
AC 2011-1396: ATTRIBUTES OF SUCCESS FOR ENGINEERING PH.D.S: PERSPECTIVES FROM ACADEMIA AND INDUSTRY

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Attributes of Success for Engineering Ph.D.s: Perspectives from Academia and Industry

Abstract

An exploration of engineering doctoral education is needed for several reasons. First, the realignment of undergraduate curricula based on studies of employers' needs and expectations are common in undergraduate education (i.e., Engineer of 2020) (National Academy of Engineering, 2004). These types of studies are not usual in doctoral education but are needed for Ph.D. programs to respond to the changing environments in industry and academia. Second, it is important to differentiate the industrial and academic expectations of engineering Ph.D.s since, according to NSF (2008), 73.3% of engineering Ph.D.s obtained jobs in industry. Finally, there is little understanding about how graduate education facilitates students' acquisition of these attributes.

In this study, eleven Ph.D.s were asked to describe the attributes for success as an engineering Ph.D., credentials expected for Ph.D. engineers working in academia and industry, and ways for institutions to develop these attributes among Ph.D.s. Related to attributes, the participants identified strong analytical skills, creativity, good communication skills, and multidisciplinary as valuable. The least commonly mentioned attributes were business management principles and adaptability. In comparing industry and academic expectations, leadership, teamwork, business management and communications skills were identified as important in industry. In academia, obtaining funding, teaching, and research were mentioned as most important. Finally, the participants felt as though the most important ways for institutions to help develop these attributes were to provide mentorship, facilitate research groups, and model behaviors. Future work based on these findings is also presented.

Introduction

ABET approved Engineering Criteria 2000 (EC, 2000) in 1996¹. Shifting from an emphasis on inputs of engineering programs (i.e., curricula) to the outputs of these programs (i.e., the knowledge, skills, and attributes that students should take away from their educational experiences), EC 2000 has been far-reaching in both academia and industry². Although efforts to explore the attributes and skills expected of engineering graduates have begun, it is unfortunate that they have been focused primarily at the undergraduate level. These types of studies are not usual in doctoral education but are needed for Ph.D. programs to respond to the changing environments of industry and academia. Additionally most engineering doctoral recipients are more likely to choose industry or self-employment options compared to obtaining a position in academe⁴ –In 2008, 73.3% of engineering Ph.D.s obtained jobs in industry NSF³, it is important to differentiate the industrial and academic expectations of engineering Ph.D.s.

For this reason, the aim of this paper is to explore the applicability of select engineering attributes for engineering doctoral students within a changing economy and environment. Additionally, insight will be provided on how graduate education facilitates students' acquisition

of these attributes. Given the limited empirical studies exploring such attributes among engineering students, the current paper reports results from eleven interviewees who were asked to map previously identified attributes for engineering undergraduate students to the expectations of doctoral students. Connections between literature at the undergraduate level and findings from the current study will be made in an effort to understand similarities and differences in identified attributes for both groups.

Perspective and Theoretical Framework

In the mid-late 1900s, the U.S. saw a dramatic increase in doctoral education. Since the Survey of Earned Doctorates (SED) began in 1957, the number of doctorates granted by U.S. universities has, on average, increased by approximately 3.5 percent per year. However, the growth in the number of doctorates was not a stable one. Until 2006, when higher education institutions awarded the highest number of doctorates with 45,596 doctorate recipients, there were periods of rapid growth and decreases in the doctorates awarded. Between 1961 and 1971, the number of doctorates awarded each year almost tripled from 10,000 to 31,867⁵. In fact,

“The number of doctoral degrees annually awarded during the late 1970s and through the early 1980s remained moderately stable at about 31,000 each year. In 1986, a second period of growth began that persisted until 1998, when 42,637 research doctorates were awarded. From 1998-2002, the number of doctorates awarded each year generally declined, reaching a low point in 2002. The trend reversed from 2003-2006 and the four years of growth have led to an all-time high for number of doctorates earned in 2006⁵.

In science and engineering (S&E) fields, this growth was due, in large part, to degrees awarded to international students, many who came to the U.S. to study following World War II⁶. In 2006, U.S. citizens received 63 percent of all research doctorates and 56 percent of science and engineering doctorates. The percentage of U.S. citizens who earned a doctorate in engineering was the lowest with 32 percent, compared to physical sciences (47%), Humanities (78%) and education (87%)⁷. As the country that awards the most Ph.D.s, the U.S. also has been the primary source of scientific achievement. Globalization over the past 10 years, however, has begun to shift dramatically the vision of S&E in the U.S and has seriously threatened the U.S.’ role of being the leading educator of engineering doctoral students.

