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The investigation of STEM Self-Efficacy and Professional Commitment to Engineering among female high school students

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This study employed social cognitive theory and social cognitive career theory (SCCT) as foundations to explore the influence of high school students' beliefs about female gender roles and female engineer role models on science, technology, engineering, and mathematics (STEM) self-efficacy and professional commitment to engineering. A total of 88 students from a national girls' high school participated in STEM project-based learning. A survey questionnaire named The STEM Self-efficacy and Professional Commitment to Engineering Questionnaire, developed by the researchers, was administered to collect data, and a structured equation model was employed to confirm the multi-theoretical model developed in this study. The results of this study show that enhancing the gender role beliefs and engineer role models of female students may increase their STEM self-efficacy and professional commitment to engineering. In other words, the female high school students' professional commitment to engineering model can explain students' intentions for future engineering careers. Thus, this study suggests integrating STEM project-based learning into the curricula of various schools and integrating female engineer role models into STEM project-based learning activities for female students, which can enhance female high school students' STEM self-efficacy and professional commitment to engineering.

Keywords: female engineer role model; female gender role beliefs; professional commitment to engineering; STEM project-based learning; STEM self-efficacy

Research background

Historically, the fields of science and engineering have been dominated by males. For instance, in the United States, between 1995 and 2010, the proportion of bachelor's degrees in engineering awarded to women increased from 17.3% to 20.1%, but only 11% of working engineers are women. In Taiwan, the ratio of women in engineering decreased from 32.22% in 1995 to 26.07% in 2010 (Directorate-General of Budget, Accounting, & Statistics, Executive Yuan, ROC, 2011; Fouad & Singh, 2011). These statistics show a great decrease in women participating and working in engineering, a gender problem in the engineering field that should receive attention. In the 1980s, scholars on women's careers focused on sex role socialization, using variables such as concepts of female family roles, work roles, and work support to reflect the low self-efficacy caused in areas that are non-traditional realms of work for females, which then limits the choices and development of female work (Astin, 1984; Farmer, 1985; Hackett & Betz, 1981). Even today, females' choices in education and employment are still affected by sexual division of labor and gender stereotypes (Chien & Ren, 2011; Yen, 2011; Fouad & Singh, 2011). Thus, educators have gradually noticed the influence of gender role identification on academic choices and career planning.

Although the gender equality law has been formed in Taiwan, the issue of how female gender roles and female engineer role models affect the self-efficacy of female students and their professional commitment to engineering has not been investigated. In view of this, some scholars in Taiwan are actively promoting STEM project-based learning in secondary schools or universities, finding that students' attitudes and learning efficiency are enhanced, which affects their future career choices (Lou, Tsai & Tseng, 2011; Liu, Lou, Shih, Tseng, Chan & Diez, 2009; Lou, Liu, Shih & Tseng, 2011a; Lou, Liu, Shih, Chuang & Tseng 2011b; Tseng, Chang, Lou & Chen, 2013). STEM project-based learning not only enhances student problem-solving abilities, but it also can effectively integrate understanding and application of complex knowledge in science, technology, engineering, and mathematics as well as cultivate student interest in engineering. Thus, this study uses female high school students participating in STEM project-based learning, using social learning theory (SLT) and SCCT as the theoretical framework to explore the correlations among female gender roles, female engineer role models, STEM self-efficacy, and professional commitment to engineering, and to construct a model.

Social learning theory emphasizes that individual behaviors in social contexts change due to the influence of others. Individuals observe, imitate, and use internal cognitive processes to learn the behaviors of others and can indirectly learn by observing others' behaviours or the consequences of others' behaviours. Observational learning is also referred to as modeling: the one to be imitated is the model. According to social cognitive theory, women's gender role beliefs and female engineer role models were gained through the observational learning process (Ho, Chung, Chang, Ho, Wang & Huang, 2008; Chang, 2010; Bandura, 1986). In other words, women's gender role beliefs can affect their learning and acceptance of female engineer role models. The characteristics of gender role beliefs and career ambition choices are related; for example, the overall career self-efficacy of students in high schools and vocational schools show significant differences due to gender, which affects personal choice of future professions (Peng & Chang, 2010). Additionally, some empirical studies have shown that gender role beliefs influence professional commitment (Mao, Chou & Hsu, 2008; Chen & Sun, 2006; Astin, 1984; Edwards & Spence, 1987).

