

Redefining learning goals of very long-term learning across many different fields of activity

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Abstract: There is a hidden agenda in our modern conception of learning—especially as embodied in education—that the learning experiences gained in one “learning situation” are naturally built-upon, expanded, and integrated with experiences from other learning situations. But we believe this implicit learning assumption has not yet been as substantially researched or discussed as is warranted by its importance. Furthermore, little support has been implemented. In this symposium, in accordance with the conference theme which encourages us to explore interrelations among individual and social cognition with technology, we would help illuminate this hidden agenda. We would take some closer looks at cutting-edge research on knowledge integration of learning outcomes from different classes, across formal and informal learning settings, and for longer time periods than usually taken up by learning science research. We would then propose to define a new set of learning goals as assuring the *portability*, *dependability*, and *sustainability* of learning outcomes.

As the newest “transfer strand” issue of the *Journal of the Learning Sciences* suggests, the field is expressing a growing concern about how far into the future learning science research should look to appraise the qualities of learning activities and outcomes. Short-term assessments of learning performances may not be as predictive as we would hope of cross-situational uses of concepts, skills and other achievements in the realism of longer time frames. This concern is clearly related to how outcomes from different settings of learning are and should be portable to other situations, be dependable when the need arises to use them in different situations, and prove sustainable in terms of providing preparation for further learning. Examination of these issues could open additional dialogues about redefining the “transfer of learning” theoretical construct, and related concepts such as “generative learning.” In this symposium, based on some cutting-edge research on knowledge integration of learning outcomes from different classes, across formal and informal learning settings, and for longer time periods than usually taken up by learning science research, we would like to propose to define a new set of learning goals as assuring the *portability*, *dependability*, and *sustainability* of learning outcomes.

Naomi Miyake and Roy Pea will open this symposium by proposing a new perspective of long-term, wide-ranged learning, and by proposing a new set of learning goals. While people gain many different learning outcomes from various “learning situations,” their integration and maintenance has not been much focused on in research. By taking a closer look at how learning outcomes from different classes at school are naturally integrated (or not integrated) in an individual, we could begin to understand an underspecified aspect of knowledge integration ranging for longer time learning, across many different learning situations. We need to better understand how learning outside of school relates to learning within schools and other designed environments, and how learning in school can spur related learning outside formal designed environments. This new look would reveal not only the complex interaction of formal and informal learning, and their different and sometimes conflicting properties (e.g., locus of control; emergence), but also the lack of supports to enable people to take full advantage of the complexity of these interrelationships.

Brigid Barron will present her newest work on the fascinating nature of middle school learners’ developing technological fluencies, across different learning ecologies, and commonly with peers and distributed resources. She will describe a learning ecologies framework and an associated empirical

research agenda to deal with how adolescents often pursue learning opportunities both in and outside of school once they become interested in a topic.

Dan Schwartz and Lee Martin will describe a new type of transfer measure, called "Preparation for Future Learning." Ideally, experiences in school can prepare people to learn and adapt once they leave school. They will present several lines of empirical results that show its value for detecting people's readiness to learn and adapt to new situations. They will also hypothesize about ways that the PFL assessments could be extended to help indicate which school-based experiences can prepare people for lifelong adaptation.

Naomi Miyake will report on her team's research on explicitly supporting the college level learning by paying closer attention to the acquisition of the portability, sustainability and dependability of what they have learned, what they are learning, as well as of what they are going to learn after graduation. Her team focuses on the acquisition of 'schematic' knowledge, a form of expertise expected to allow the learners to apply it to solve the wider scope of similar problems, as well as to create new problems and solutions. Her team has been developing and testing college level learning environments in the domain of cognitive science, emphasizing the acquisition of some explicit metacognitive schemata on how people learn, and how they could take advantage of such knowledge. In the two-year course, the students are first introduced to the notion of schematic learning by experiencing their own formation of schemata, and then are guided to reflect upon the process, through carefully designed collaborative activities, supported by technology. They are also constantly encouraged to form a schema from their learning experiences of different classes, as well as to integrate their learning experiences with scientific literature through collaborative discussion. She will describe on the theoretical bases of the practice, concrete learning activities, technological supports, and some results of the evaluative analyses of the learning processes and the outcomes.

