AC 2011-993: COMPUTING-RELATED SELF-EFFICACY: THE ROLES OF GENDER, ACADEMIC PERFORMANCE, AND COMPUTATIONAL CAPABILITIES

CHIA-LIN HO, North Carolina State University

Chia-Lin Ho is a doctoral student in Industrial/Organizational Psychology at North Carolina State University. She received a B.S. in Psychology and a Bachelor of Business Administration at the National Cheng-Chi University in Taiwan in 2002 and her Masters in I/O Psychology at the University of North Carolina at Charlotte in 2005. Her research interests include measurement and evaluation issues, individual differences, leadership, cross-cultural studies, work motivation, and the application of technology on human resources management.

Dianne Raubenheimer, North Carolina State University

Dr. C. Dianne Raubenheimer is Director of Assessment in the College or Engineering and Adjunct Assistant Professor in the Department of Adult and Higher Education at NC State University. Within the College of Engineering she serves as the coordinator of ABET and other accreditation processes, acts as a resource/consultant to faculty in the different programs, develops and implements assessment plans, and serves as the primary educational assessment/data analyst adviser on the Dean's staff. A particular interest is in helping faculty to develop and implement classroom-based assessment and action research plans to establish the effectiveness of instruction and to use the data to improve teaching and student learning. She is currently working with several engineering faculty assessing the impact of in-class use of technology on teaching and student learning. Dianne has also worked as an education consultant for a number of organizations conducting program evaluations and is currently serving as external evaluator on several grants. Her research interests focus on faculty development, action research, the role of technology in teaching and learning, and assessment in higher education.

Computing-related Self-efficacy: The Roles of Computational Capabilities, Gender, and Academic Performance

Abstract

Research has documented that self-efficacy is a good predictor of individuals' behavior and motivation. In engineering education, self-efficacy has received much attention in dealing with issues regarding the retention of female engineering students. As an effort to further understand the role of self-efficacy in computer science and engineering education, this study focused on students' self-efficacy beliefs about engineering/computer science, as well as self-efficacy beliefs about computer usage, and then examined their relations to computational capabilities, gender, and academic performance.

This study is part of a larger project, supported by a National Science Foundation CISE Pathways to Revitalized Undergraduate Computing Education (CPATH) grant, designed to prepare students for pervasive, advanced computing in the workplace. These data included participants (N = 389) enrolled in undergraduate computer science or engineering courses in several engineering programs in 2009 and 2010. Participants completed measures of engineering/computer science self-efficacy, computer self-efficacy and self-ratings of six computational capabilities which had been indicated by industry as important for new hires: (1) database fundamentals, (2) process modeling and design, (3) basic knowledge of programming, (4) data analysis skills, (5) communication /organization tools, and (6) web searching.

Two multiple regression analyses were conducted, one for engineering/computer science self-efficacy and one for computer self-efficacy. Gender, GPAs, and the six computational capabilities were regressed on each measure of self-efficacy. The results revealed significant gender differences on both self-efficacy constructs, providing support for the continuing existence of gender differences in computing-related self-efficacy. Individuals with higher GPAs reported higher levels of engineering/computer science self-efficacy. Each of the six computational capabilities showed a different relationship to engineering/computer science self-efficacy and to computer self-efficacy. Specifically, by controlling for gender and GPA, engineering/computer science self-efficacy was predicted by capabilities on database fundamentals, basic knowledge of programming, and data analysis. Computer self-efficacy was predicted by capabilities on basic knowledge of programming, communication /organization tools, and web searching. Process modeling and design did not predict either self-efficacy constructs.

The study results provide support for the relationship among computing-related self-efficacy, gender, GPA, and specific computational capabilities. Given the importance of self-efficacy in learning, these findings have implications for computer science and engineering education. Besides continuing to acknowledge gender differences in computing-related self-efficacy, training interventions to enhance specific computational capabilities should be implemented to increase students' beliefs in their ability to perform successfully in computing-related disciplines, in turn leading to better learning outcomes and higher learning motivation.