A Combination of our primary focus on undergraduate engineering attributes and concerns about the preparation of graduate students in general^{8,9,10,11,12,13} was the foundation for exploring what is expected of engineering doctoral students. In this report, a group of distinguished educators and practicing engineers from diverse backgrounds identified the ideal attributes needed by an engineer in 2020. The list of attributes produced in this report was strikingly similar to that of the ABET criteria and included professional skills such as strong analytical skills, communication, practical ingenuity, leadership, professionalism, ethics, and lifelong learning.

Methods, Techniques, or Modes of Inquiry

Qualitative methods were used to conduct the current study, which is one part of an exploratory study about engineering Ph.D.s¹⁴. To define the attributes of engineering Ph.D.s and to identify strategies to help engineering Ph.D.s to acquire expected skills, researchers conducted semi-

structured interviews with industry and academic professionals in engineering fields. Results were analyzed from four questions (two about attributes and two about strategies). The research team interviewed eleven individuals from industry and academia. Each interview was recorded, transcribed and coded for reoccurring themes. A constant comparative method¹⁸ was used to highlight the similar or different views of the faculty members and industry experts regarding the attributes of an engineering Ph.D. The constant comparative method developed by Glaser and Strauss¹⁸ as a means to develop grounded theory, is one of the most common methods used to construct categories and subcategories^{19, 20} in qualitative studies. The basic strategy in the constant comparison method, as its name implies, is to constantly compare results during analysis.

Data Sources

Forty engineering professionals who submitted papers to the 2009 conference of the American Society for Engineering Education (ASEE) were recruited to participate in the study after researchers identified their presentation of graduate engineering education topics at the conference and compiled information about them via the World Wide Web. Eleven individuals (i.e., eight during the conference and three after the conference) completed semi-structured interviews with the research team (which included two PhDs and a graduate student, who were immersed in the literature previous to the interviews). The research team strategically scheduled interviews between sessions where the participants were available for an extended periods of time. This required each team member interview one participant, and three interviews were conducted with the participation of two research team members. eight interviews were conducted face to face during the ASEE conference. However, because of the hectic schedule during the conference, three of the participants agreed to be interviewed at a later time. These three individuals were interviewed via phone interviews. Each interview lasted from thirty to sixty minutes and was recorded (including phone interviews) digitally.

For the interviews, participants were given information about previously identified attributes in engineering, and they were asked about strategies that they thought were needed relative to the attributes presented in the first part of the study. At the beginning of each interview, participants were given the following list of attributes identified implicitly and explicitly in the *Engineer of 2020*¹⁵: strong analytical skills; practical ingenuity; creativity; good communication skills; mastery of business and management principles; leadership; high ethical standards; professionalism; dynamism, agility, resilience, and flexibility; globalization; and multidisciplinary education. Interviewees then were asked to select attributes they deemed most relevant to Ph.D. students in engineering disciplines. Lastly, the interviewer asked, “Of the attributes that you selected, which three or four are most relevant to engineering doctoral education? Why?” and “How can you engage engineering doctoral students in “attribute 1,” “attribute 2,” and “attribute 3” in their graduate education experience?” For the second part of the interview, participants were asked, “What skills are needed for engineering Ph.D.s to adjust to these changes after graduation?” and “What needs to be done to help engineering doctoral students acquire these skills during their graduate school experiences?”

The data analysis was conducted by one of the research team members. For the purpose of the data analysis, a codebook²¹ was compiled by the research team via the initial readings of the interviews and the use of literature. After the initial coding of the interviews, two other

researchers coded the interviews. At the end there were more than 80 percent agreement between the coders.

Results

Attributes of Engineering Ph.D.s

Participants identified attributes that are important for engineering Ph.D.s. The most frequently identified attributes included strong analytical skills, multidisciplinary, good communication skills, and creativity. Each of these attributes was mentioned by the vast majority (i.e., nine) participants. Over half of participants (i.e., six) also listed practical ingenuity (i.e., an engineer’s “skill in planning, combining, and adapting” to identify problems and find solutions¹⁶). Most participants did not consider business and management principles and adaptability as important to engineering Ph.D.s as other attributes, since these were the two least frequently acknowledged attributes in the list.

