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Impact of International Collaborative Engineering Education upon the Epistemological Development of Chinese Engineering Students

Miss Qunqun Liu, Shanghai Jiao Tong University

Qunqun Liu is a graduate student at the Graduate School of Education in Shanghai Jiao Tong University. She obtained a B.S. in public administration from China Agricultural University. Her current interest focuses on the cognitive development of engineering graduate and undergraduate students, the assessment of teaching and learning in graduate education.

Dr. Jiabin Zhu, Shanghai Jiao Tong University

Jiabin Zhu is an Assistant Professor at the Graduate School of Education at Shanghai Jiao Tong University. Her primary research interests relate to the assessment of teaching and learning in engineering, cognitive development of graduate and undergraduate students, and global engineering. She received her Ph.D. from the School of Engineering Education, Purdue University in 2013.

Miss BO YANG

Graduate School of Education, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai, China email: by8023@sjtu.edu.cn

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Abstract

International collaborative engineering education facilitates the efforts of launching multiple cross-cultural cooperative programs and has enhanced the international learning experiences of engineering students. Intense effort has been geared towards understanding students' academic performance or extracurricular experience as a result of these international collaborative activities. Considering the impact of students' epistemic thinking on their academic performance, this study applied modified Perry's theory to examine the impact of international collaborative engineering education upon the epistemological development of engineering undergraduate students from an international joint program in China. Preliminary results suggest that diverse factors as related with the international teaching and learning environment are closely associated with students' epistemic thinking. Future studies are proposed to explore other potential factors within international collaborative programs that are associated with engineering students' epistemic thinking.

Introduction

International collaboration has become a global trend. To facilitate global education and research collaboration, Chinese universities have launched multiple international collaborative initiatives in the higher education system, especially in the realm of engineering education [1, 2, 3].

International collaboration in engineering education has provided students with an increased exposure to advanced pedagogical methods, a close contact with world-class professors, and diverse opportunities to study in an international learning environment [4, 5, 6]. For example, Sino-French Engineer School that was jointly established by Beihang University and Groupe des Ecoles Centrales has adopted case-based teaching and problem-based learning pedagogical methods to promote students' creative thinking, innovative skills, adaptability, etc. University of Michigan (UM)-Shanghai Jiao Tong University (SJTU) Joint Institute, functioning as an independent unit for engineering education within SJTU, strives to prepare students for a global work place by engaging students in state-of-the-art research projects and cross-cultural internship opportunities [3, 7]. These types of international collaborative programs offer students with diverse learning experiences and international experiences.

Despite the wide scope of international collaboration in engineering education, currently the

assessment of these efforts focuses on students' academic performance or extracurricular experience. Students' high level of thinking or their personal epistemology was rarely investigated. Considering the potential influences on one's epistemic thinking from diverse learning experiences[8], and considering the critical role of personal epistemology in guiding students' learning strategies [9], it is useful to understand the impact of international collaborative engineering education on students' epistemological development.

Literature Review

Considering the significance of international cooperative efforts on engineering education, there have been multiple initiatives to facilitate international collaboration. The types of international collaboration include branch campuses, cross-border collaborative arrangements such as student and faculty exchange, dual degrees, joint capstone projects, etc. [10]

Multiple studies have been conducted to understand the organization, implementation, and impact of international collaborative programs, identified the specific benefits and opportunities of international collaboration in engineering disciplines, and investigated the state and trajectory of engineering education research collaborations [11, 12]. Other researchers also explored the impact of international collaboration on engineering students' learning outcome and their learning experiences [6, 13, 14]. Specifically, McNeill used qualitative methods to examine the experiences and learning outcomes of three groups of engineering students involved in global engineering education programs. Dwyer suggested that studying abroad has a significant impact on students in the areas of continued language use, academic attainment measures, intercultural and personal development, and career choices. Despite of prior effort, little has been done as related to students' epistemic thinking. Considering the impact of students' epistemic thinking on their academic performance, this study focuses on understanding the impact of international collaborative engineering education upon engineering students' epistemic thinking. To achieve this goal, we examine engineering students from an international joint program.