Roy Pea will present findings from the Family Math project, involving interviews and observations of 20 diverse families to understand when, how and under which conditions mathematical practices arise in everyday problem solving and interaction. When do daily contexts generate common or distinctive problems that are solved with mathematical concepts and tools (and of what kinds), what resources do family members use for solving problems together, how are activities structured socially, and in what ways does such mathematical activity leverage—but also differ significantly from—knowledge acquired in formal settings? Unlike many school-based mathematical problems, those arising in family life do not come prepackaged with well-defined goals, pre-established problem-solving methods and normative solution paths. As problems emerge, family members must decide whether and how to deal with them. Playing central roles in when and how math-relevant activities are approached and engaged are *interacting value systems* (e.g., time-efficiency, cost-efficiency, different kinds of costs to error, social accommodation to power relations inside and outside of the family, aesthetics, and for some families, the symbolic value placed on 'school math'). The types and dominant family mathematical activities for roughly four hundred reported and observed math events illustrate the complexity of the math that is engaged. The content put to use in families is wide ranging and often more than one type of math is brought to bear, including fractions, decimals and percents; ratios and proportions (direct and indirect); measurement and conversion; probability and odds; basic geometry; charts and graphs; statistics (such as averages), and statistical comparisons.

Rogers Hall, Ken Wright, and Karen Wieckert will report ethnographic and cognitive studies of learning, teaching, and generalizing statistical concepts as statisticians advise clients across different research domains (e.g., the epidemiology of infectious disease, laboratory research on human metabolic processes, the community ecology of social insects, and large-scale conservation planning). By comparing consulting sessions across consultants and client domains, his group seeks a better understanding of how the same concepts (e.g., statistical independence) are made generally applicable in different research contexts. Their approach treats complementary expertise between statistical consultants and their clients as a critical context for cognitive and interactional processes of teaching, learning, and generalizing statistical concepts.

More detailed papers by Barron, Schwartz & Martin, and Hall, Wright & Wieckert follow.

A multiple case study on middle school learners' technological fluencies across different learning ecologies

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In this presentation I will report a study that was designed to better understand the conditions that support children's persistent engagement in technologically mediated activities that are likely to build knowledge, confidence, and interest in a broad range of subject domains including digital arts, computer science, and human computer interaction. This work builds on ecological and developmental perspectives, and is designed to contribute to a larger research agenda that seeks to better articulate the interdependencies between child level and environmental variables in development and acknowledge the tight intertwining of person and context in producing developmental change (Bronfenbrenner, 1979; Cole, 2000; Lerner, 1991; Lewin, 1951; Rogoff, 2003). One focus within this broad agenda involves further specification of types of roles people play in a learner's knowledge network and how these support learning interactions, description of the nature of activities that propel learning and the ways that activities evolve over time or with age, and the role of distributed resources such as books or Internet based communities (Barron, 2004; 2006, Barron et al, 2007).

In this study eight middle school students, their parents, one of their teachers, and any learning partners they nominated were interviewed. A two-stage process was used to identify these case study participants. First we administered a survey focused on use of computers to approximately 50 students at a public middle school located in the Silicon Valley region who were currently enrolled in either a programming or a web design class. Second we interviewed them about their activities that they sustained after school. Our multi-informant interview methods yield reports on learners' histories in the form of conversations between the interviewers, the learners, and their parents. Responses to questions posed by the interviewer include rich information about children's activities, their learning resources, the ways their parents and peers support their learning, as well as their future goals, attitudes, and interests. These interviews are summarized to create portraits of learning about technology in a genre that has been called "technobiography" in recent work (Henwood, Kennedy, & Miller, 2001). A life narrative approach allows us to chart a learning history in terms that go beyond metrics such as numbers of courses taken to include the meaning and attribution behind decision making and narratives of how the learning activities unfolded across time, resources, and historical context (Bruner, 1994; Elder, 1994; Linde, 1993). In addition, interviews can reveal processes that are missed through other methods and provide us with portraits that go some distance toward "recovering the person" in our theorizing about human development (Mishler, 1996).

