A successful undergraduate program will be characterized by significant intellectual development among its students. William Perry’s study of Harvard students in the 1950’s and 60’s represents a watershed moment in the study of intellectual development at the post-secondary level (Perry 1970, ix). Several models have been developed and investigated since then (Felder 2004, 271-275; Huntzinger et al. 2007, 220-225; Pike and Kuh 2005, 276-278). Although there are many components of students’ developmental processes, research experiences during the college years have a significant impact on this development, particularly in science and engineering. This article highlights the need for more detailed investigation of the qualitative impact of undergraduate research (Sims et al. 2012, 23-25). Our presentation of ethnographic data adds to current quantitative studies of the impact of research experiences during the college years on students’ intellectual development and their trajectory within the field of engineering. In the spring of 2012, we conducted six interviews loosely based on the framework used by Perry and Belenky (Perry 1970, 7, Belenky et al. 1986, 11) in their studies of intellectual development. Invitations to participate in this study were extended to students known to be engaged in a faculty-led research project within engineering. Five of the six were involved participants worked in Kaya’s research lab while the other worked in one of Kaya’s colleagues’ labs. Students in Kaya’s lab were involved in a variety of tasks related to their overarching interest in sensor technology such as design and implementation of motion and relative humidity sensors. That participation was ultimately voluntary may help explain why our sample is so small. The six students interviewed had been involved in the research project during the previous semester, and most were traditional college-aged students (18 to 25), although one was in his 30’s. All of the students were male, four of the five domestic students were Caucasian, with the fifth being an American of Asian descent. The sixth participant was an international student from China. While we would have appreciated a more ethnically diverse sample, approximately 90 percent of the students at our institution are Caucasian.

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Comments regarding the importance of synthesizing material from various sources and their gradual realization that there are multiple ways one can solve a problem. We also identified a theme of interpersonal development, which was manifested in comments regarding autonomy and collegiality. A final pattern noted was students’ realization that they needed to “buckle down” and get serious about college. The students joined the research team at different times, but each one had this realization just prior to pursuing involvement in the faculty-led research project.

Choosing Engineering
Although all of the students in our sample had a father or a grandfather who was an engineer, they did not necessarily understand very well what the daily life of an engineer was like or what would be demanded of them in an engineering program. During the course of the interviews, we discovered that students came to engineering for a variety of reasons, but that their positive experiences on a research team reinforced their interest in and commitment to the discipline. This finding supports the work of Hammond and Lalor, who found in their review of students who completed an interdisciplinary, STEM-focused, undergraduate research experience, that students reported greater interest in pursuing a STEM career than they had previously expressed and also felt more confident in their ability to succeed within STEM fields (Hammond and Lalor 2009, 29-30).

Some of the students interviewed had a natural inclination towards STEM disciplines. Student C chose engineering as a major because he thought it would be fun and interesting. Student F traced his interest in engineering back to his childhood when he was “taking things apart, never really putting them back together, causing headaches for [his] parents.” For these students, their intrinsic interest in the subject of engineering was what typically motivated them to participate in faculty-led research projects. Student A said that if the students “were something boring and monotonous we probably wouldn’t be nearly as productive, but since it is so interesting, we can keep going.” This is not a credit-bearing activity and the students could quit at any time but they continue working on the project because it is personally fulfilling.
Intellectual Development among Participants in Faculty-Led Research

Lauren Griffith, Tolga Kaya
Central Michigan University

A successful undergraduate program will be characterized by significant intellectual development among its students. William Perry’s study of Harvard students in the 1950’s and 60’s represents a watershed moment in the study of intellectual development at the post-secondary level (Perry 1970, ix). Several models have been developed and investigated since then (Felder 2004, 271-275; Huntzinger et al. 2007, 220-225; Pike and Kuh 2005, 276-278). Although there are many components of students’ developmental processes, research experiences during the college years have a significant impact on this development, particularly in science and engineering. This article rehashes Sims’ call to CUR Quarterly authors to progress “beyond counting the quantitative impact ... to capturing the qualitative impact of undergraduate research” (Sims et al. 2012, 23-25). Our presentation of ethnographic data adds to current quantitative studies of how participation in research projects enhances engineering students’ intellectual development.