Context of the Study

The international joint program described here aims to help Chinese engineering students develop different global competencies through various in-class and out-of-class activities. The SPEIT (SJTU-ParisTech Elite Institute of Technology) program was established under the strategic alliance of the Paris Tech Group and SJTU on 2012. The whole education lasts 6 years, composed by two cycles (Figure 1): the fundamental cycle, which is supervised by experienced French professors, combines the requirement of a scientific background for engineering schools and a solid foundation of multidisciplinary education; the engineering

cycle is carried on in a close collaboration between four French schools and Shanghai Jiao Tong University, which will prepare students to be engineers in a global context [15].

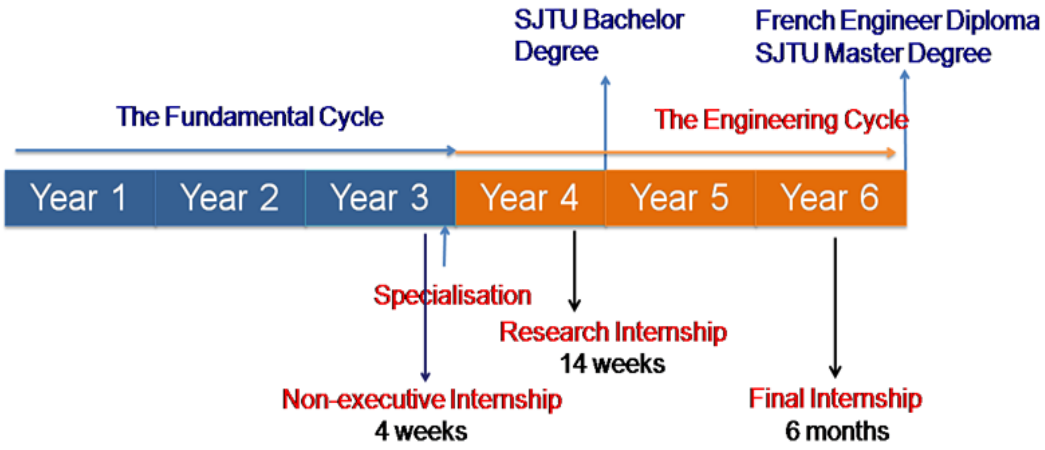

Figure 1 Students' educational cycles in the SPEIT program

Specifically, the SPEIT program establishes a learning environment that emphasizes student engagement, team work, student-faculty interactions and timely feedback processes, etc. For example, students will have three exams per month to help them review timely what they have learned in that month. In addition, French engineering teaching highlights the development of students' analytical thinking through mathematic and logical reasoning. Therefore, it is of particular to explore the potential impact of the learning activities upon students' epistemic thinking.

In this study, we try to understand students' personal epistemological development in the international joint program. In particular, we focus on exploring the impact of different factors that are associated with the international collaborative educational environment on students' epistemological development. In this report, our research questions read,

1. What are the epistemological development profiles of Chinese engineering undergraduate students within the SPEIT program?

2. What factors are related to Chinese engineering undergraduate students' epistemological development within the SPEIT program?

Theoretical Framework

To depict students' epistemological development, we adopt the ongoing refinement of Perry's model [8, 16] as our theoretical framework. The ongoing refinement of Perry's model suggests

the nine positions of the original Perry's model can be clustered into four sequential categories: *Dualism, Multiplicity, Relativism, and Commitment (within Relativism)* [16]. Multiple theories on personal epistemological development were proposed after Perry's theory [17, 18, 19, 20]. Despite of differences in the respective theoretical focus, these subsequent models all shared a common thread and confirmed the developmental trajectory that was first proposed by Perry, that is, individuals moved a dualistic view of knowledge to a contextual, constructivist perspective [8, 21].