Beyond these informant accounts of learning, the interviews offer a sample of language that can be analyzed with respect to vocabulary, means of expression, and syntax. In order to maximize the potential for developing new insights from these records, Barron's research team has created a number of intermediate representations that summarize the raw interview data. Each representation highlights unique information contained within the records. These representations include *narrative texts* that tell a learners' story along a number of set dimensions; *excel spreadsheets* that tabulate types of learning resources and allow us to code and quantify variables such as the number of people in the child's knowledge network or the number of structured learning contexts a child has participated in; *lists* of the technical terms a learner used while recounting their history or describing a project they created during the Artifact Based Interview; *formal codes* for parent roles that are applied to turns; *graphs and tables* that present descriptive statistics for each code; and finally, *visual representations* in the form of developmental timelines that locate fluency building activities across setting and age, depict relations between activities, show the involvement of peers or adults in the activity, and note the types of material resources used for learning. *Developmental timelines*. This visual representation easily lets us see where activities are clustered, when they began, who was involved. Comparing the timelines of individual learners highlights differences in developmental history (see figure 1).

These portraits, as well as our others, have revealed the critical role that parents, peers, and other mentors play in supporting the engagement of these highly engaged learners. The participation of peers or

adults in activities was sometimes recruited by the learner, and other times parents or others recruited the child's attention and led the learning. In other cases the forming of a teaching/learning partnership was a highly reciprocal and interdependent process. Though socio-cultural perspectives have emphasized social learning processes generally, and the importance of guided participation specifically (Rogoff, 2003), the variety of roles played by others in our cases is striking and suggests the value of further specifying types and patterns of participation as an important direction for future research. The number and diversity of learning partnerships, their duration, and their content, are all variables that could be productively defined and perhaps quantified. To that end we have begun to develop coding schemes that can help us better specify social learning networks and chart how they differ for individual learners. Parent roles in learning were developed based on a review of the transcripts for the learning ecologies and parent interviews of all eight cases. We believe that they will help account for important individual differences in engagement and conceptual development and have implications for how we seed informal learning networks. In this presentation, individual portraits and the analysis of parent roles in learning will be presented

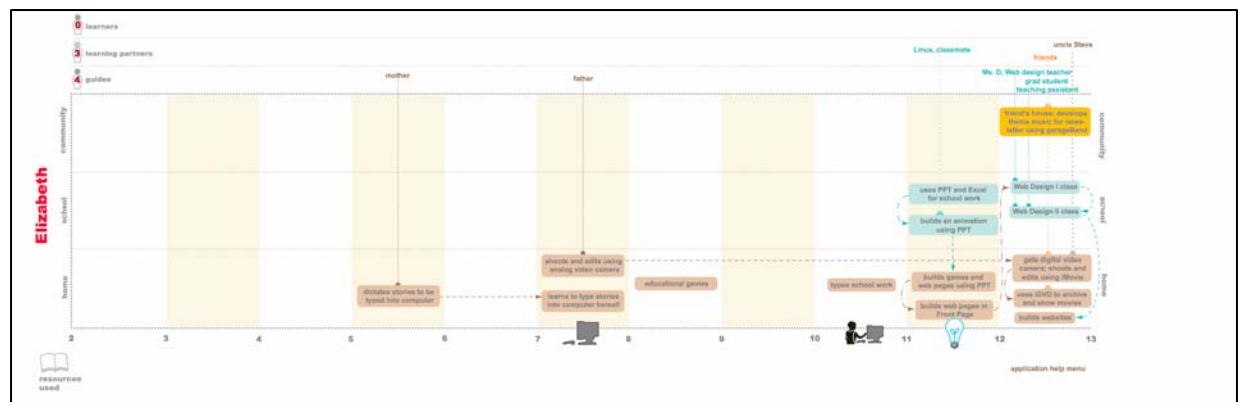


Figure 1A & 1B. Example of a learning history visualization and key

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INSTRUCTION AND ASSESSMENT FOR FUTURE LEARNING

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The learning measures used in many instructional studies are retrospective; they ask what students have learned. However, if one's interest is whether instruction will help people continue to learn once they leave school, then it may be more appropriate to use prospective measures. Over the past few years we have been working on developing and evaluating prospective measures of learning. We first describe the characteristics of retrospective and prospective measures. We then describe how we have used these measures to differentiate instruction that prepares people to learn. These studies have all occurred on a short-time scale within schools. Therefore, we also present the results of a study that examined the long term effects of sustained education on people's preparation to adapt and learn from new situations.

Retrospective measures take a common form called Sequestered Problem Solving (SPS) (Bransford & Schwartz, 1999). Students receive a problem or series of problems, and like a jury, they are sequestered from any resources that might help them learn during the test (and contaminate the results). SPS measures are excellent for determining the efficiency with which students can apply their prior knowledge to solve problems. A limitation of SPS measures is they do not directly measure student abilities to adapt to new situations and learn from them. SPS measures do not include any resources for learning. Students may flexibly use what they know to solve a tricky problem, but they cannot adapt their understanding in response to new information in the environment, because there is no new information.