Social cognitive career theory originates from the social learning theory of Bandura (1977a, 1986), which primarily explores the influence of cognition and belief on career decisions, emphasizing that an individual's belief about whether the task can be successfully completed has a crucial influence on the actual performance (Lent, Brown & Hackett, 1994; Lent, Brown & Hackett, 2000; Lent & Brown, 2008). The core concept of this theory is self-efficacy, and one of the contextual factors of self-efficacy is role model contact (O'Brien, 2003). Empirical research shows that being close to successful models inspires students' experiences through vicarious learning and action and elevates their self-efficacy in the field (Chien & Lien, 2009). Role models and self-efficacy influence students' career choices, and the former is more important than the latter (Wu, 2009; Kerr & Nicpon, 2003; Quimby & DeSantis, 2006). These facts show that gender role beliefs relating to socialization would affect role model would affect self-efficacy, and, finally, gender role beliefs, role modeling, and self-efficacy would all affect professional commitment. Thus, this study argues that female gender role beliefs and female engineer role models are factors that influence women's STEM self-efficacy and professional commitment to engineering, as shown in Figure 1.

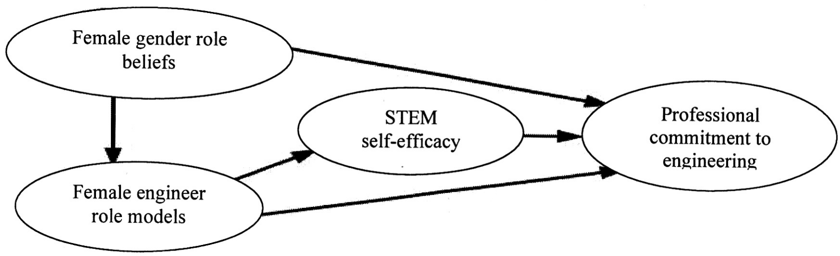

Figure 1 Female Students' professional commitment to engineering theoretical model

Research Purpose

The purpose of this study was to explore the influence of female high school students' gender role beliefs and female engineer role models on their STEM self-efficacy and professional commitment to engineering.

Definition of Terms

(1) Female gender role beliefs: the female behavioral model under cultural expectations and individual cognitive beliefs about different gender roles (Li & Chung, 1996; Chang, 2010). This study defines female gender role beliefs as women's self-development and gender equality.

(2) Female engineer role model: refers to female role models in the engineering field. Because the research subjects in this study are female high school students, this study defines female engineer role models broadly as female models found through reading biographies, news and magazine reports and observing friends

and relatives in the engineering field. Responses to role models are categorized as emotions, behavior or cognition.

(3) STEM self-efficacy: self-efficacy can be seen as confidence at one's work or the subjective evaluation of one's personal ability in achieving a certain type of work (Chang, 2010; Pintrich, 1989). This study classifies self-efficacy as the self-evaluation of concepts, principle applications, and experimentation ability in science, technology, engineering, and mathematics required for the completion of STEM projects.

(4) Professional commitment to engineering: professional commitment is comprised of professionalism and commitment, defined as the individual's psychological processes or behavioral inclinations of identification or devotion to his profession (Taylor, 1988). Considering that the subjects in this study are female high school students and not working professionals, professional commitment to engineering is seen as a kind of behavioral intention: professional value identification, intention for professional career involvement, and intention for professional hard work in the engineering field.

Methods and Procedures

This study employed STEM project-based learning, with a STEM internet platform (Lou, Tsai & Tseng, 2011) for group member discussion and data uploading. The female students design, produce, and complete cup speakers or Stirling engine. After the group completes project report presentations, questionnaire surveys are used to explore the influence of gender roles and engineer role models of female high school students on STEM self-efficacy and professional commitment to engineering. In the following sections, the components of the study are explained: the research structure and hypotheses, research subjects, research tools, research design and implementations, and data collection and analysis.

Research Structure and Hypotheses

This study used a model that synthesized social learning and social cognitive career theories as its foundation. The theoretical model is shown in Figure 1; the research hypotheses are listed as follows:

H0: There is a good model fit of female gender roles, engineer models, STEM self-efficacy, and professional commitment to the engineering structural model.

H1: The female gender role beliefs of female high school students have a positive effect on female engineer role models.

H2: The female gender role beliefs of female high school students have a positive effect on professional commitment to engineering.

H3: The female engineer role models of female high school students have a positive effect on STEM self-efficacy.

H4: The female engineer role models of female high school students have a positive effect on professional commitment to engineering.

H5: The STEM self-efficacy of female high school students has a positive effect on professional commitment to engineering.

Research Participants

This study employed purposive sampling. A total of 88 female students voluntarily participated in this study, selected from a public girl's high school with a total of 1,236 students in southern Taiwan. Each team consisted of four members, and there were 10 teams for the cup speaker project and 12 for the Stirling engine project.

