WHAT UNDERGRADUATE RESEARCH CAN TELL US ON RESEARCH ON LEARNING

David Lopatto
Professor of Psychology
Grinnell College

Anyone who desires to give his hearers a perfect conviction of the truth of his principles must, first of all, know from his own experience how conviction is acquired and how not. He must have known how to acquire conviction where no predecessor had been before him-that is, he must have worked at the confines of human knowledge, and have conquered for it new regions.

A reader who has attended the recent Project Kaleidoscope assembly, Linking Insights About How People Learn to Curricular Reform, at the University of Richmond will notice that I have transposed the title of the plenary session. The published title, supplied by PKAL, was "What research on learning can tell us about undergraduate research." An earlier plenary had touched on the impact of the National Research Council's book, How People Learn, a useful report on what might be called the cognitive science of learning. When Dr. Elaine Seymour, Director of Ethnography and Evaluation Research at the University of Colorado at Boulder and I began our collaborative research on the benefits of undergraduate research experiences we were aware of the book, and I recall citing the book in our original grant proposal. We wrote a passage on "learning theory relevant to undergraduate research." Here is what we wrote:

> Just as there is a lack of research on the impact of undergraduate research, there is a lack of well-grounded theory. Theories of science education tend to be most appropriate for children. In so far as the needs of older students are addressed, the theory centers on classroom pedagogy such as inquiry-based learning. The present research may aid in the extension of learning theory to the undergraduate research experience. As a preliminary look at the kind of information that the present proposal might yield, we summarize the current theory regarding "How People Learn" (NRC, 1999) and draw the analogy to undergraduate researchers.
>
> Children are active learners whose learning is motivated by a desire for mastery. How they learn is partially determined by what they already know, including the schemes and perspectives they bring to new situations. Children's current level of learning is not a true measure of their potential, rather, each child has a "zone of proximal development," a potential learning level beyond what they currently know. This zone can be estimated by giving a child problems to solve that are beyond her current level of accomplishment. If the child can solve these problems through imitation, then the child is said to have learning potential. Children learn best in a supportive environment, which includes expert teachers and modern physical facilities. They learn well in groups, "a community of learners" involving active learners, often with more skilled partners to learn from. One important outcome of the learning experience is transfer of training, both to new academic experiences and to everyday life (NRC, 1999).
>
> What is the analogy to college students involved in undergraduate research? College students are active learners who are motivated by a desire for mastery. It may be said that undergraduate researchers are

gaining expertise. A feature of this expertise is professional, that is, the experts that the student emulates are researchers and teachers in the field. Career choice is a feature of their motivation. How undergraduates perform is partially determined by what they already know, however, the degree to which a curricular experience informs independent research work remains to be studied. Part of the prior experience of the undergraduate research is social; in programs in which research is not required undergraduates are likely to work with a mentor they know and from whom they have learned in the classroom. As with a child, an undergraduate's prior classroom learning may not be the true measure of their potential. College undergraduates may have a "zone of proximal development" which mentors intuitively assess when they select research assistants. This intuitive judgment may influence the selection of undergraduate researchers at institutions where research is not a required exercise. It may be that student potential is further tested by exposing undergraduate researchers to graduate school-like conditions during the research experience, however, this possible test of potential has not been systematically studied. College students learn best in a supportive environment, which includes faculty mentoring, state-of-the-art instrumentation and modern physical facilities (Rothman & Narum, 1999). They may form a community of learners, becoming part of a group of active researchers that includes faculty mentors and more experienced students. An important outcome of their experience is transfer of training, both in the specialized sense of continuing in the professional field and in the more flexible sense of succeeding in unexpected careers (e.g., Bunnett. 1984). Thus, applying current learning theory to the undergraduate research experience uncovers deficiencies in current knowledge that the current proposal will begin to address.

After the first year of a survey on the benefits of undergraduate research experiences, I revisited the hypotheses from How People Learn. After analyzing the data from our ROLE survey, I presented some conclusions that students viewed their mentors as having a variety of positive traits. These traits correlated with student reports of satisfaction with their UR experience and with a group of benefits of the UR experience. Here is what I wrote about the topics in How People Learn:

> The hypothesis that a democratic and responsive mentor who spends time with the student is contributing to a satisfying and beneficial experience is not surprising. It is, however, intriguing when regarded in the context of literature on "how people learn". Extrapolating from the literature, we may hypothesize that (1) college undergraduates enjoy gaining expertise within their chosen field; (2) that social interaction, including peer interaction, contributes significantly to learning; and (3) that students may have a "zone of proximal development", that is, a potential to do more challenging work than they have done in the classroom if they can be shown how by an expert. The current survey results support these three hypotheses:
>
> (1) The current survey data indicate that students did value mastering their field of expertise. The students selected expertise-related benefit items (such as learning a topic in depth and understanding the research process in their field) as items that were both most important and on which they made the largest gains.
>
> (2) The data indicate that students benefited most when the mentor exhibited traits…that are consistent with positive social interactions. Students also benefited from working in groups or teams…students frequently characterized group work as either moderately enhancing the research experience or as the best part of the experience. Further analysis shows that students working with peers had a higher overall satisfaction with the undergraduate research experience than students working alone, and that they reported higher gains in their ability to collaborate and to show leadership.

(3) The data indicate that students who described their style of interaction with their mentor as one of learning by example rated their satisfaction with the experience as slightly higher than students who described their style of interaction as self-organized (working alone) or as executive (mentor gave the orders). This tentative finding is obscured somewhat because of the interactions with two other variables: student's year in school and student's engagement with the project. Some of the sample sizes in these interactions are too small to analyze reliably, but the data carry the suggestion that interactional styles suitable to the student's "zone of proximal development," including learning by example, are better related to satisfaction than styles that leave the student on his or her own.

As far as our research can be aligned with the propositions found in *How People Learn*, it appears that the outcomes of undergraduate research experiences are generally consistent with those propositions. Characteristics of learning, learning environments, motivation for competency, and transfer of training all exist in the typical undergraduate research experience. Of the many topics discussed in the book, Dr. Seymour's research and my own amplify the topics of competency motivation and the transition from novice to expert. When we look closely at the benefits of undergraduate research experiences as reported by the students we find some clues as to how they learn and why they learn.

THE BENEFITS OF THE UNDERGRADUATE RESEARCH EXPERIENCE

Seymour et al. (in press) interviewed 76 students who had participated in undergraduate research experiences in the sciences at one of four liberal arts colleges. The interviews were transcribed and coded for reports of the benefits of undergraduate research experiences. Elaine is present at this conference and is much more capable of elaborating on these results than I am. A summary of her final "parent codes" is presented in Table 1.

The findings summarized in Table 1 illustrate that both learning and changes in attitude are taking place during the undergraduate research experience. Specific skills are being learned and enhanced, competency is being established, and a transformation from novice to expert is taking place. These three topics – skill learning, competency motivation, and expertise – are discussed in How People Learn. But there seems to be an additional developmental aspect to the experience that is not extensively treated in the book. Before I focus on

Table 1. Summary of the seven benefit categories presented by Seymour et al. (in press)

Personal/professional	Increased confidence in ability to do research and other tasks; feeling like a scientist; working relationships
Thinking and working like a scientist	Application of knowledge and skills; increased knowledge and understanding of science and research work
Skills	Improved communication, lab/field techniques, work organization, computer, reading, working collaboratively, information retrieval
Clarification, confirmation and refinement of career/education	Validation of disciplinary interests; graduate school intentions; increased interest for the field
Enhanced career/graduate school preparation	Authentic research experience; opportunities for collaboration/networking; resume enhanced
Changes in attitudes toward learning and working as a researcher	Undertaking greater responsibility for project; increased independence; intrinsic interest in learning
Other benefits	A good summer job; access to good lab equipment

that developmental aspect, however, let me present findings from the quantitative half of our research collaboration that might help validate these categories of benefits.

By drawing on the literature of purported benefits of undergraduate research and by receiving early reports of Seymour's findings, I was able to construct a survey instrument for students doing undergraduate research at the same four liberal arts colleges where Elaine had interviewed. In each of two summers, students in the sciences filled out an extensive survey. Some items asked about the topics mentioned earlier in this paper; more pertinent is the fact that the surveys contained a list of 45 possible benefits of undergraduate research. Each student respondent was asked to rate his or her gain on the benefit on a scale of 1 (no or little gain) to 5 (very large gain). A large data set (N = 384) yielded a wealth of information on the various questions. A more restricted data set (N = 181), consisting of those respondents who rated every one of the 45 benefits, was employed to perform an exploratory factor analysis to construct the dimensions that might organize the 45 benefit variables. Exploratory Factor Analysis is a statistical procedure for quantitative data and so is a very different methodology from coding qualitative data, as Seymour, et al., did. Nevertheless, because the two studies drew from the same kind of experience (summer undergraduate research) at the same four research sites we hope to see some congruence between the qualitative codes and the quantitative factors. By finding agreement between two attempts using different methods to measure the same benefits, I hope to establish the validity of the findings .