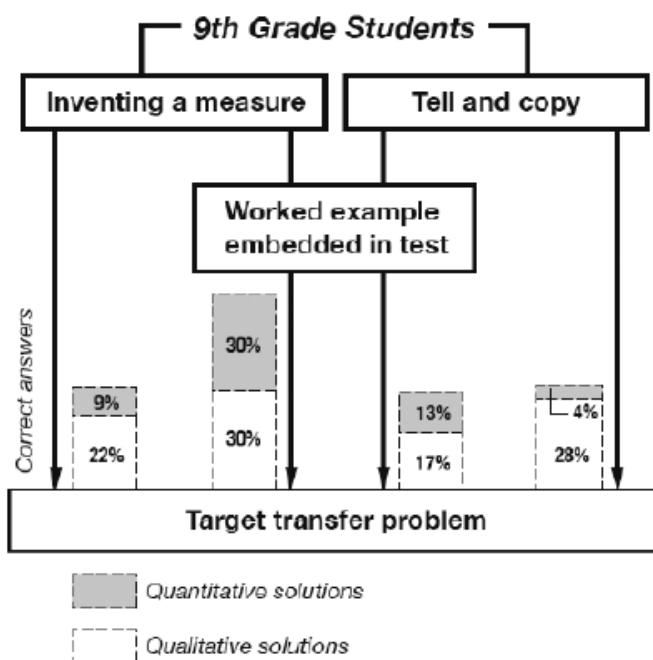
Prospective measures differ from SPS measures because they include resources for learning at the time of test. These resources can include feedback, verbal materials, examples, and even other people. The question is whether students have been prepared to take advantage of these learning materials to help themselves learn how to solve a novel problem. Such prospective assessments measure students' Preparation for Future Learning (PFL). It is fair to say that PFL assessments are transfer measures, because students need to transfer learning from prior experiences into a novel experience or problem, which differs significantly from problems that they have already solved. Yet PFL assessments are different than most transfer measures; PFL assessments examine whether people can transfer to *adapt* and *learn*, whereas most transfer measures examine whether people can *recognize* that they have already solved a given problem type. The emphasis on learning and adaptation makes PFL measures highly relevant to issues of whether and how school experiences can prepare people to be life-long learners. Over the past few years, we have been conducting studies that show that PFL measures capture something different from SPS measures when it comes to readiness for future learning (see Schwartz, Bransford, & Sears, 2005 for examples). A primary goal of these studies has been to show that some types of instructional experiences lead to learning gains on PFL measures, even though these instructional experiences may not yield any appreciable differences on SPS measures. This has been useful in showing the hidden value of pedagogies that engage students in creating knowledge rather than only receiving and practicing.

For example, in a study with college students, we compared (a) students who analyzed and looked for patterns in simplified data sets from classic psychology experiments; and (b) students who wrote a summary of a chapter on the same psychology experiments (Schwartz & Bransford, 1998). On an SPS true-false test immediately following these learning experiences, the summarizing students performed much better, presumably because they had read tidy summaries of the studies. However, an additional, PFL measure revealed what the SPS measure could not: the analyzing students were better prepared to learn new material. Students from both conditions heard the same lecture that explained the psychological experiments, their results, and their implications for broader human behavior. To see if the two groups were equally prepared to learn from this shared learning opportunity, we had them predict the results of a novel experiment which was highly relevant to what they had learned, but had very different surface features. On this transfer test, the students who had analyzed the data did much better than the students who had summarized the chapter. It was not simply that data analysis taught them more, because

a comparison group who analyzed data but never heard the lecture performed very poorly on the transfer test. Instead, students in the data analysis condition were more prepared to learn from the lecture and then transfer this learning to make predictions about the novel experiment. Had we not included a PFL assessment, the data analysis activity would have seemed like a waste of time, because the students did so poorly on the SPS test relative to students who summarized the chapter. Notably, after the data analysis students had heard the lecture, they did extremely well on the SPS measure. Knowledge-creation opportunities need not look bad by retrospective measures of learning, if those opportunities are complemented by formal treatments that help students organize what they have learned.