National bodies that have a vested interest in the training of future engineers have been strong advocates for offering research experiences to undergraduates. A primary goal of research experiences for STEM (science, technology, engineering, mathematics) students is to help them cultivate the disciplinary habits of thought that will be essential in their future careers (Idzco et al. 2010, 20-22). Engineering education has long been a focus of the National Science Foundation’s education division. The agency solicits funding proposals periodically for several relevant programs, including Research Experience for Undergraduates (REU), Research in Engineering Education, and Research Initiation Grants in Engineering Education. The programs supported by the NSF grants actively involve undergraduate students in faculty research projects to promote “research based learning.” Assessment of student gains in REU-financed faculty research projects to promote “research based learning.” Assessment of student gains in REU-financed faculty research projects to promote “research based learning.” Assessment of student gains in REU-financed faculty research projects to promote “research based learning.” Assessment of student gains in REU-financed faculty research projects to promote “research based learning.” Assessment of student gains in REU-financed faculty research projects to promote “research based learning.” Assessment of student gains in REU-financed faculty research projects to promote “research based learning.” Assessment of student gains in REU-financed faculty research projects to promote “research based learning.” Assessment of student gains in REU-financed faculty research projects to promote “research based 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“research based learning.” Assessment of student gains in REU-financed faculty research projects to The Accreditation Board for Engineering and Technology (ABET) requires all engineering programs to offer research opportunities to undergraduates. The ABET criteria state that “At least 30 percent of the students at a program’s institution must have an opportunity for hands-on research activity, and at least 10 percent of the students must be engaged in a faculty-led research project within their engineering program” (Commission 2011, 3). Students show improvements in motivation and academic performance as they gain active research experience (Zydney et al. 2002, 295). Graduate students also benefit from more thorough examination of academic material through their mentoring of undergraduate researchers (Zydney et al. 2002, 296).

In light of this research literature, Central Michigan University’s (CMU) young School of Engineering and Technology (established in 2004) has been increasingly focusing on undergraduate research (Delong and Langereder 2012, 324-353). Students are encouraged to attend regional conferences of the American Society of Engineering Education (ASEE) and have recently been receiving awards at these gatherings. Although our population of engineering students is relatively small, retention and job placement rates are significantly high, thanks to faculty members’ involvement in research with undergraduate students.

Ethnographic Data on Student Development

This paper uses ethnographic data to describe how participating in an undergraduate research program influences students’ intellectual development and their trajectory within the field of engineering. In the spring of 2012, we conducted six interviews loosely based on the framework used by Perry and Belenky (Perry 1970, 7, Belenky et al. 1986, 11) in their studies of intellectual development. Invitations to participate in this study were extended to students known to be engaged in a faculty-led research project within engineering. Five of the six were involved participants worked in Kaya’s research lab while the other worked in one of Kaya’s colleagues’ labs. Students in Kaya’s lab were involved in a variety of tasks related to their overarching interest in sensor technology such as design and implementation of motion and relative humidity sensors. That participation was ultimately voluntary may help explain why our sample is so small. The six students interviewed had been involved in the research project during the previous semester, and most were traditional college-aged students (18 to 25), although one was in his 30s. All of the students were male, four of the five domestic students were Caucasian, with the fifth being an American of Asian descent. The sixth participant was an international student from China. While we would have appreciated a more ethnically diverse sample, approximately 90 percent of the students at our institution are Caucasian.