Research Tools

This study employed social learning theory and social cognitive career theory to develop a cross-theoretical model and the STEM Self-efficacy and Professional Commitment to Engineering Survey Questionnaire (Liu, 2012). After the questionnaire was developed, six scholars and experts in the related fields were invited to determine the content validity of the questionnaire. After some modifications were made, the official questionnaire was completed. A five-point Likert scale was employed in the questionnaire, containing four domains: female gender role beliefs, female engineer role models, STEM self-efficacy, and professional commitment to engineering. After the STEM project activities were completed, 88 questionnaires were distributed; 86 valid questionnaires were returned (97.73% of return rate). Confirmatory factor analysis (CFA) in a structural equation model (SEM) was used to test the reliability and validity of the variables in the questionnaire.

Normative examination of dimensions on the professional commitment to engineering for female high school students shows that the skew values are between -1.24 and .52, while the kurtosis values are between -.83 and .94, and the observed variables conform to the norms for single variables (Kline, 2005; SPSS, 2008). This study uses maximum likelihood as the method of model estimation. CFA shows that the model generally conforms to the fit evaluation indices (Goodness-of-Fit index (GFI) is .90, Normal Fit index (NFI) is .91, Comparative Fit Index (CFI) is .98, Critical N (CN) is 91, Root Mean Square of Approximation (RMSEA) is .06, all of which conform to standards). Additionally, the convergent and discriminant validity of the variables are evaluated (see Tables 1 and 2):

Convergent validity comprised the following: (1) a factor loading between .62 and .90; (2) a square multiple correlation (SMC) between .41 and .82; (3) a composite reliability (CR) between .71 and .89; and (4) an average variance extracted (AVE) between .52 and .73; 2. Discriminant validity is tested with Analysis of Moment Structures (AMOS) providing the estimation method for three types of confidence intervals: (1) bias-corrected percentile method; (2) percentile method estimation; and (3) point estimation value ±2 times standard error ($\varphi \pm 2\sigma$). First, the repetitive sampling number is 1000, and under the confidence level of 95%, if the standardized coefficients do not include 1 in the confidence interval (1 means completely correlated), then these two dimensions have discriminant validity. The variables of this study conform to standards (Chang, 2011). Thus, the professional commitment to engineering questionnaire for female high school students shows that latent dimensions in female gender role beliefs, female engineer role models, STEM self-efficacy, and professional commitment to engineering all exhibit convergent and discriminant validity.

Table 1 Confirmatory factor analysis of dimensions in the professional commitment to engineering of female high school students

Name of latent variable	Code for observed variable	Factor loading λ value	SMC	CR	AVE
Female gender role beliefs	Women's self- development (g1234)	.89	.80	.86	.75
	Gender equality (g5678)	.84	.70		
Female engineer role model	Attitude emotions dimension (f1234)	.89	.79	.86	.76
	Behaviour and cognition dimension (f567)	.85	.72		
STEM Self-efficacy	Science self-efficacy (S)	.82	.67	.81	.51
	Technology self-efficacy (T)	.70	.49		
	Engineering self-efficacy (E)	.62	.38		
	Mathematics self-efficacy (M)	.71	.50		
Professional commitment to engineering	Professional value identification (d1to6)	.74	.55	.88	.72
	Intention for professional career involvement (D712)	.90	.81		
	Intention for professional hard work in the engineering field (D1318)	.89	.79		

Research Design and Data Collection Procedures

The project implementation in this study uses the cup speakers and Stirling engine, in which group members are interested, as the guiding projects of the research. The research design accommodates the principles and characteristics of STEM project-based learning, carrying out three stages of activity during the winter vacation from school, as shown in Table 3. After students complete their projects, questionnaire surveys are used to collect data for this study.

Table 2 Estimation of confidence intervals for coefficients in professional commitment to engineering questionnaire for female high school students

Parameter		Relevant estimation values	φ±2σ		Bias-corrected		Percentile method	
			Lower	Upper	Lower	Upper	Lower	Upper
Engineer model	<--> Self-efficacy	.68	.53	.83	.51	.81	.51	.81
Engineer model	<–> Professional commitment	.85	.73	.97	.69	.94	.71	.96
Engineer model	<–> Gender roles	.41	.18	.63	.22	.64	.17	.61
Self-efficacy	<--> Professional commitment	.76	.64	.87	.63	.86	.63	.86
Self-efficacy	<--> Gender roles	.24	.00	.48	.01	.48	-.02	.45
Professional commitment	<–> Gender roles	.48	.28	.68	.28	.67	.26	.65

Data Analysis

After the projects were completed, the results of the survey questionnaires were analysed by SEM of the AMOS 17 version statistical software. The CFA was first used to test whether the observed variables can effectively reflect their latent variables, including testing for convergent and discriminant validity. Next, the structural models and research hypotheses are tested; finally, path effect analysis is conducted, and the explanatory power of the overall model is analysed.