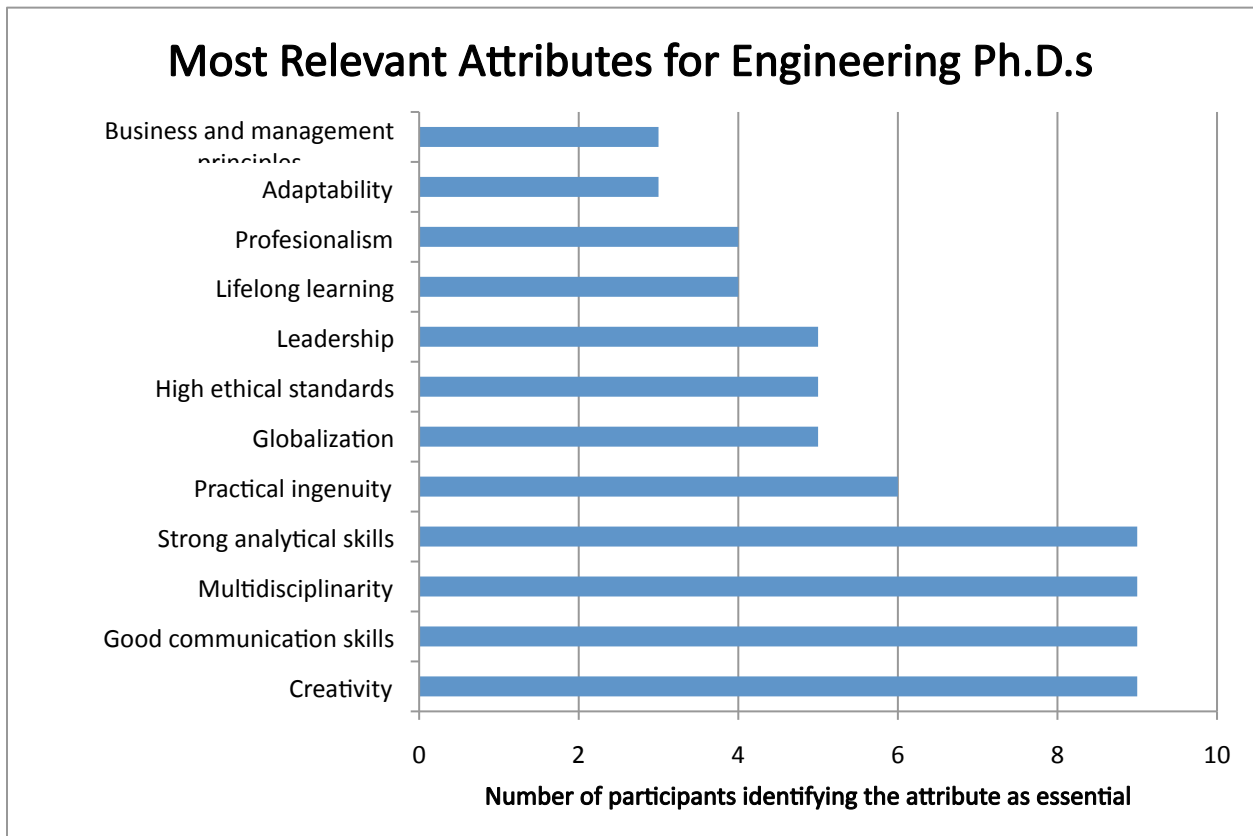


Figure 1. Attributes Identified by Participants as Necessary for Engineering Ph.D.s

Strategies to Develop Attributes

Participants were asked to suggest strategies by which the essential attributes in Figure 1 might be developed. The number of participants that mentioned each strategy to develop essential attributes is presented in Figure 2. Results identify each group’s (i.e., students, institution/faculty) responsibility to implement strategies. Participants provide a variety of additional

strategies (e.g., teach study skills, experiential learning) that might be implemented at the institutional or faculty level. The most frequently cited (i.e., six) explicit strategy was to provide mentoring to engineering Ph.D.s while they are pursuing their graduate degrees. The facilitation of research groups and modeling behaviors were recommended by four participants each. Seminars and project-based learning were also suggested as possible strategies for development.