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Interviews were coded using the NVivo software in order to fulfill that research “were something boring and monotonous we probably wouldn’t be nearly as productive, but since it is so interesting, we can keep going.” This is not a credit-bearing activity and the students could quit at any time but they continue working on the project because it is personally fulfilling.
Other students’ engagement in the discipline was motivated by the promise of a secure financial future. Student B said that "engineering seemed to have a better opportunity for making the income level that [he] was looking for," compared to his prior career in massage therapy. This student had considered a number of different career options after deciding to return to college, but knew he “didn’t want to be working in a career where [he’d] be having to struggle.” The combination of an engineer’s lucrative salary with the student’s interest in the topic motivated his selection of a major. Nonetheless, the choice was grounded in his belief that “beginning this training is a good opportunity to get in at the ground floor level” in a rapidly changing field. Student D professed an affinity for some of the humanities courses he had taken, but “didn’t really see a use for it outside of the classes.” Because he also did well in math and sciences, he chose engineering as a more practical, and still interesting, field of study.

In addition to strengthening their resumes, participation in the faculty-led research reinforced a constructivist approach to learning. Student A realized that graduating with a degree in engineering was about more than gaining keys to his chosen profession. He indicated he realized the schooling was about developing the metacognitive skills that will help him to become a lifelong learner, an essential skill in the rapidly changing field of technology. He said that “when you walk out with your bachelor of science in … mechanical or electrical engineering or some sort of technological major for sure, you’ve demonstrated that you have the capability to learn. … Education is developing that capacity to learn and see things in a new light.” He felt that this would appeal to employers and give them confidence in his ability to tackle new challenges. Student F likewise put the onus of responsibility for achievement on himself, consciously rejecting the notion that knowledge can be passed on from one person to the next without the student’s deliberate engagement. He said, “If you go to class and you don’t do anything, you are going back, after school you’re going to be the person that said, ‘If you go to class and you don’t do anything, you sit in the back, after school you’re going to be the person that can’t find a job.’”

Getting Serious about College

Many of the students interviewed had had an experience that marked a significant transition for them in terms of how seriously they took their studies. During his sophomore year, Student A performed poorly on the first two exams in one of his core engineering courses. He recognized that he would have to work harder than he ever had to pass the course. His hard work paid off both in terms of the class and in terms of his self-efficacy. He reports thinking to himself, “That was the hardest thing I’ve ever done, ever. If I can get through that, there’s probably not much I can’t get through.” Student C also recognized that he needed to refocus his energy on studying. His high school prepared him so well for science and math courses that he did not feel much need to study. However, when he received some grades that were “not perfect,” he recognized that he was spending too much time hanging out with friends and playing video games. Sometimes buckling down required sacrifices. Said Student E, “I don’t … hang out or go to the bars or do dumb things with [my friends] anymore.” The tradeoff was worth it for him because of the academic and entrepreneurial achievements he had been able to attain as a result. He too had experienced a semester in which he earned a low grade-point average, which he attributed to being “still in the high school mode,” and he recognized that college was “a slap in the back of the head” that forced him to change his habits. These crises preceded students’ involvement in research, but they suggest that it might be fruitful to explore how pursuing research experiences fits into some students’ determinations to take control of their own learning.

Thinking Like an Engineer

The realization that through their participation in faculty research they were contributing to a growing corpus of knowledge was highly motivating for these students and reinforced their interest in engineering. Student B said he “never figured [he] would be doing that;” and that “it feels like really positive doors are opening.” Student F was also motivated by “making a significant scientific improvement … and educating other people about it … so they don’t have to repeat the same thing themselves.” Recognizing that they are producers of knowledge, not just consumers of it, and that they engage in the same processes as professionals in the field when they participate in research is an important step forward in students’ intellectual development.

All of the students in our sample showed evidence of understanding the processes professional engineers use to conduct their work. They often discussed this in conjunction with their reflections on their own work in the laboratory. For example, Student A said that his experiences on the research team have led him to see problems differently than he did in the past. He said, “I can see, especially with this research … now it’s not so much, ‘Here’s a problem, now solve it.’ Now it’s, ‘We have a whole system, what can we do to manipulate that in our favor?’” In the past he looked for a direct path to get the right answer, which is indicative of a dualistic approach to learning. Now he recognizes that he is an active agent in the discovery of new knowledge.