The results of the factor analysis are presented in Table 2. The ten factors are selected because they each meet a conventional criterion of accounting for more than one original variable. The ten factors together account for 66% of the variance in the data. The factors are named by the analyst, who inspects the variables that correlate with (or load on) the factors. Table 2 shows my names for the factors together with the variables with the strongest loadings (only loadings of .4 or better are shown).

Comparing the statistical analysis in Table 2 to the earlier coding analysis in Table 1, we notice that there are 10 factors versus 7 categories. This difference does not prove to be a serious difficulty, however, if we notice that Seymour, et al., coded a "skills" category that was generic while the factor analysis, on the other hand, broke out several categories of skills, reflecting the underlying pattern of correlations. Allowing for the difference in number of categories, I proceed to line up the two analyses in Figure 1. In order to judge the alignment, the reader should look back at Tables 1 and 2, and based on the similarity of the concepts that go into a code category (or the survey items that load on a factor) judge the congruence between the two sets of findings. I found a high degree of linkage between the qualitative and quantitative results, with only a few qualifications. First, as I mentioned, the qualitative "skills" category incorporates five of the factors, all of which are specific sorts of skills. Second, one of the qualitative categories, a small category called "other benefits," has no corresponding items in the survey. Finally, one of the factors, called "interaction/communication skills," overlaps with two of the qualitative categories. While some of the items that make up the factor are clearly skills, at least one item, "learning to work independently," also coheres with the qualitative category "changes in attitudes toward learning and working as a researcher." All in all, it is my belief that the results of the two methods map onto each other well.

Both the qualitative and quantitative analyses suggest a developmental dimension of learning for which undergraduate research experiences may set the occasion. Students report a rich mixture of personal and professional development that may help us understand the concept of expertise. How People Learn treats expertise as cognitive; experts exceed novices in chunking relevant information and contextualizing knowledge. But expertise may also include the acquisition of independent thought and the motivation to pursue new regions of knowledge based on a belief about the value of that knowledge. This belief, perhaps no more than a hunch, becomes a strong source of motivation to continue working in the face of obstacles, skepticism, and opposition. In other words, experts learn commitment.

INTELLECTUAL DEVELOPMENT IN UNDERGRADUATE RESEARCH

William Rauckhorst presented a paper at a 2001 PKAL conference based on the work of Marcia Baxter Magolda. Baxter Magolda had assessed summer research students with an instrument she devised called the MER (Measure of Epistemological Reflection). This measure permits the researcher to categorize the student's epistemological level. According to

Table 2. Summary of the 10 factors resulting from survey data on benefits of undergraduate research experience.	
Interaction and communication skills	Skill at oral, visual, and written communication; leadership; becoming part of a learning community; working independently; ability to collaborate with other researchers
Data collection and interpretation skills	Ability to collect data according to a plan; ability to analyze data; skill in interpretation of results; lab techniques; ability to solve technical or procedural problems
Professional development	Understanding professional behavior in your discipline; understanding personal demands of a career in your discipline; understanding the research process in your field; understanding how professionals work on real problems
Personal development	Sense of accomplishment; tolerance for obstacles; self-confidence; interest in a discipline
Design and hypothesis skills	Ability to employ appropriate design methods; ability to integrate theory and practice; critical evaluation of hypotheses and methods in the literature
Professional advancement	Opportunities for publication; sense of contributing to a body of knowledge; opportunities for networking; enhancement of your professional or academic credentials; developing a continuing relationship with a faculty member
Information literacy skills	Ability to read and understand primary literature; ability to locate and identify the relevant literature; ability to see connections to your college course work
Responsibility	Learning safety techniques; learning the ethical standards in your field
Knowledge synthesis	Learning a topic in depth; understanding how current research ideas build upon previous studies
Computer skills	Computer skills (either user or programmer)

Baxter Magolda, student intellectual development follows a series of stages. These stages are summarized in Table 3. The table is a mere outline; it does not do justice to the richness of the theory. But it can be seen that each stage represents a more sophisticated level of understanding than the previous one. Rauckhorst reported that, based on MER scores, students who had a summer undergraduate research experience showed more frequent transitions up the stages than students in a control group. For example, 14 of 35 initial transitional knowers among research students shifted up to independent knowers at the end of the summer. In the control group, none of the 31 initial transitional knowers showed any shifting up the developmental ladder.