Introduction

Today's somewhat disjointed approach to discipline-specific computing and generic computer literacy does not accurately mirror the knowledge, skills and abilities needed by the engineer of the future global workplace. Computing in the workplace is pervasive and involves many complex tools, many approaches to problem solving, strategic decision making and synthesis. Knowledge, comprehension and application are no longer enough for one to be labeled highly competent in computing. A successful engineer will also need mastery of computing applicable to the higher level cognitive skills of analysis, synthesis and evaluation. To prepare students for pervasive, advanced computing in the workplace, a project funded by the National Science Foundation CISE Pathways to Revitalized Undergraduate Computing Education (CPATH) was initiated to achieve two overarching goals: (1) to create a computational thinking thread in computer science and engineering programs that spans from the freshman to senior years and bridges the divide between freshman year computing and computing in upper-level classes, and (2) to enable students to take computing competencies to the next level, where they are able to perform high-level computing tasks within the context of a discipline.

To develop an effective strategy for infusing computational capabilities through an undergraduate engineering program, a series of data collection and analysis were conducted from numerous sources to identify computational skills and competencies different engineering industries expect of graduates as they enter the workforce and in their first years on the job. Acquisition of computational capabilities (actual competence) and self-perceptions of those capabilities (perceived competence) are both important in determining one's performance [1]. The perception of one's own abilities to perform a task, referred as self-efficacy, has evidenced as a robust predictor of academic performance [2] and work-related performance [3]. In an effort to understand the role of self-efficacy in engineering education, this study focused on engineering/computer science self-efficacy and computer self-efficacy and examined their relationship to computational capabilities, gender, and academic performance. In particular, the research question addressed in this study was whether acquiring specific computational capabilities would contribute to students' self-efficacy beliefs in engineering/computer science and in the use of computers. Additionally, replication of the relationship of self-efficacy to gender and academic performance was expected.

Self-efficacy

Self-efficacy refers to an individual's belief(s) that s/he can successfully perform behaviors that will bring about specific outcomes and is involved with perceived ability rather than actual ability. Self-efficacy beliefs are formed through four primary sources: mastery experience, modeling, verbal persuasion, and physiological states (anxiety reduction) [4]. Research has demonstrated the positive relationship among self-efficacy and different motivational and behavioral outcomes. In particular, a meta-analysis evidenced that self-perceived competence was positively related to academic performance and persistence across a wide variety of subjects, experimental designs, and assessment methods [2]. Self-efficacy beliefs account for 14% of the variance in students' academic performance and 12% of the variance in their academic persistence. The positive relationship between self-efficacy and work-related performance was also supported by Stajkovic and Luthans's meta-analytic study [3].

Measurement of self-efficacy could be general or task-specific. General self-efficacy measures a uni-dimensional trait that predicts behavior across domains. On the other hand, task-specific self-efficacy is a more direct measure of one's perceived competence, and predicts behavior better than general self-efficacy for any single domain [5]. Given that the current study focused on computing competencies and student behaviors in engineering disciplines, task-specific self-efficacy was considered more suitable for measuring students' beliefs about their abilities. In particular, two types of task-specific self-efficacy were measured: engineering/computer science self-efficacy and computer self-efficacy.

Computational Capabilities

With the goal of examining relations between computing-related self-efficacy and specific computational capabilities, six computational capabilities deemed as important for new engineering hires to possess, were derived from data gathered from professional engineers. Our engagement with industry included two primary strategies: a face-to-face daylong workshop with an industry panel and a Delphi process with another group of industry representatives. From the results of the industry workshop, some common themes of computational capabilities emerged. These computational themes were used to inform the Delphi process [6], a method used to inductively identify the specific needs of engineering-oriented industries; needs that have been ill-defined in the literature. In the Delphi process, two rounds of survey administration were involved: a survey with open-ended questions (Round 1) and a Likert scale survey (Round 2).The Delphi Round 1 survey consisted of a set of open-ended questions about the computing competencies that industry expects of new engineering hires and those expected after a few years on the job. Responses of engineering line managers to the Round 1 survey were used to develop a Likert scale survey for Round 2, which was used to collect industry ratings of the importance of various computing competencies for success in the workplace. The detail of the Delphi process we used was described in previous conference papers [7, 8]. In the current study, the six computational competencies were those that appeared most frequently in the industry responses to the Delphi Round 1 survey.