In a study of engineering students’ intellectual development—within the context of a first-year course in research design, Rose Marra and colleagues at Penn State found that the multiplicity of designs developed by the teams in the class challenged students’ notions of a single answer being correct (Marra, Palmer and Litzinger 2000, 41-43). This was important in the intellectual development of three of our own students (C, E, & F). The semester after he began working as part of the research team, Student C noticed that he started “to have [his] own way to learn, to do different things … how to approach class, how to approach the research problem, the project.” Not only did his approach become more systematic, but he also felt a greater degree of ease when approaching problems. He attributes this, in part, not only to designing his own portion of the research project on which his team was working, but also to his engagement with a network of peers who each approached their work in different ways. Whereas Student B used to “be eager for a solution,” he now realizes “it takes more time and research … to figure it out.” Student F was perhaps the most relativistic thinker of the sample saying, “There’s definitely multiple ways you can solve any problem … just like there’s no real one solution to what’s the answer of the world.”

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Balancing Autonomy and Teamwork

Having autonomy was an important feature of these students’ experience with the research projects in which they were engaged. All six of the students in our sample referred to this, although having autonomy did not necessarily mean that the students were not being held accountable for contributing to the main goals of the project. Student F corrected himself when he began talking about having “free will” in the laboratory. Rather, he said, it is “not the free will, but having the ability to go your own way with it, throw your own spine on it.” Because these students were working on small parts of a larger project, they were all accountable to one another and to the faculty member directing the research. However, they had considerable latitude in terms of how they approached their work and when they completed it. Student A repeatedly remarked on his appreciation for his professor’s flexibility in this regard.

Students may feel a degree of uncertainty about their ability to undertake and successfully complete research tasks, particularly in the beginning of their involvement with a research project (Bruno et al. 2011, 38). Several of the students developed confidence as a direct result of their professors’ trust in their abilities to perform at a high level. Student E used to frequently ask his professor questions that were either directly or tangentially related to the topic being researched, but eventually he gained the confidence to talk to his professor about various ideas of his own. The professor would comment on the feasibility of his proposal and ultimately suggested that the student apply for a grant so he could conduct his own study. This relationship has changed from one in which Student E “didn’t know what to do so [he] talked to [the professor] about everything,” to a relationship in which the professor provides more guidance than instruction. Similarly, early on in his experience on the research team, Student A said that his professor would either walk him through various processes “step-by-step” or would use Socratic techniques to draw answers out of the students. The
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professor, he said, "already knew the answer; he just wanted us to get there. But now, since we've got all that experience, we kind of know where things are going, so we have the freedom to choose what path we want to get to that end goal." In the beginning, the professor would monitor stu-
dents' progress on an hourly basis. As their knowledge and
skills grew over time, this interval was gradually lengthened,
and students now report their achievements and goals on a
weekly or monthly basis. When someone does get off track,
the professor steps in to redirect his efforts in a gentle and
supportive manner.

Two of the students in our sample construed their positions
within the research lab as being more dependent upon oth-
ers —such as the faculty member in charge or even more
senior students who had been involved with the project for
some time. Student B, who was relatively new to the lab
and more extrinsically motivated to be an engineer, did not
consider himself to have a great deal of autonomy in the
lab because he said that he "kind of came into the process
not really knowing that much about this so [he] figured the
best thing [he] can do is follow the instructions [he's] been
given." Whether his level of intellectual development pre-
dicts his preference for receiving specific instructions or the
lower level of autonomy he perceives restricts his intellectual
development is unclear, yet there seems to be a correlation
between autonomy and intellectual development.

Student D, who exhibited similar characteristics to Student
B, was actually motivated to participate in the research
because he was impressed that other students on the team
already had "much leeway in making something that [they]
want to work on." This student recognized that he was "still
on the lower rungs with a lot of people above [him]," but he
could envision his future work on the project as being more
self-directed. In this sense, working with more advanced
peers on a research project might provide students at a lower
stage of intellectual development with models of autono-
mous learning that they can emulate as they become more
involved with the research.

