Intellectual Development among Participants in Faculty-Led Research

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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 heeds 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 (Edgcomb 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 research showed that participation in research produced improvements in areas including student retention and graduation rates (Seymour et al. 2004, 500-510). Research experiences help students develop the ability to apply content knowledge, which is a learning objective identified by the Accreditation Board for Engineering and Technology (Commission 2011, 3).

Some studies in the literature specifically focused on practical issues and solutions for recruiting students into STEM fields (Bott 2003; Burrell & Colton 1999; Kaya 2012). One of the most effective means of recruiting, retaining, and engaging students is to involve them in research projects. According to a study conducted at a similar institution within our geographic region, offering research opportunities to undergraduates can be significant both in attracting high-performing candidates to the university and in retaining them once they have enrolled (Wonziak 2011, 10-12). Another comprehensive study supported the conclusion that retention rates increased for undergraduates who were involved in research programs (Swan, Cooper and Stockwell 2007). The same study revealed that sophomore students benefit the most from such research opportunities (Nagda et al. 1998, 65-68). On the other hand, another study showed that even first-year engineering students can benefit from participation in research projects (Deek, et al. 2003). Students show improvements in motivation and academic performance as they gain active research experience (Zydney et al. 2002, 293). When student researchers work on a project for longer than one year, the perceived benefits increase accordingly (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 (DeJong and Langerderfer 2012, 534-535). 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.

One author, Tolga Kaya, announced the research project to his students, but the formal invitation came from the second author, Lauren Griffith, an instructional designer who had no official relationship with the students. Griffith had sole responsibility for interviewing the students and transcribing these sessions. The interviews took place at the campus teaching center to avoid any potential pressure that a student might feel if interviews were to take place in the laboratory setting. After transcribing the interviews, Griffith analyzed the texts to determine the extent of students' intellectual development and the degree to which research participation affected their college experience.

Interviews were coded using the NVivo software in order to compare the frequency of different themes across the six transcribed interviews. The most striking evidence of students' intellectual development was apparent in their 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 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 bachelors 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 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 F, "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' determination 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 E 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."

Two of the students (C and F) described synthesis as an important aspect of their work on their research team, a trait far less frequently required in their regular coursework. Student C said that when working in the lab, he had the opportunity to "use [his] knowledge and combine multiple disciplines together. It's not just like this class, teaching this area; that class, that area. They need to be combined." Similarly, Student F said that in "the classroom you only look at a certain part of the project … so [research is] unique in its own aspect of looking at the whole entire project on a large scale."

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 spice 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 at 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 this 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 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 students' 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 others —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 predicts 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 autonomous 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 development upon which he and his fellow researchers could be positioned. For example, he said that sometimes he observed newer 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 ethnographic methods as part of an exploratory phase in which we queried 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 successfully navigated prior challenges in their education, these students 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 particular 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 the same path they themselves have.

Based on the data gathered in this phase of a larger project, we conclude that working on a faculty-led research project does promote intellectual development among students, particularly in terms of developing disciplinary habits of mind and the ability to work autonomously within a collaborative environment. However, it also affects other aspects of the development of students' identities. The results of this study will inform the second phase of our research, in which we will investigate first-year college students' intellectual development and motivations to become engineers. We believe that including a sample of students who have not participated in faculty-led research projects will lend a comparative perspective to our work and will ultimately result in a better understanding of students' intellectual development. We will also seek information that could help us develop pathways to participation in research projects for underrepresented populations such as women and engineers of color.

Acknowledgements

We would like to thank the engineering undergraduates who participated the interviews, and the College of Science and Technology for providing the funding for this project. Discussions during the High Impact Teaching Academy, organized by the Faculty Center for Innovative Teaching, were most helpful in conceptualizing this project.

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