These six computational capabilities consist of (1) database fundamentals, (2) process modeling and design, (3) basic knowledge of programming, (4 data analysis skills, (5) communication/ organization tools, and (6) web searching. The *database fundamentals* competency involves an understanding of data structures, SQL and databases, how they are implemented, and knowledge of what problems they may be applied to. *Process modeling and design* relates to the ability to use design programs including AutoCAD, analysis programs and the use of steady-state and dynamic process modeling programs. *Basic knowledge of programming* includes use of C/C++, Java, VBA, Matlab and other programming tools to conduct tasks that require basic programming. *Data analysis skills* involve data manipulation tasks, use of statistical analysis tools, and other data analysis tools and skills. *Communication and organization tools* include e-mail/scheduling, use of video/phone conferencing and/or webinar software, and use of production tools for digital photo or video editing. The *web searching* competency includes the ability to search on the Web and the ability to use Google to find answers for basic questions.

Self-efficacy and Computational Capabilities

Research has support the importance of self-efficacy in learning behavior, motivation, and performance outcomes [1]. Identifying interventions for enhancing students' computing-related self-efficacy would help achieve the goal of the CPATH project, which was to prepare students for pervasive, advanced computing in the workplace through instructional changes. In particular, we examined whether any specific computing capabilities would relate to students' computer self-efficacy or to their engineering/computer science self-efficacy. If this were found to be the case, training interventions for specific computing competencies would help enhance students' computing-related self-efficacy and in turn, influence their career and academic options, as well as their persistence and success in their chosen majors [1].

Self-efficacy and Gender

Gender differences in students' beliefs about their computer/technology abilities have received much attention in education because they provide a potential interpretation of females' low participation in computer-related fields [9]. Females tend to have less confidence in their computer-related skills than males, and this pattern has been found from elementary school [10] to college [11, 12]. The gender inequity on computer-related self-efficacy can be attributed to different socialization experiences of females and males, and was found to be a reflection of gender biased social expectations as expressed by parents [13]. With an expectation of replicating the gender pattern, we examined the relationships between gender and two self-efficacy constructs.

Self-efficacy and Academic Performance

Past performance is one primary source from which self-efficacy beliefs are formed [4]. Research has supported the relationships between self-efficacy and academic performance. For instance, mathematics self-efficacy was found to be positively related to math course grades [14]. Furthermore, Multon, Brown, and Lent's meta-analytic study [2] demonstrated the positive relationship between perceived competence and three types of performance measure in education (i.e., classroom performance, standardized achievement test, and skill task). In the current study, we examined whether self-efficacy predicted grade point average (GPA) as an index of academic performance.

Method

Participants and Procedure

A sample of 389 students completed a survey in 2009 and 2010. All had declared engineering as their major and were enrolled in undergraduate computer science and/or engineering courses at a large research intensive university in the southeast. Most students surveyed were between the ages of 19 to 21 years of age (74.5%), male (78.7%), and white (81.0%). Students (10.5% freshmen; 39.6% sophomore; 36.2% junior; 13.4% senior) were recruited from ten courses (including courses in graphical communications, computer science, chemical engineering, mechanical engineering, industrial engineering and textile engineering). Participants were asked to complete the survey online.

Measures

The survey consisted of several sections, namely, (1) self-ratings of the six computational capabilities, (2) a measure of computer self-efficacy, (3) a measure of self-efficacy towards engineering/computer science, and (4) a section on demographic information.

Self-reported skill level. Six questions were presented, each associated with one of the computational capabilities of (1) database fundamentals, (2) process modeling and design, (3) basic knowledge of programming, (4) data analysis skills, (5) communication /organization tools, and (6) web searching. These were the areas highlighted by industry representatives as essential skills for graduates to possess for successful employment. Along with the six questions, examples of each computational capability were included, to clarify the meaning/topic of the questions [see the Computational Capabilities section above]. Students were asked to rate their skill level in each of the six computing areas on a 5-point response scale ranging from novice to expert.

Engineering/computer science self-efficacy. Nine items assessing self-efficacy beliefs in engineering and computer science were used to assess a student's perceived ability to perform well in the field of engineering and/or computer science. Sample items were 'I am confident that I can solve engineering/computer science problems efficiently' and 'I am sure I can perform well on engineering/computing related work.' A 5-point response scale, ranging from strongly disagree to strongly agree, was employed. Internal consistency estimated by Cronbach's alpha was .81.

Computer self-efficacy. Computer self-efficacy belief was assessed using 7 items, including the Vekiri and Chronaki's 3-item scale [13]. Sample items are 'I could complete my task using new software if there was no one around to tell me what to do' and 'I'm a quick learner of new software.' A 5-point response scale, ranging from strongly disagree to strongly agree, was employed. Internal consistency estimated by Cronbach's alpha was .88.

Demographic information. Gender, age, self-reported GPA, and year of study were collected.