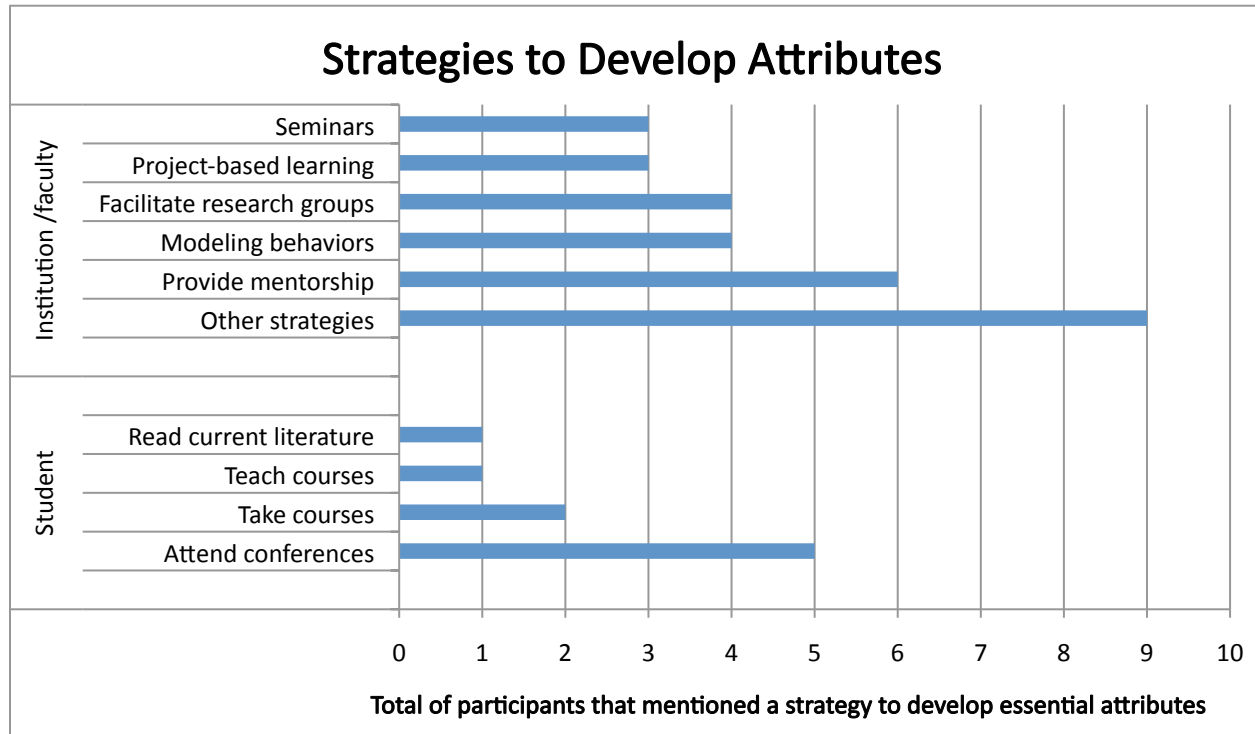


Figure 2. Suggested Strategies to Develop Attributes of Engineering Ph.D.s

Expectations of Industry versus Academia

The expectations that respondents cited as most important varied depending on whether an engineering Ph.D. graduate chooses to pursue a career in academia or industry. Leadership, teamwork, communication skills, and business management were commonly referred by respondents as the most essential attributes an engineering Ph.D. working in industry should possess. Three out of eleven respondents considered “leadership” and “teamwork” as vital qualifications for engineering Ph.D.s in industry. One participant said engineering Ph.D.s should not only contribute to the improvement of engineering technology but also to be able to lead groups of people. The following participant gave a specific example using a turbine design for aircraft:

“You know, that they’re (engineering Ph.D.s) focused on the turbine design, they could come in and not only contribute to better design, improved design, but they are capable of growing a group, leading a group, managing a group that will be focused on those issues”.

The statement shows the importance of leadership and teamwork credentials in engineering Ph.D.s. “Communication skills” and “business management” were mentioned by two out of eleven respondents. A range of other credentials for engineering Ph.D.s in industry were suggested by four respondents including analytical, multidisciplinary, localized work skills, and the ability work internationally.