As a second example, we describe a study with hundreds of 9th-grade students in which we compared two methods of teaching statistical concepts and procedures associated with variance (Schwartz & Martin, 2005). In one condition, students received standard tell-and-practice lessons. In the second condition, students had to invent their own formulas for solving a set of problems. After attempting to invent their own formulas, the students were shown how experts solve these types of problems. Students in both conditions had the same time on task. After several weeks of instruction, students received a long posttest, which contained a target transfer problem. It was a very far transfer problem, because it included novel content and a novel type of problem (i.e., finding and using standardized scores to compare athletes across history). Because we did not expect many students to be able to solve this problem in SPS form, we included a learning resource within the test. The students received a worked example in the middle of the test showing how to solve a problem, and then they had to copy the steps using a new set of numbers. For these students, following the worked example was quite easy, and nearly all of them did it perfectly on the posttest. The question was whether they would learn from the worked example, which held the key to solving the target transfer problem later in the test. To make sure any differences between conditions were due to learning from the worked example, we constructed two forms of the test. For half of the students in each condition, their test included the worked example. For the other half of the students in each condition, we omitted the worked example. Including the worked example made the transfer problem a PFL measure, and excluding the worked example made the transfer problem an SPS measure. The figure shows the combined results of the original study and a replication study. We coded answers to the transfer problem whether they were correct quantitatively or correct qualitatively (for example, a student made a graph instead of computing). The results showed that the PFL version (that included the worked example to learn from) was more sensitive to the differences between conditions than the SPS version (no worked example in the test). The results also showed that one of the benefits of asking students to create knowledge is that it prepares students to learn subsequently and to spontaneously apply that learning later.

If we extrapolate from the preceding studies, it would appear that a steady diet of tell-and-copy instruction may not prepare students to learn once they leave school. In contrast, opportunities to create knowledge in school may prepare students to learn and create knowledge once they leave school. Of course, this is a speculation. We did find that, a year later, the 9th-grade students in the statistics study showed excellent memory for the statistics they



had learned, but we did not test whether they were learning better in their other classes, let alone outside of school.

In more recent work, we have been examining whether sustained school experiences can have a lasting influence in how people adapt and learn from new situations. In one study, we provided participants with a medical diagnosis task. They received a set of reference cases, which included test results and disease diagnoses for several patients. Participants had to diagnose new patients by ordering tests and considering how the results compared to those in the reference cases. One goal of the study was to determine whether people develop representational adaptive expertise – do people learn to make visual representations to help organize complex and novel information? The critical question was whether the participants would make visual representations to help them organize information in the reference cases and thus help them optimize their ordering of tests and diagnoses. To examine the effect of school experiences, we compared undergraduates with graduate students. The graduate students were selected to only include students who worked in data rich fields (e.g., biology, computer science). The undergraduates and graduate students completed the task with the reference cases always available. This made it possible for them to solve the problem without creating a visual representation; they could work by shuffling through the reference cases. Both conditions were successful at diagnosing the new cases. However, the results indicated that all of the graduate students created visual representations to help solve the diagnosis problems, whereas very few of the undergraduates made any sort of explicit representation. Creating the visual representations slowed down the graduate students relative to the undergraduates. But, in the long run, creating the visual representations paid off. The graduate students were more optimal in their ordering of tests, and they were able to diagnose the new cases just as quickly. In addition, there was a second phase of the study, where both groups received a new set of reference cases about several new diseases. The graduate students were able to outperform the undergraduates in search optimality and time per diagnosis. It was not the case that undergraduates did not know how to use visual representations. In a third condition, another group of undergraduates completed the same task, but we removed the reference cases each time they received a new patient (they were allowed to consult the reference cases between patients). In this case, the undergraduates did make visual representations to help alleviate the memory burden. All told, the results indicate that extended experiences with managing complex information (i.e., as a graduate student) transferred to a new task. The graduate students spontaneously created visual representations, even though they could have solved the problems without them and the task of creating the representations led to a temporary inefficiency. They were exhibiting adaptive behavior, because they did not just plow into the problems, but rather, they took the time to create some organization that would help them work and learn more effectively in the long run.

In summary, we have been looking at ways of measuring people's abilities to adapt and learn in new situations. This is relevant to life long learning, because in contemporary society people need to adapt to new jobs, technological innovations, and so forth. With the help of these new PFL measures, we have begun to illuminate the experiences that prepare people to continue learning, and we have been able to document the effects of sustained experiences on people's readiness to adapt and learn in a new situation.