A person in the stage of *Dualism* is characterized by holding a dualistic, right-or-wrong view of the world. Authorities are expected to know the truth and to convey it to the learner. *Multiplicity* represents a modification of dualism, with the beginning of the recognition of diversity and uncertainty. Authorities who disagree are deemed to be still at a state of seeking the right answer. An individual believes that all views are equally valid and that each person has a right to his or her own opinion. At *Relativism*, individuals shift from a dualistic view of the world to a view of contextual relativism, and perceive knowledge as relative, contingent, and contextual. Meanwhile, by sensing the limit of reasoning, one starts to realize the need for commitment even after a careful evaluation process. At *Commitment within Relativism*, individuals claim and confirm their commitments to values, careers, relationships, and personal identity, assuming major responsibilities in different arenas of life.

Personal epistemological development models, in particular Perry's theory has been widely used in the assessment of students' epistemological development in engineering education and other disciplines. Results suggested that many engineering undergraduate students' epistemological development was in still multiplicity [22, 23]. Gender differences and grade level differences have also been investigated as related to personal epistemology [8, 21, 22, 24]. Epistemological beliefs become more sophisticated as students' progress in their educational levels [23, 24].

Addition to factors such as gender and grade levels, other factors related to teaching and learning were also explored as related to students' epistemic thinking. Factors such as the use of project-based /problem-based learning and teamwork in students' learning were pointed out to be closely associated with students' epistemological development [8, 24, 25, 26]. Since international collaborative engineering education incorporates many of the above-mentioned innovative educational elements, it is therefore of particular interest to investigate the impact of these efforts on students' epistemic thinking, especially on the development of advanced levels of thinking styles.

Method

Sample

An explanatory mixed-methods design was adopted for this study. Through this design, quantitative data and results first provided a general picture of students' epistemic thinking; it was then followed by a qualitative study which refined the results by providing in-depth details on the results [27]. The participants for this study included 112 (75 male and 37 female) engineering undergraduates who were enrolled in the SPEIT program. The numbers of students represent a reasonable distribution across the academic progress (36 freshmen, 49 sophomores, and 27 juniors) (Note: the SPEIT program did not have senior students because it was established on 2012). Among the 112 complete responses, seven (6 males and 1female) students agreed to be interviewed in a one-on-one manner.

Data Collection

All research participants responded to the modified Zhang Cognitive Development Inventory [8] online. In addition, they responded to a demographic questionnaire that elicited information such as the participants' gender, grade, background, and region. The modified Zhang Cognitive Development Inventory consists of 49-item that was developed and validated in the context of an epistemological development theory [8, 28]. Additional survey questions were added concerning the duration of their international experience (⩽3 months; 3-6 months; >6 months) and co-op experience (⩽3 months; 3-6 months; 6 months-1 year; 1-3 years; >3 years). Based on their self-reported results, twenty-two students had extended stays (less than 3 months) at a university abroad and 90 students have had any international experiences; Eight students have worked in a company in less than 3 months and one student has worked in 6 months to 1 year, 103 students none.

Follow-up interviews were conducted. The interview questions were modified from Baxter Magolda's prior interview protocol [8]. We started with the broad question, "What stands out for you so far in your college experience?" [29]. Other questions were asked to explore the roles of themselves/faculty members/peers.

Data analysis

Previous researchers have found that cognitive development [8, 17, 30] are associated with gender, grade and previous experiences. This study explored several variables of interest. The dependent variables were the four dimensions (*Dualism, Multiplicity, Relativism, and Commitment*) of Perry's theory. The independent variables included the duration of students'

international experiences, co-op experiences, academic progress, gender, etc. A T-test was used to identify students' prominent epistemic thinking. A correlation test was used to analyze the correlation between the duration of international experiences/ co-op experiences and students' epistemic thinking.

Seven students were interviewed. All interviews were transcribed. Five students' prominent epistemological thinking styles were identified as *Relativism and/or Commitment in Relativism* through our survey results. We focused on these five students who have demonstrated higher levels of thinking to understand the related factors to their epistemological development. Open coding procedure was used to identify the categories for related factors. Themes and patterns were summarized through the analyses.

Preliminary Results

An Overall Profile of Epistemological Stages

Preliminary results suggested that 88% of the participants were found to show *Relativism* and/or *Commitment in Relativism* in the thinking styles. This means that Chinese engineering undergraduate students within the program has already demonstrated a contextual or relativistic way of thinking. The quantitative result is depicted in Figure 2.