Results

Means and standard deviations of all the variables and inter-correlations among variables are presented in Table 1. Engineering/computer science self-efficacy was strongly correlated with computer self-efficacy, indicating these two self-efficacy constructs are highly related.

All six computational capabilities were significantly correlated with one another, with the exception that there is no relationship between web searching and basic knowledge of programming. All the computational capabilities were also significantly related to the two self-efficacy measures.

Gender related to the two self-efficacy measures and four of the computational capabilities. Particularly, in comparison to females, males tended to be more confident about their computing-

related ability and more competent in database fundamentals, process modeling and design, basic knowledge of programming, and data analysis.

GPA was correlated only with engineering/computer science self-efficacy. Because class level was not significantly related to the two measures of self-efficacy ($r < .01$ for engineering/ computer science self-efficacy; $r = .04$ for computer self-efficacy), this variable was dropped from the subsequent regression analyses.

Table 1: *Descriptive Statistics and Inter-Correlations for Variables (N = 389)*

Variables	*M*	*SD*	1	2	3	4	5	6	7	8	9
1. Engineering/computer science self-efficacy	3.60	0.55									
2. Computer self-efficacy	3.92	0.63	.46**								
3. Database fundamentals	1.95	1.04	.31**	.20**							
4. Process modeling and design	2.18	1.20	.22**	.19**	.41**						
5. Basic knowledge of programming	1.91	1.11	.29**	.31**	.36**	.36**					
6. Data analysis skills	2.54	1.05	.33**	.18**	.46**	.42**	.32**				
7. Communication/ organization tools	3.76	1.03	.18**	.31**	.22**	.26**	.15**	.39**			
8. Web searching	4.40	0.75	.17**	.30**	.11*	.18**	.07	.22**	.53**		
9. Gender	-	-	.17**	.17**	.17**	.16**	.17**	.15**	-.01	-.04	
10. GPA	3.20	0.55	.12*	-.04	-.03	-.10	-.08	.04	-.03	.02	-.13*

Note. For gender, females were coded as zero; males were coded as 1.
**$p < 0.01$; *$p < 0.05$

To examine the relationships between computing-related self-efficacy, computational capabilities, gender, and academic performance, two multiple regression analyses were conducted, one for engineering/computer science self-efficacy and one for computer self-efficacy. Gender, GPA, and the six computational capabilities were regressed on each measure of self-efficacy. The results showed that after controlling for gender and GPA, the different computational capabilities related differently to engineering/computer science self-efficacy and to computer self-efficacy. Database fundamentals, basic knowledge of programming, and data analysis skills predicted engineering/computer science self-efficacy ratings; while basic knowledge of programming, communication/organization tools, and web searching predicted computer self-efficacy beliefs (Table 2).

Table 2: *Results of Multiple Regression of Engineering/Computer Science Self-efficacy and of Computer Self-efficacy (N=389)*

Variable	Engineering/Computer Science self-efficacy	Computer self-efficacy
Database fundamentals	.16**	.06
Process modeling and design	.01	< .01
Basic knowledge of programming	.17**	.25**
Data analysis skills	.15**	-.07
Communication/organization tools	.02	.17**
Web searching	.10	.21**
Gender	.11*	.14**
GPA	.15**	.01
R^2	.20**	.22**

**$p < 0.01$; *$p < 0.05$

Significant gender differences in engineering/computer science self-efficacy, as well as in computer self-efficacy, were found, indicating a pervasive gender bias in general computing-related self-efficacy.