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Learning in Activities that Cross Disciplinary Boundaries

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We report ethnographic and cognitive studies of learning, teaching, and generalizing statistical concepts as statisticians advise clients across different research domains (e.g., the epidemiology of infectious disease, laboratory research on human metabolic processes, the community ecology of social insects, and large-scale conservation planning). By comparing consulting sessions across consultants and client domains, we seek a better understanding of how the same concepts (e.g., statistical independence) are made generally applicable in different research contexts. Learning, from this perspective, occurs both at individual and collective levels of analysis, involves not only people but also a dynamically distributed technical culture of things (algorithms, code fragments, graphical displays, and argument structures), and extends in temporal scale from moments to years. This approach treats complementary expertise between statistical consultants and their clients as a critical context for cognitive and interactional processes of teaching, learning, and generalizing statistical concepts. Consultants and clients each know different things, and a successful outcome—a set of findings based on a defensible model for a client’s research problem—requires that these differences are turned into complementary strengths in the consulting relation. Field data include audio and video recordings of consulting meetings, semi-structured interviews about material selected from these recordings, historical and ethnographic analysis of changes in client work practice, and working documents produced and used in consulting sessions.

Within consulting meetings, three recurring processes appear to drive learning and teaching, with far-reaching consequences for client work practices and for the career trajectories of participating statisticians.

(1) *Consulting narratives (stories) assemble future work.* Consulting meetings involve purposeful efforts to displace some aspect of the client’s existing infrastructure for representation and modeling with another way of working. In this sense, consultations are a disruption in the client’s project timeline, and within the meeting, different ways of assembling the client’s future work are created and compared in conversation. These are produced as narrative structures that involve basic processes of animation, gesture, and inscription to assemble new ways of working. Each such narrative assembly orders objects in the client’s work (e.g., specimens, machines, and systems of classification), people on the project as human labor and spokespersons for objects, and statistical techniques or concepts.

For example (Hall, Wright & Wieckert, 2007), in a consultation between a biostatistician and entomologists considering the use of cluster analysis (CA) to identify new termite species, a senior research client proposed using CA to *confirm* insect groups they observed in the field. The consulting biostatistician pointed out that CA finds clusters, regardless of their meaning, and a second senior researcher proposed, instead, that they use CA to *discover* insect groups that are confirmed using independent field and laboratory data. This seemingly simple, narrative repair in how CA should be used in the client’s work avoided a logical error and, over time, became a standard method for identifying group structures as species candidates.

(2) *Parables position clients’ statistical decisions.* Statisticians (exclusively, in our case studies) tell parables that offer clients alternative subject positions in stories about statistical inference and data modeling. These stories have highly evaluative outcomes, depending on which position a client takes. For example, in the case of entomologists using cluster analysis (above), the statistician compared their situation to blood type shown on a California driver’s license. The lead entomologist initially responded from the position of a harried Type O blood donor, but later realized that in the completed parable, he would grant licenses on the basis of blood type (i.e., blood type is a real structure, but it has nothing to do with obtaining a driving license). In another example concerning whether to cut a continuous variable around high/low risk values for diagnostic use, a senior biostatistician told a story in which a doctor following “evidence-based medicine” mis-used a blood cholesterol test:

I mean I knew an eighty-four-year old woman with leukemia who grew up in New Orleans and loved French cooking, whose doctor told her to quit eating French food, ‘cause her cholesterol was high. Um, the doctor should have been shot, or sentenced to McDonald’s for a year.

In both examples, subject positions offered to clients (in some cases to other statisticians) are meant as cautions or criticisms, pointing to common mistakes they should avoid when using statistical concepts or techniques.

(3) *Analogical reasoning builds project infrastructure.* A third and centrally important process of learning and teaching in statistical consulting is the use of analogy to borrow and modify statistical methods or approaches to modeling appearing in prior publications, sometimes out of field for research clients. SCADS findings here are similar Dunbar’s (1995) studies of scientific research groups, but in our cases, consulting statisticians work as brokers to map and evaluate analogies that are brought into consulting meetings by research clients.