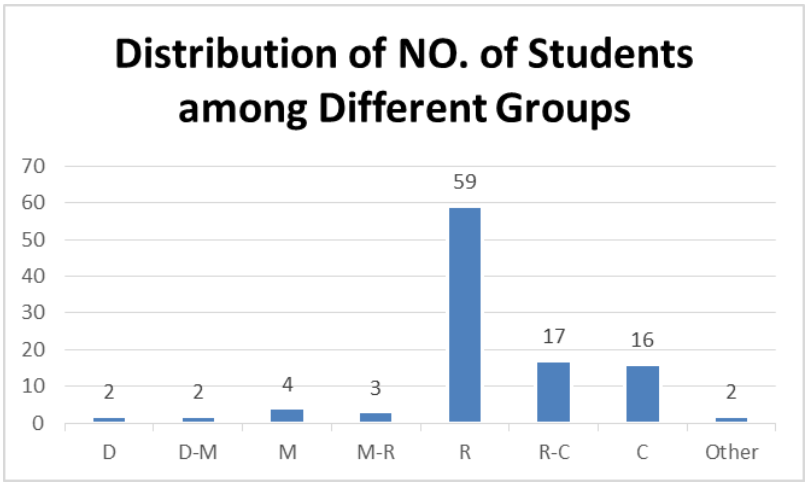

Figure 2 Distribution of the number of students among different groups

Note: "other" includes D-M, D-M-R, D-R, M-R, M-C, with less than four persons in each group: D-*Dualism*, M-*Multiplicity*, R-*Relativism*, C-*Commitment*.

No statistically significant difference in their epistemological thinking scores was observed for students from the first three academic years. Due to the fact that the program was

established on 2012 and has no senior students, follow-up longitudinal studies are yet to be conducted on students' epistemological thinking when they progress to their senior years to provide a complete picture on engineering students' epistemological development with regards to their academic progress.

Correlation Analysis

As seen from Tables 1, a weak positive correlation (Spearman's r_s=.182; p<0.05) was observed between cross-cultural experiences and students' relativistic thinking. A weak positive correlation ($r_{s=}$.165, $p < 0.05$) was also observed exists between co-op experiences and students' commitment to relativistic thinking.

Table 1: Correlation (Spearman's r_s) between cross-cultural experiences/ co-op experiences and students' epistemic thinking

Variable	D	M	R	C
Cross-cultural Experiences	-.106	.129	**.182***	.144
Co-op Experiences	.-.070	.041	.049	**.165***

*Correlation is significant at the 0.05 level (1-tailed).

For cross-cultural experiences, it is referring to short international experiences such as attending international academic conferences or extended stay (3 months or more) at a university abroad. Similarly, co-op experiences were classified according to the duration for which they have worked in a company. For both experience, our results indicated a trend of position correlations to the higher levels of thinking (*Multiplicity*, *Relativism*, *Commitment*), and negative correlations to the lower thinking (*Dualism*).

Factors Related to Relativistic/Commitment to Relativistic Thinking

The quantitative data indicate some factors that are potentially related with student's epistemological development, including cross-cultural experiences and co-op experiences. These factors provide some insight into the potential factors which can facilitate the students' epistemological development. With finding based upon qualitative data analysis, this study investigated the factors that were associated to higher levels of thinking, relativistic thinking and/or a commitment to this type of thinking. Four preliminary factors that are associated with students' relativistic thinking were identified through our preliminary analyses. These

factors are explained below with student quotations for each category.

Prompt and diverse teaching feedback

The SPEIT program is featured with varied forms of teaching feedback. For example, students will have three monthly exams to help them review timely what they have learned in that month. What's more, there are weekly exams ("colle" in French). By communicating orally with a professor, students will have some face to face instructions in a direct and timely manner. Some of them have said:

"Because of this monthly exam, we get to connect the former and latter parts, say, you may get to see the connection between the first and the second sections of chapter one. Then, after you go through the whole thing, you then get the whole point! It helps to integrate ideas so that the understanding of the whole course is more systematic. Also, you can find the weak points in your own understanding. "-Robin

"This oral test, it's all about what you have just learned in the past month. The professor will give you some exercises on the spot, and you need to finish them right there. While you are finishing the problem, he will be there watching the (problem-solving) process. You can ask the professor if you have any questions. Or, maybe, if you made some mistake, he can point out right away….You need to explain the thought process, … not give just the final answer, but also the process"- Robin

This type of feedback seemed to have contributed to students' deep understanding of core concepts. It also facilitated students' reflection and articulation of what they have learned.