However, a positive relationship between GPA and self-efficacy was found only in engineering/computer science self-efficacy, indicating that students with higher GPAs tended to be more confident in their ability to perform well in engineering or computer science. GPAs were not related to computer self-efficacy after controlling for all other variables (Table 2). Note that these results indicate the unique impact of each variable of interest on computing-related self-efficacy. The relationships are shown in Figure 1.
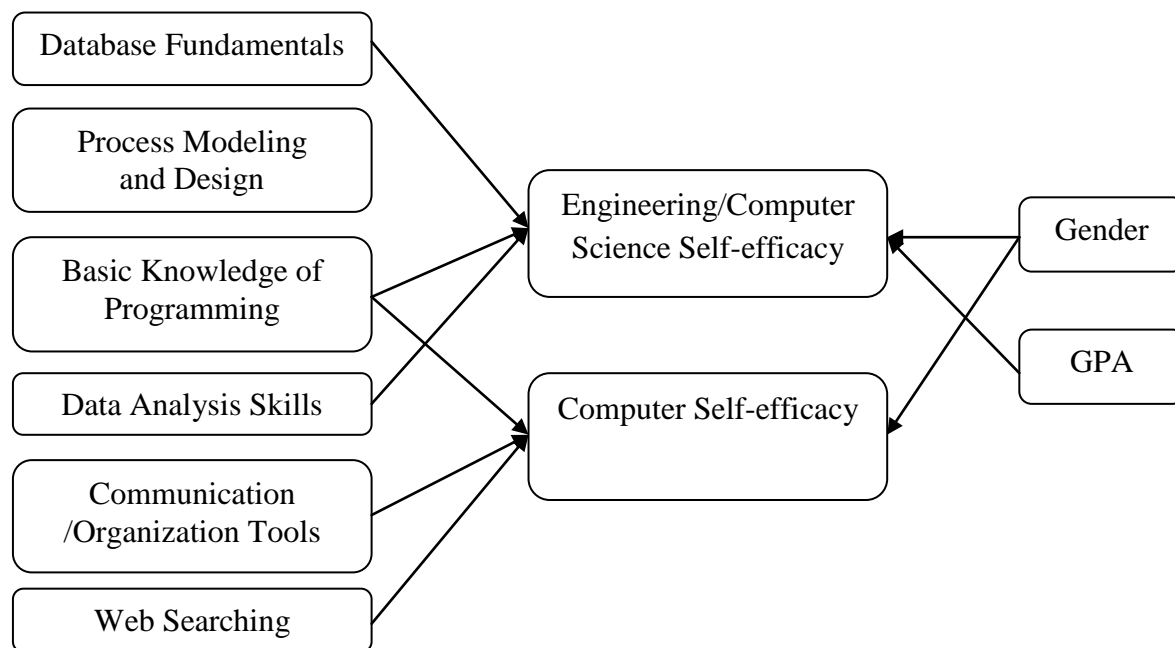
Figure 1. *Diagrammatic representation of the relationships among six computational capabilities, computer self-efficacy, engineering/computer science self-efficacy, gender, and GPA.*

Discussion

An individual's belief in his or her ability to perform a behavior is as important as his or her actual ability. The role of self-efficacy beliefs in learning has been well recognized [1]. In the current study, we found one's self-efficacy in computing and engineering/computer science were positively related to some, but not all, specific computational capabilities industry expected of new engineering hires. Specifically, acquisition of basic knowledge of programming was associated with both computer self-efficacy and engineering/computer science self-efficacy. Students who self-rated mastery in database fundamentals and data analysis skills also tended to have more confidence in dealing with engineering related problems. Two computational capabilities, communication/organization tools and web searching, were related to computer self-efficacy beliefs. These findings imply that acquiring certain computational capabilities may boost one's self-efficacy in computing and/or engineering/computer science. Since self-efficacy beliefs can come from different sources, designing curricula to improve students' computational capabilities identified as critical to self-efficacy beliefs could be one intervention to enhance students' self-efficacy in the two areas considered in this study.

To further understand computing-related self-efficacy in college students, we also related students' perceived competence in computing and engineering/computer science to gender and GPA. Consistent with past research, gender differences were found in two computing-related self-efficacy measures. These findings suggest that more interventions would be in need to close this gender gap. As Vekiri and Chronaki [13] recommended, parental support for engaging in

computing-related activities would be one approach. On the other hand, GPA related differently to the two specific self-efficacy measures. In particular, engineering/computer science self-efficacy was predicted by GPA, but this was not the case for computer self-efficacy. The result may imply that not all subtypes of self-efficacy have impacts on academic performance. For this engineering student sample, GPA was a better index of their performance across engineering courses; therefore, engineering/computer science self-efficacy was related to GPA. Taken together, the relationship between self-efficacy and academic performance was partially confirmed in this study.

Recommendations and Future Work

The relationships between two computing-related self-efficacy constructs and computational capabilities suggest that designing a course to enhance specific capabilities may help increase students' perceived competence in computer science and engineering disciplines. Future research using an experimental or quasi-experimental design would be needed to make causal conclusions that relate computing-related self-efficacy to specific computational capabilities. In addition, in this study we used self-assessments of actual computational capabilities. However, the use of other sources of ratings of students' abilities or other forms of ability assessments would strengthen these findings.

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