The research environment also reinforced to students that
their unique skills were valued by other members of the
team. Student F said he valued not only being able to call
upon others' expertise, but also "helping other people." Student
A was able to conceptualize a continuum of devel-
opment upon which he and his fellow researchers could be
positioned. For example, he said that sometimes he observed
students with the same research team and thought,"After
they take next year's class, they'll be like, 'Oh, that's
simple.'" Whereas in the past he needed the faculty member
to guide his actions "step-by-step," he now sees how far he
has come and how much further his junior colleagues have
yet to progress.

**Conclusion**

This study began with a general desire to understand how
students' intellectual development was influenced by their
participation in faculty-led research projects. We used eth-
ographic methods as part of an exploratory phase in which we
studied students regarding the major turning points they
had experienced in their college careers. Not surprisingly,
this general prompt resulted in detailed discussions of their
research experiences, although they also spoke freely about
the development of their identities as future engineers and
how this affected their personal lives.

While most students participated in research because of
an innate fascination with the discipline of engineering, even
those who had chosen the discipline—and the participation
in research—for more pragmatic reasons found the research
topic to be important and worthy of study. Having success-
fully navigated prior challenges in their education, these stu-
dents were attuned to how important research was to their
educational development. Their experiences helped them to
see that there is more than one way to approach a particu-
lar problem, which is a key marker of intellectual maturity.
They often recognized shades of their former selves in their
less-advanced colleagues. They commented upon this in
supportive terms, recognizing that the peer relationships
built into the lab, as well as the autonomy they are given by
their faculty mentors, will help these novices advance along
their developmental pathways to participation in research projects for underrep-
resented populations such as women and engineers of color.

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professor, he said, “already knew the answer; he just wanted us to get there. But now, since we’ve got all that experience, we kind of know where things are going, so we have the freedom to choose what path we want to get to that end goal.” In the beginning, the professor would monitor stu-
dents’ progress on an hourly basis. As their knowledge and
skills grew over time, this interval was gradually lengthened,
and students now report their achievements and goals on a
weekly or monthly basis. When someone does get off track,
the professor steps in to redirect his efforts in a gentle and
supportive manner.

Two of the students in our sample construed their positions
within the research lab as being more dependent upon oth-
ers —such as the faculty member in charge or even more
senior students who had been involved with the project for
some time. Student B, who was relatively new to the lab
and more extrinsically motivated to be an engineer, did not
consider himself to have a great deal of autonomy in the
lab because he said that he “kind of came into the process
not really knowing that much about this so [he] figured
the best thing [he] can do is follow the instructions [he’s] been
given.” Whether his level of intellectual development pre-
dicts his preference for receiving specific instructions or the
lower level of autonomy he perceives restricts his intellectual
development is unclear, yet there seems to be a correlation
between autonomy and intellectual development.

Student D, who exhibited similar characteristics to Student B,
was actually motivated to participate in the research because
he was impressed that other students on the team
already had “much leeway in making something that [they]
wanted to work on.” This student recognized that he was “still
on the lower rungs with a lot of people above [him],” but
he could envision his future work on the project as being more
self-directed. In this sense, working with more advanced
peers on a research project might provide students at a lower
stage of intellectual development with models of autono-
mous learning that they can emulate as they become more
involved with the research.

The research environment also reinforced to students that
their unique skills were valued by other members of the
team. Student F said he valued not only being able to call
upon others’ expertise, but also “helping other people.”
Student A was able to conceptualize a continuum of devel-
ompment upon which he and his fellow researchers could be
positioned. For example, he said that sometimes he observed
other members of the research team and thought,
“After they take next year’s class, they’ll be like, ‘Oh, that’s
simple.’” Whereas in the past he needed the faculty member
to guide his actions “step-by-step,” he now sees how far he
has come and how much further his junior colleagues have
yet to progress.