An emphasis on rigorous reasoning

The SPEIT program encourages a teaching and learning environment that emphasizes analytical thinking through mathematic reasoning and the like. This focus had allowed for students' development of rigorous thinking progresses:

"The French have a rigorous logic process. Say, for some equations, he may start with the subject and go through from the beginning to the end through critical analysis. After that, they may do it one more time backward. That is to say, they will do the proof backwards. Just like what we call 'a double-check'. Maybe, for science and engineering, rigor is very critical for French. I think that's what I can learn from them."-Roger

A cooperative learning environment

What's more, small-class teaching format have and professors' teaching tactics, such as a sense of humor, have encouraged students' participation. Professors paid close attention to the communication with students, which seemed to have also helped students' learning effectiveness as shown in some of the comments from our participants:

"We normally have a small class, the class culture is fairly nice. Everybody has a chance to speak up. I think this is great. More communication could expand our scope of knowledge."- Roman

"We are mainly taught by French teachers, their teaching styles are quite open. In our classes, say, our Physics teachers are quite humorous, we have a very active classroom. We get to learn through fun activities. "-Roman

Informative site visits

In our interviews, students talked about the rich information acquired through site visits to French companies that were in collaboration with this joint program. The students got exposure to the required qualities to be an engineer as well as the potential career paths through visiting the French companies:

"Visiting the companies could help me find my own position. I also obtained lots of information related to my future career. "- Richard

"The requirements are not same for different engineers. But everyone needs to be equipped with some professional qualities, we should have a good comprehension of the whole system. We knew more about the detailed things of being an engineer. It will help our training, I mean, it will offer some guidance and inspiration."- Robin

"A company had offered us a particular training, which is exactly the kind for their new employees. We played different roles of a company, trying to model the way in which a company operated. I learned a lot through the training. Through the visit, we get an idea about different future posts and the actual tasks related to a position, the kind of people one might work with, and the requirements from the supervisors."- Cyrus

Company visits described by the students have offered first-hand experiences as to what it would be like to be an engineer in a real company. Combining classroom learning and experiential learning outside of class, the joint program seemed to offer students with diverse learning experiences and therefore enhanced students' epistemic thinking by strengthening their analytical thinking, reflective thinking, etc.

Discussion

In sum, our quantitative results suggest that most of the Chinese engineering undergraduate students' prominent thinking styles fell into the higher level of thinking (*Relativism and Commitment to Relativism*) according Perry's theory (nearly 88%). Prior findings indicated that most of engineering undergraduate students' epistemological development was in multiplicity [22, 23, 31]. We speculate that different factors could have facilitated students' development in their thinking styles along the Perry's scale. Other researchers have pointed out possible factors, such as the advisor-students interactions [8], curriculum content and structure [24], etc. may have close association with students' epistemic thinking. Our follow-up interviews with students suggest that factors that are related with their international collaborative educational environment may also have influenced their epistemological development.

Preliminary results showed some factors that are associated with the international collaborative efforts, such as prompt and diverse feedback from instructors, teaching styles that highlight rigorous reasoning, a cooperative learning environment, and informative site visits to companies.

Concerning giving prompt feedback to students, researchers have pointed out the importance of providing timely feedback to students. For example, the HPL-inspired pedagogy that supports a cooperative learning environment also emphasizes the significance of assessment-centeredness in the framework [32, 33]. Instructors can help students in mastering core concept and knowledge by providing them with formative and summative feedback [32, 34]. Moreover, other researchers pointed out that providing timely guidance can also facilitate their epistemological development [8, 35]. Similarly, instructors in the SPEIT program used prompt and diverse teaching feedback to help students' adopt deep learning approach to understand what they have learned, which might have promoted students' epistemic thinking.