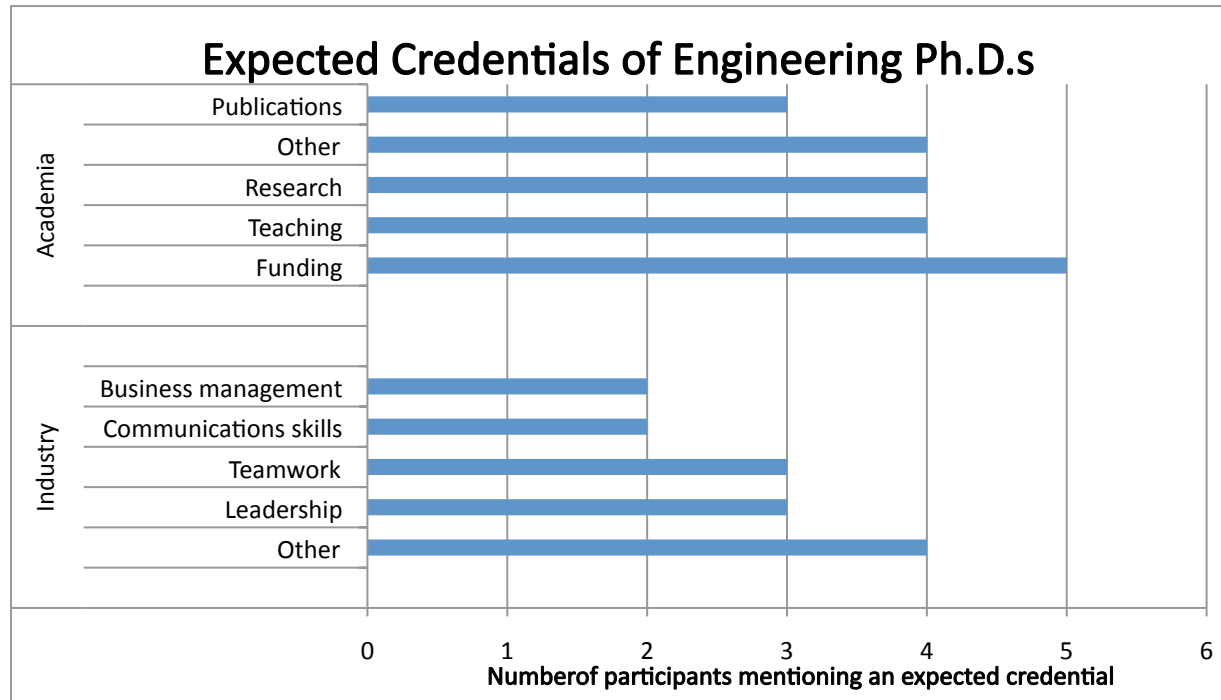


Figure 3. Expected Credential of Engineering Ph.D.s in Academia and Industry

Respondents expected an engineering Ph.D. in academia to demonstrate strong credentials related to finding research funds, teaching, conducting research, and publishing. Among those credentials, grant funding was the most commonly mentioned credential by respondents (five out of eleven respondents). According to one participant, grant funding is an important qualification, because it will create opportunities for students and colleagues. Furthermore, it is an essential skill in supporting research and maintaining a research lab. Competencies in teaching and research were listed as important credentials by four out of eleven respondents. One participant emphasized that engineering faculty should be rewarded not just for the research and publications but also for teaching and working with students. Publications were considered as an essential credential for engineering Ph.D. students in academia by three respondents. One of the respondents said engineering Ph.D.s need to identify new problems and be able to publish the results. Various other credentials expected of engineering Ph.D.s in academia pointed out by four respondents were training in educational teaching methods, being an independent thinker, networking, working as a team, having technical expertise, and management skills. Figure 3 provides a graphical representation of what is expected of engineering Ph.D.s in academia and industry as mentioned by the eleven participants.

Scholarly Significance of the Study

There are many reasons why this study is significant. First, it identifies the attributes and skills that engineering Ph.D.s need in order to be successful in the changing environments of industry and academia. Secondly, it suggests that there are strategies that can be implemented by higher education institutions and things that engineering Ph.D. students can do to improve their skills. Third, it postulates that since the expectations for engineering Ph.D.s vary depending on where they are employed after graduation (industry or academia), the graduate education they receive should provide them with the opportunities to develop the skills and attributes critical to success in both sectors. The findings provide implications both for further research and practice in graduate education.