The possibility that the benefits of undergraduate research may be measured by the intellectual development of the student is intriguing, but being something more than absolute knowers ourselves, some undergraduate researchers and I explored this area of research in the summer of 2003. Using information from Baxter Magolda supplemented by the work of King and Kitchener (1994) on reflective judgment, we prepared an interview protocol that provided respondents an opportunity to tell us something about their thinking on controversial issues. 42 students working on summer research projects for a ten-week period were interviewed early and late in the summer. We discovered that coding

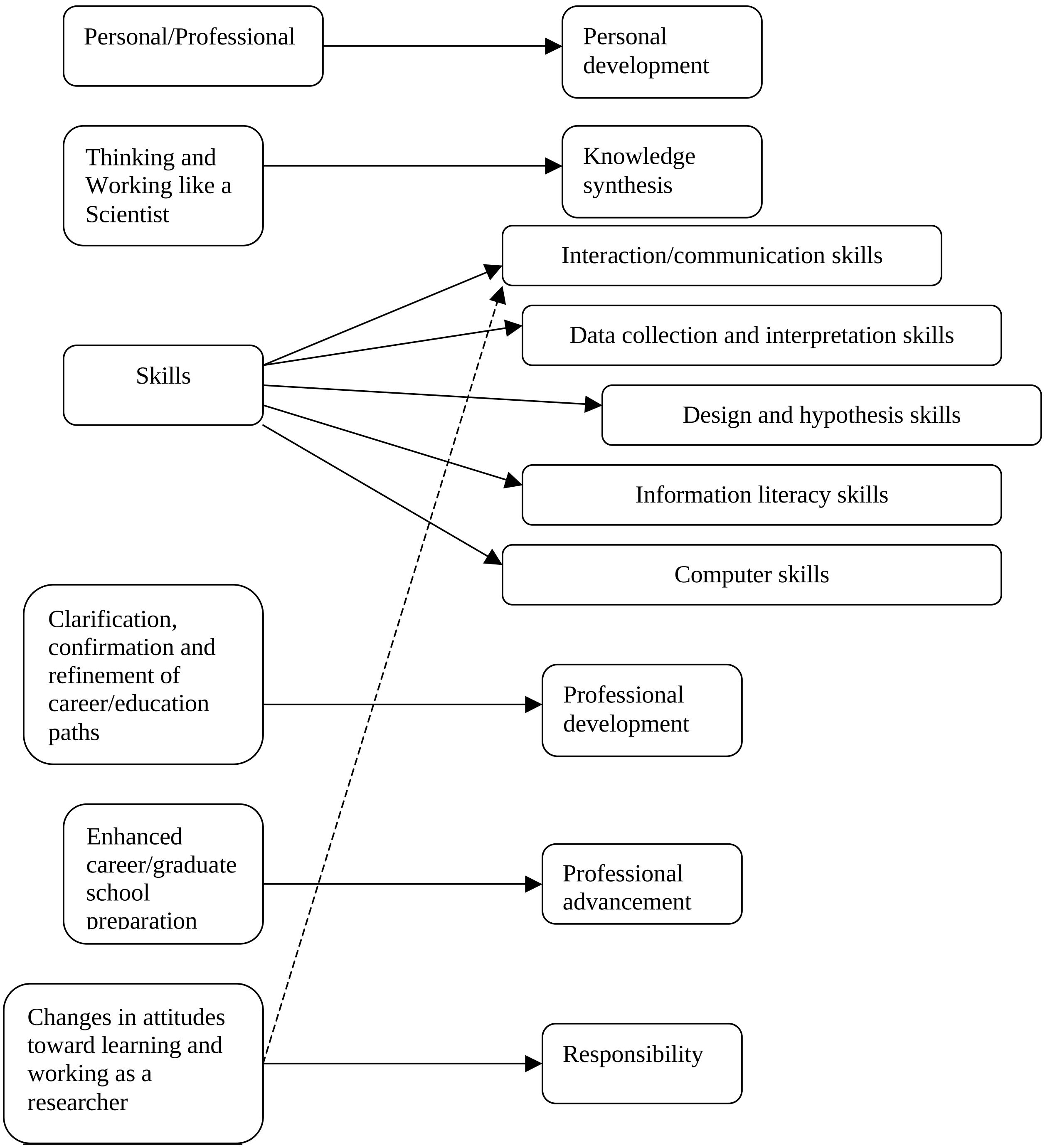

Figure 1. An attempt to align the seven parent categories of student benefits found by Seymour et al. (left) with a factor analysis of survey data on student benefits (right).

the student responses into categories of development is hard work; students often make a series of responses that cross categories. Nevertheless, we were able to form a consensus about placing each student respondent into a pretest category and a posttest category that roughly conformed to the Baxter Magolda levels. We placed 16 students into the absolute/transitional range, 20 students into the transitional/ independent range, and six students into the independent/contextual range. Posttest classifications showed that 12 of the 16 students in the lower range on the pretest moved up the scale on the posttest; nine of the 20 mid-range students moved up; while none of the six students in the top range moved up. 12 of the students were not in the sciences; they showed the same patterns as the science students.