Table 3 Project implementation plans for cup speakers and Stirling engines

Project learning stages and tasks	Cup speakers STEM project	Stirling engine STEM project
Preparation stage: Develop STEM project activity design Construct STEM internet platform system Hold STEM project-based learning information meeting	Week 1 Confirm cup speakers (Chuang, 2009) project Hold STEM project information meeting Accept sign-up applications from student teams	Week 1 Confirm Stirling engine (Chou, 2008) project Hold STEM project information meeting Accept sign-up applications from student teams
Implementation and presentation stage: Team members arrange to divide work, establish plans according to the tasks, collect data for experimentation, discover problems, discuss problems, analyse and verify, and upload the work	Week 2: Task A voice coil Week 3: Task B drivers Week 4: Task C sound box Week 5: Task D microphone	Week 2: Task A principles of internal-combustion engines Week 3: Task B transmission and revolution Week 4: Task C high-speed challenge Week 5: Task D application of image design, Task E revolution speed and speed per hour
Evaluation and modification stage: Results display and presentation, testing of product efficacy, self-evaluation of peers	Week 6: Hold cup speakers creative design achievement presentations Conduct questionnaire survey	Week 6: Hold Stirling engine creative design achievement presentations Conduct questionnaire survey

Results and Discussion

Verification of the model fit evaluation and research hypotheses

First, fit evaluation was carried out for the professional commitment to engineering model of female high school students. Because there are fewer samples in the model indices, the CN value is 93. Although it does not conform to the general standard of a CN value greater than 200, Chang (2011) proposes that if the CN value is lower than 75, then the model is unacceptable; thus, the value of our model is still in an acceptable range. The remaining three types, including absolute, relative, and parsimonious indices, all conform to evaluation indices (GFI =.90, RMSEA =.06, χ^2/df =1.29, NFI =.91, Non Normal Fit Index (NNFI) =.97, CFI=.98, Parsimoney Goodness-of-Fit Index (PGFI) =.53, Parsimoney-adjusted Comparative Fit Index (PCFI) =.69, and Parsimoney-adjusted Normal Fit Index (PNFI) =.65, which all measure up to standards), indicating that the resulting model is a fit model and can thus explain gender roles, engineer models, self-efficacy, and professional commitment to engineering through sample data analysis. Hypothesis 0, that there is a structural model fit involving female gender roles, engineer models, STEM self-efficacy, and professional commitment to engineering, is thus established.

Additionally, in confirming Hypotheses 1 to 5 in the research model, the path value is the standardized coefficient, with the following path coefficients: female gender role beliefs→female engineer role model (.42*); female gender role beliefs→ professional commitment to engineering (.17*); female engineer role model→STEM self-efficacy (.68*); female engineer role model→professional commitment to engineering (.54*); and STEM self-efficacy→professional commitment to engineering (.35*). The above-mentioned paths have reached the level of significance; thus, Hypotheses 1 to 5 are confirmed (Figure 2), indicating that enhancing the female high school students' gender role beliefs and providing a female engineer role model can improve their STEM self-efficacy, which then influences their professional commitment to engineering.

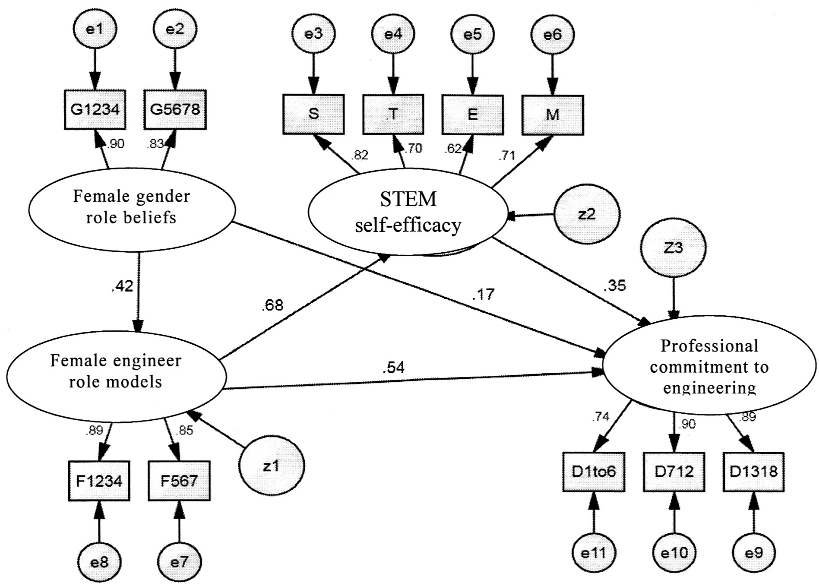

Figure 2 The professional commitment to engineering structural model for female high school students