In addition, the SPEIT program highlights the establishment of a learning environment that embraces rigorous reasoning. By a rigorous learning environment, it means that instructors focus on students' development of analytical thinking and the abilities to express their thinking process. The development of these skills resembles the core ideas of a relativistic thinking, which emphasizes the analyses of different evidences, factors, and ideas [20, 29].

Meanwhile, instructors in the program put a strong emphasis on cooperation in a learning environment. This environment allows students to work in teams, take responsibility for their own learning and develop in-depth understanding of the nature of knowledge [35, 36]. In addition, a teaming environment exposes students to multiple ideas. The exposure to diverse

idea represents a critical step for a person's epistemological development [29].

With regard to company site visits, it seems that students acquired informative as regards to their future career paths. According to Perry's theory, responsibility and the way of life including career, marriage and social endeavors etc. are the major themes for the stage of commitment [29]. The experience of site visits contributed to student's awareness of the responsibilities as a future engineer by exposing them to different career choices. Through this process, students may start to reflect upon their career options and seek to find their own positions.

In sum, by establishing a learning environment that incorporates prompt feedback, highlights rigor and cooperation, and engages students in experiential learning through company visits, the SPEIT program could have helped students develop sophisticated thinking.

Conclusion

This study has provided the epistemological development profiles of Chinese engineering undergraduate students within the SPEIT program. Our findings suggest that cross-culture experience and co-op experience may have positive impact on students' epistemological development. Moreover, multiple innovative educational measures and practices adopted by the program, such as prompt and diverse feedback from instructors, teaching styles that highlight rigor and cooperation, and informative site visits to companies, were associated with students' epistemological development. Our findings offer insights as to possible impact of different educational innovations on engineering students' epistemological development, which will be beneficial for future design and undertaking of different educational measures and practices. By investigating students' learning experiences from other international collaborative programs, we vision that other possible factors can be identified as related to engineering students' epistemic thinking.

References

[1] Altbach, P. G. (2009). One-third of the globe: The future of higher education in China and India. *Prospects, 39*(1), 11-31.

[2] Fazackerley, A. (2007). British universities in China: The reality beyond the rhetoric. *Agora: the Forum for Culture and Education*. Retrieved on Oct 18, 2014 from: http://academiccouncil.duke.edu/wp-content/uploads/2008/05/Agora-China Report1.pdf.

[3] Zhang, S.S. (2011). Introducing innovation stepping into the first-class engineering education reform at

UM-SJTU Joint Institute. *Higher Engineering Education*(2), 16-26.
[4] Shulman, L.S. (2005). Signature pedagogies in the professions. *Daedalus, 134*(3), 52-59.
[5] Maillacheruvu, K.Y. (2014). Impact of international collaboration on the learning environment. Paper presented at the *American Society for Engineering Education*.
[6] McNeill, N.J. (2010). *Global Engineering Education Programs: More than just International Experiences*. Retrieved from Proquest, Purdue University.
[7] Xiong, Z., Yu, L.M., Xu, P. (2012) Interpretation of french engineer diploma education accreditation and case analysis. *Higher Engineering Education*(5), 77-83.
[8] Zhu, J. (2013). *Personal epistemological development of Chinese engineering doctoral students in U.S. institutions: An application of Perry's theory* (Doctoral Dissertation). Retrieved from ProQuest, Purdue University.
[9] Hofer, B. K., Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*(1), 88-140.
[10] Altbach, P. G., & Knight, J. (2007). The internationalization of higher education: Motivations and realities. *Journal of Studies in International Education, 3*(11), 290-305.
[11] Jesiek, B.K., Borrego, M., & Beddoes, K. (2010). Advancing global capacity for engineering education research (AGCEER): Relating research to practice, policy, and industry. *Journal of Engineering Education, 99*(2), 107-119.
[12] Jesiek, B. K., Chang, Y., Shen, Y., Lin, J. J., Daniel Hirleman, E., & Groll, E. A. (2011). International research and education in engineering (IREE) 2010 China: Developing globally competent engineering researchers. In *American Society for Engineering Education*.
[13] Dwyer, M. M. (2004). More is better: The impact of study abroad program duration. *Frontiers: The Interdisciplinary Journal of Study Abroad*, 10, 151-163.
[14] Allert, B., & Atkinson, D. (2005). Work in progress-identifying learning outcomes of a multi-semester international program in mechanical engineering. In *Frontiers in Education, 2005. FIE'05. Proceedings 35th Annual Conference* (pp. S1D-15). IEEE.
[15] Archives from Shanghai Jiao Tong University website (2015). Retrieved from http://speit.sjtu.edu.cn/indexen!list.html?topNav=300.
[16] Culver, R.S., & Hackos, J.T. (1982). *Perry's Model of Intellectual Development* (Vol. 72). Engineering Education.
[17] Belenky, M. F., Clinchy, B. M., Goldberger, N. R., and Tarule, J. M. (1986). *Women's Ways of Knowing: The Development of Self, Voice and Mind*. New York: Basic Books.
[18] Baxter Magolda, M. B. (1992). *Knowing and Reasoning in College*: San Francisco: Jossey-Bass.
[19] 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.
[20] Kuhn, D. (1991). *The Skills of Argument*. England: Cambridge University Press.
[21] Hofer, B. K. (2001). Personal epistemology research: implications for learning and teaching. *Educational Psychology Review, 13*(4), 353-383.