Conclusion

In this study, eleven engineering professionals were asked to describe the attributes for success as an engineering Ph.D., various credentials expected for engineering Ph.D.s working in academia and industry, and ways for institutions to develop these attributes among Ph.D.s. Leadership skills, strong analytical skills, and skills in securing research funding were among those cited as the most essential. Participants felt the most important way to develop these attributes was through mentoring. These strategies relate to the socialization aspect of doctoral education and are consistent with recommendations posed by Austin¹⁷.

Acknowledgements

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References

1. Lattuca, L. R., Terenzini, P. T., & Volkwein, J. F. (2006). *Engineering Change: Findings from a Study of the Impact of EC2000, Final Report*. Baltimore, MD : ABET, Inc.
2. Besterfield-Sacre, M., Shuman, L. J., Wolfe, H., Atman, C. J. McGourty, J., Miller, R. L., Olds, B. M. and Rogers, G. (2000). Defining the outcomes: A framework for EC 2000. *IEEE Transactions on Engineering Education*, 43(2), 113-122.
3. NSF/NIH/USED/USDA/NEH/NASA. (2008). *Survey of Earned Doctorates*. Data File. Retrieved from <http://www.nsf.gov/statistics/nsf10309/pdf/tab29.pdf>
4. Ibid.
5. Hoffer, T. B., Hess, M., Welch, V., & Williams, K. (2007). *Doctorate recipients from United States universities: Summary report 2006*. Chicago, IL: National Opinion Research Center.
6. Bound, J., Turner, S. and Walsh, P. (2009). "Internationalization of U.S. Doctorate Education". NBER Working Paper no. 14792, March 2009.
7. Hoffer, T. B., Hess, M., Welch, V., & Williams, K. (2007).
8. Committee on Science, Engineering, and Public Policy (COSEPUP) of the National Academy of Sciences, The National Academy of Engineering, and the Institute of Medicine. (1995). *Reshaping the graduate education of scientists and engineers*. Washington, DC: National Academy Press.
9. Nerad, M., & Cerny, J. (2000). From rumors to factors: Career outcomes of English Ph.D.s. *ADE Bulletin*, 124, 43-55.

10. Nyquist, J. D., Abbott, R. D., & Wulff, D. H. (Eds.). (1989). *Teaching assistant training in the 1990s*. New Directions for Teaching and Learning, No. 39. San Francisco: Jossey-Bass.
11. National Research Council (NRC) (2006). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, D.C.: National Academies Press. Available online at: <http://www.nap.edu/catalog/11463.html>.
12. Austin, A.E., & Wulff, D.H. (2004). The challenge to prepare the next generation of faculty. In *Paths to the professoriate: Strategies for Enriching the Preparation of Future Faculty*. San Francisco: Jossey-Bass.
13. Golde, C.M., & Walker, G. (Eds.). (2006). *Envisioning the future of doctoral education: Preparing stewards of the discipline - Carnegie essays on the doctorate*. San Francisco: Jossey-Bass.
14. Cox, M.F., Cekic, O., Branch, S., Chavela, R., Cawthorne, J., & Ahn, B. (2010). Ph.D.s in Engineering: Getting Them through the Door and Seeing Them Graduate- Faculty and Industry Perspectives. 2010 *Proceedings of the American Society for Engineering Education* (7 pages).
15. National Academy of Engineering (NAE). (2004). *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, D. C.: The National Academies Press.
16. Ibid.
17. Austin, A.E. (2002). Preparing the Next Generation of Faculty. *Journal of Higher Education*, 73(1), p94-122.
18. Glaser, B. & Strauss, A. (1967). *Discovery of grounded theory: Strategies for qualitative research*. Chicago: Aldine Publishing Co.
19. Merriam, S. B. (1998). *Qualitative research and case study applications in education: Revised and expanded from case study research in education*. San Francisco: Jossey-Bass.
20. Lincoln, Y. S., and Guba, E. G. (1985) *Naturalistic inquiry*. Thousand Oaks, California: Sage.
21. MacQueen, K. M., McLellan, E., Kay K., & Milstein, B. (1998) Codebook Development for Team-Based Qualitative Analysis. *Cultural Anthropology Methods* 10(2):31-36