For example (Hall, Wieckert & Wright, 2006), in a case where research epidemiologists were seeking to estimate the number of young children hospitalized with influenza (these could not be counted completely), the lead researcher borrowed a capture-recapture estimate (CRE) from prior publications in epidemiology, but made an overly narrow assumption about matching hospital days for two screening procedures. The consulting statistician advised that matching days were not required, yet the client was not convinced, posing an extreme case in which a 1 day screen would be incorrectly (he thought) combined with a 7 day screen. After further discussion and a concrete demonstration, the statistician was able to convince the client to use all screening days, and the resulting estimate of children with influenza (now in print) was more robust. In the same consultation, the statistician convinced epidemiologists at a national public health agency that screens with quite different coverage could be combined, as long as there were no dependencies (temporal or otherwise) among them. As a result, new studies and a national influenza monitoring program for adults are underway, using the client’s extreme negative case (1 versus 7 screening days) as a *feature* of the new health surveillance system.

Looking across SCADS cases and ongoing analyses, we find a multi-lineal process of learning, teaching and development summarized in Figure 1. Client research projects have ongoing histories (shown as dashed lines) that are intentionally disrupted (Hall, Stevens & Torralba, 2002; Engestrom, Brown, Christopher & Gregory, 1997) in consulting meetings with statisticians. In these meetings (shown as shaded regions) different ways of assembling the client’s research and statistical modeling are proposed and compared (i.e., narrative assembly, evaluative use of parables, and analogical reasoning), and new uses of models circulate back into the published literature, where they are borrowed and extended by other investigators. The capacity of client research groups is expanded, and statistical consultants act as “boundary spanners” or brokers (heavy line) by moving across projects and accumulating a consulting portfolio. Within particular research fields these multi-lineal patterns of circulation yield a kind of horizontal development, as clients’ research methods and group capacity become more powerful. By moving across different research projects and fields, statisticians find opportunities for vertical development of new and more powerful (or more useful) statistical methods.

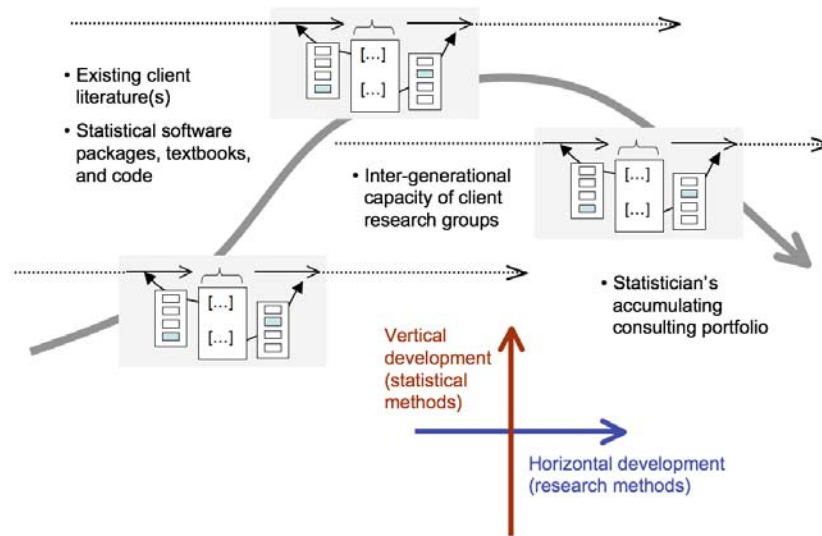


Figure 1. Statistical consulting as an intentional disruption to research clients' work practices. Consulting trajectories help put new and more powerful methods into circulation within research fields (horizontal development), while providing statisticians with opportunities to create new statistical methods (vertical development).

Our analyses and findings support a view of statistical consulting as a set of boundary encounters, places where clients and statisticians bring complementary expertise to bear on particular research problems, craft “do-able problems” (Fujimura, 1987) that enable clients to answer questions in ways that are appropriate and more powerful than they might manage on their own. These boundary encounters occur in organizational environments already dense with resources for modeling, statistical description and inference (i.e., prior publications, statistical software and user-extensible code, consultants with identified expertise, and diverse capacity within research groups). As a result, statistical concepts are used more widely across research projects and fields, this use involves changes in client work practices (including what researchers “know” and the nature of arguments they make), and the statistical concepts, themselves, take on new meanings and potential as research tools. In this sense, statistical consultations feed back into a larger, distributed system of resources for conducting research, a boundary infrastructure that we have analyzed simultaneously at interactional and historical levels.

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