Conclusion

This study began with a general desire to understand how
students’ intellectual development was influenced by their
participation in faculty-led research projects. We used eth-
ographic methods as part of an exploratory phase in which we
Science and Technology for providing the funding for this project.

The impact of engaging undergraduates in research on the development of their identities as future engineers and how this affected their personal lives.

Our findings suggest that participation in research can provide students with opportunities to develop their intellectual and personal identities. Students who engage in research projects are not only acquiring knowledge and skills, but also gaining confidence and a sense of self-worth. This can lead to increased motivation and a desire to pursue advanced degrees in science and engineering.

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Introducing Primary Scientific Literature To First-year Undergraduate Researchers

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In the past decade, recommendations for reforming the way we teach science to undergraduate students have surged. In particular, emerging research suggests that students benefit from self-guided learning practices that are focused on core concepts and competencies rather than on content coverage. (National Research Council 2003, 2007, 2009; American Advancement for the Advancement of Science 2011) It is well-established that performing undergraduate research greatly enhances the educational experience (Lopatto 2004, Seymour et al. 2004). The process of researching a topic in the primary literature, designing experiments, implementing those experiments, and analyzing the results is critical for developing the analytical skills necessary to become a scientist. Furthermore, students benefit from undergraduate research experiences through increased graduation rates (Nagda et al. 1998), increased pursuit of graduate education (Kremer et al. 1990; Hathaway et al. 2002), and increased interest in science careers (Fitzsimmons et al. 1990).

Our institution, North Carolina State University, has a strong culture of mentoring upper-level undergraduates in research projects within investigator-funded research labs. First-year undergraduates, however, can find it difficult to secure positions in research laboratories for varying reasons (e.g., lack of personal confidence, labs being filled before students arrive on campus, reluctance of faculty mentors to take “unproven” students). Therefore, some students with great potential withdraw from STEM (science, technology, engineering, and mathematics) disciplines before they have a real chance to become engaged in the discipline beyond simple coursework.

To provide some of our first-year students with an authentic research experience, we participated in a program funded by the Howard Hughes Medical Institute, the Science Education Alliance-Phage Hunters Advancing Genomics and Evolutionary Science (SEA-PHAGES) program (http://www.hhmi.org/grants/sea/index.html). In this program, students each isolated and characterized a novel mycobacteriophage in the first semester, and then annotated the genome of one of the phages in the second semester. The student experience at our institution incorporated critical aspects of undergraduate research, including: project ownership; keeping a detailed laboratory notebook; disseminating research findings in both oral and written forms; and—the focus of this article—reading and discussing relevant primary scientific literature.

Other papers have been published on introducing undergraduates to the scientific literature. Notably, the C.R.E.A.T.E. approach (consider, read, elucidate hypotheses, analyze and interpret data, think of the next experiment) has been shown to enhance upper-level undergraduates’ analytic abilities, positively affect students’ confidence in understanding the literature, and provide insight into the scientific process in an intensive course focusing on primary literature (Hopkins et al. 2011). Another study showed that weekly journal clubs, in conjunction with independent undergraduate research and opportunities to present the research, increased student confidence and scientific literacy and facilitated the transition to graduate school for students in their final three undergraduate semesters (Kozeracki et al. 2006).

Not surprisingly, most studies investigating the benefits of introducing undergraduates to the scientific literature have focused on upperclassmen. One study that did center on first-year students examined the integration of information and science literacy. However, students only read one “model” journal article and selected one journal article to read on their own in a general biology course. The authors of the paper state that while this was a start in introducing the students to the literature, it was not sufficiently intensive to produce literate graduates (Porter et al. 2010).

The unique aspect of our research is that it focuses on first-year students in the context of an original research experience, in which students read literature relevant to their own work. In our courses, reading of primary scientific literature was introduced early, in a low stakes manner that then required written summaries, classroom discussion, and, gradually, full student responsibility for guiding classroom discussion of the assigned research articles. At the completion of the second semester, students reported a high degree of exposure to and confidence in reading the scientific litera-