[22] Felder, R. M., & Brent, R. (2005). Understanding student differences. *Journal of Engineering Education, 94*(1), 57-72.
[23] Pavelich, M. J., & Moore, W. S. (1996). Measuring the effect of experiential education using the Perry model. *Journal of Engineering Education, 85*(4), 287-292.
[24] Wise, J.C., Lee, S.H., Litzinger, T., Marra, R.M., & Palmer, B. (2004). A report on a four-year longitudinal study of intellectual development of engineering undergraduates. *Journal of Adult Development*, 11(2), 103-110.
[25] Marra, R. M., Palmer, B., & Litzinger, T. (2000). The effects of a first-year engineering design course on student intellectual development as measured by the Perry scheme. *Journal of Engineering Education, 89*(1), 39-45.
[26] Douglas, E. P., & Chu-Chuan, C. (2009). *Work in Progress - Use of Guided Inquiry as an Active Learning Technique in Engineering.* Paper presented at the Frontiers in Education Conference.
[27] Creswell, J W. (2012). *Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research*. England: Pearson College Division.
[28] Zhang, L. F. (1997). *The Zhang Cognitive Development Inventory*. Unpublished text, The University of Hong Kong, Hong Kong. See Appendix A.
[29] Perry, W. G. (1970). *Forms of Intellectual and Ethical Development in the College Years: A Scheme*. San Francisco: Jossey-Bass.
[30] Zhang, L. F. (1999). A comparison of U.S. and Chinese university students' cognitive development: The cross-cultural applicability of Perry's theory. *The Journal of Psychology*, *133*(4), 425–439.
[31] Zhang, L. F. (1995). *The Construction of a Chinese Language Cognitive Development Inventory and Its Use in a Cross-Cultural Study of the Perry Scheme.* The University of Iowa.
[32] Cox, M. F., & Cordray, D. S. (2008). Assessing pedagogy in bioengineering classrooms: Quantifying elements of the "how people learn" model using the vanit observation system (vos). *Journal of Engineering Education, 97*(4), 413-431.
[33] Linsenmeier, R.A., Kanter, D.E., Smith, H.D., Linsenmeier, K.A., & McKenna, A.F. (2008). Evaluation of a challenge-based human metabolism laboratory for undergraduates. *Journal of Engineering Education, 97*(2), 213-222.
[34] Brandsford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How people learn: Brain, mind, experience, and school*. Washinton, DC: National Academy Press.
[35] Felder, R. M., & Brent, R. (2004). The intellectual development of science and engineering students. part 2: teaching to promote growth. *Journal of Engineering Education, 93*(4), 279-291.
[36] Marra, R. M., & Palmer, B. (2004). Encouraging Intellectual Growth: Senior College Student Profiles. *Journal of Adult Development, 11*(2), 111-122.