I freely admit that my students and I are amateurs when it comes to coding interview data into stages of intellectual development. I also admit that, unlike Rauckhorst, et al., we had no control group. We were attempting to "acquire conviction" about this sort of research before accepting it. I am convinced that, despite the methodological difficulties, it is a line of research worth pursuing.

It seems that the undergraduate research experience ignited "a bright period of maturation." According to Baxter Magolda (2001) the goal of this maturation is "self-authorship," which includes reflection on epistemology, but also the discovery of self and the choosing of beliefs. Within the context of developmental theories like this one, expertise is not defined solely by cognitive capacity, as it seems to be in How People Learn, but includes self-knowledge and beliefs to which one becomes committed. Thus developmental theories attempt to describe not just how people learn but why people learn.

Of course, the quest for self-development is not limited to undergraduate students in the sciences. The same theme is echoed by Sharon Daloz Parks (2000), whose interest is in the development of faith, an ostensibly unscientific concept. Parks draws on the seminal work of William Perry (1999) concerning the development of commitment. Parks suggests that young adults attempt a "probing commitment," a tentative attempt to discover truths that may be held in a contextual world. If successful, the young adult may grow to have a "confident inner-dependence;" meaning that one is able to "include the self within the arena of authority." Confident inner-dependence resembles the stage of "independent knowing," and both concepts suggest the development of a person who is actively engaged in searching for truth.

From my reading of these developmental theories I conclude that the upper levels of intellectual development are stages in which beliefs and hypotheses about the world, whether concerned about religious faith or about science, become "live" (James, 1896). In contrast to the cold cognitive description of the expert found in How People Learn, the image of experts that emerges from intellectual development theories is that mature people have the motivation to commit to a point of view and defend it by using the rules of evidence of the relevant domain. Furthermore, the young adult who continues to mature into an expert committed to a point of view may wish to mentor others along the same path. The upper stages of development provide a feedback loop: Parks suggests that a mature individual is ready to become a mentor.

I seem to have wandered away from the topic, that is, what undergraduate research can tell us about research on learning, so let me ask Herman von Helmholtz to put me back on track. Over a century ago Helmholtz made the statement that leads this article. He was defending the superiority of scientist-teachers over professional teachers who were good performers but had no direct experience with their subject matter. Helmholtz asserted that a good teacher teaches with conviction based on direct experience. It is necessary, in his view, for a person to be both a scientist and a teacher, in order to know "how conviction is acquired." This is exactly the sort of experience that undergraduate research provides. The undergraduate researcher makes strong and measurable gains in "how conviction is acquired" - how his or her own view matters in the commitment to beliefs. The work of Seymour, et al., reveals the strong professional and personal development that accrues to the student who performs undergraduate research; the work of Baxter Magolda gives us a rubric by which we can articulate the changes. My own research convinces me that these conclusions are valid. The undergraduate research experience enables us as scientists to cultivate the next generation of scientists, and as mentors to cultivate the next generation of mentors.

WHAT UNDERGRADUATE RESEARCH CAN TELL US ABOUT RESEARCH ON LEARNING

REFERENCES

Baxter Magolda, M.B. (2001). Making their own way: Narratives for transforming higher education to promote self-development. Sterling, VA: Stylus Publishing, LLC.

Bunnett, J. (1984). The education of butchers and bakers and policy makers. Journal of Chemical Education, 61, 509-510.

James, W. (1896). The will to believe. In J.J. McDermott (Ed.), The writings of William James (published 1967). NY: Random House, Inc.

King, P.M., & Kitchener, K.S. (1994). Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults. San Francisco: Jossey-Bass Publishers.

Park, S.D. (2000). Big questions worthy dreams: Mentoring young adults in their search for meaning, purpose, and faith. San Francisco: Jossey-Bass Publishers.

Perry, W.G. (1999, originally published 1968). Forms of intellectual and ethical development in the college years: A scheme. San Francisco: Jossey-Bass Publishers.

Rothman, F.G., & Narum, J.L. (1999). Then, now, and in the next decade: A commentary on strengthening undergraduate science, mathematics, engineering and technology education. Washington, D.C.: Project Kaleidoscope.

Seymour, E., Hunter, A-B., Laursen, S.L., & DeAntoni, T. (in press). Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. Science Education.