged by the administrators and supported through good professional development communities. In addition, that amount of instructional change can be properly supported within existing professional development resources (i.e., with 20 hours of professional development).

While perceptions of weaknesses in current instruction are critical for teacher willingness to try and continue to use the replacement units, we learned the hard way that this criterion is not sufficient for sustainability in the current high-stakes testing environment. The first replacement unit that we developed was wildly successful: fully implemented by 85% of teachers by the second year. However, the content of the unit (electronics) did not match state standards, and thus was entirely removed from the curriculum two years later. Thus, all of the more recent replacement units have also had to meet the criterion of involving content that is well represented in state standards (e.g., Newton's laws in physics or Central Dogma in biology).

This replacement unit growth model also assumes that grade level/course professional development communities rather than building-specific communities are the target given the highly specific nature of content knowledge in science (e.g., little in common between adjacent grades within a building). Another factor is the relatively small number of teachers of any one grade in secondary. In secondary science, most US urban districts have between 10 and 50 teachers of a given grade level. Assuming that good professional development sessions can be run in groups up to 25 teachers, this means that all teachers can be reached with two cohorts. The benefit of having only two cohorts (as opposed to 10 to 20 cohorts as a building-specific model would require) is that an external reform entity (e.g., developer of the replacement units) can directly engage with the initial professional development of more than half of all relevant teachers, and then leaving only a second year to teachers promoted to trainer level. Other models of reform require working only with trainers of trainers, which can lead to immediate dilution of training efficacy.

References

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175-218.

Garet, M. S., Porter, A. C., Desimone, L. M., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal, 38*(4), 915-945.

Ingersoll, R. (2003). Is there a shortage among mathematics and science teachers? *Science Educator, 12*, 1-9.

Martin, M. O., Mullis, I. V. S., Gonzalez, E. J., Gregory, K. D., Smith, T. A., Chrostowski, S. J., et al. (2000). *Timss 1999 international science report: Findings from iea's repeat of the third international mathematics and science study at the eighth grade*. Chestnut Hill, MA: International Study Center, Lynch School of Education, Boston College.

Mehalik, M. M., Doppelt, Y., & Schunn, C. D. (2008). Middle-school science through design-based learning versus scripted inquiry: Better overall science concept learning and equity gap reduction. *Journal of Engineering Education, 97*(1), 71-85.

Schunn, C. D. (2008). Engineering educational design. *Educational Designer, 1*.

Vogel, G. (1996). Science education: Global review faults u.S. Curricula. *Science, 274*(5286), 335.