Path effect analysis

The results of variable analysis show that the female engineer role model is only directly affected by female gender role beliefs (.42); the female engineer role model has the greatest direct influence on STEM self-efficacy (.68); the indirect effect of female gender role beliefs is smaller (.29); professional commitment to engineering is directly and significantly affected by female gender role beliefs, female engineer role model, and STEM self-efficacy and is indirectly and significantly affected through STEM self-efficacy by female gender role beliefs and female engineer role model. Female engineer role model has the most significant influence (.78), followed by female gender role beliefs (.50), and STEM self-efficacy (.35) (Table 4). These results show that having a female engineer role model strongly influences STEM self-efficacy and professional commitment to engineering.

In addition, according to the structural model of female high school students' professional commitment to engineering (Figure 2), the latent variables' variance explanatory power (R^2) for the model show that the explanatory power of female gender role beliefs, female engineer role models, and STEM self-efficacy for professional commitment to engineering is as high as 81%, and the explanatory power of female engineer role models and female gender role beliefs for STEM self-efficacy is 46%. Thus, the empirical data show that the latent variables have good explanatory power for the overall model, indicating that the cross-theoretical model in this study can use female gender role beliefs and female engineer role models to predict STEM self-efficacy and professional commitment to engineering among female high school students.

Discussion

The results of the study confirmed that the female high school students' gender role beliefs, female engineer role models, and STEM self-efficacy are all factors that affect professional commitment to engineering. These findings are similar to some prior studies concerning gender role beliefs influencing professional commitment (Mao et al., 2008; Chen & Sun, 2006; Astin, 1984; Edwards & Spence, 1987), role models and good teacher examples influencing career ambitions (Wu, 2009; Kerr & Nicpon, 2003), and self-efficacy influencing personal choices of profession in the future (Peng & Chang, 2010). As for variables influencing the STEM self-efficacy of female high school students, female engineer role models have the greatest influence; this also agrees with the views of many scholars (Yang, 2007; Chien & Lien, 2009; Bandura, 1977b). When female students observe or learn from the successful examples of female engineer role models, their self-efficacy can be motivated and enhanced. Additionally, female engineer role models can be affected by the beliefs about female gender roles. According to the social cognitive theory perspective, female gender role beliefs and female engineer role models both act through the observational learning process; thus, women's gender role beliefs would affect their learning and acceptance of female engineer role models.

In summary, when female high school students identify women's self-development and gender equality perspectives, they tend to be more easily affected by female engineer role models. The students' enthusiasm or confidence in learning engineering or in the engineering field can enhance their science, technology, engineering, and mathematics ability determinations through learning and modeling behaviour. The increased self-efficacy further influences the selection intention in the engineering profession.

Table 4 Effect values among latent variables in the professional commitment to engineering model for female high school students

		Female engineer role model	STEM self-efficacy	Professional commitment to engineering
Female gender role beliefs	Direct effect	.42	--	.17
	Indirect effect	--	.29	.33
	Overall effect	.42	.29	.50
Female Engineer role model	Direct effect	--	.68	.54
	Indirect effect	--	--	.24
	Overall effect	--	.68	.78
STEM self-efficacy	Direct effect	--	--	.35

Conclusion and Suggestions

Conclusion

This study employed Stirling engine and cup speaker projects in STEM project-based learning, using social cognitive theory and SCCT as the foundation for developing a model through SEM verification. We found that female high school students' STEM self-efficacy and professional commitment to engineering is influenced most strongly by female engineer role models, followed by female gender role beliefs. For the girls who participated in the STEM projects, observing or learning from the successful examples of female engineer role models gave them the experience of vicarious learning, further devoting themselves to STEM projects and improving their evaluations of their own abilities in STEM. Meanwhile, the results enhance the female high school students' evaluation of the engineering field, as students can develop enthusiasm and confidence in studying engineering as a result of having female engineer role models. The elevation of personal STEM ability would further affect their selection intentions in the profession of engineering. In addition, when female high school students identify with the perspectives of women's self-development and gender equality, they would be less constrained by traditional female roles and would show greater self-confidence in the engineering field. Gradually, the students would have more interest in and enthusiasm for learning about engineering or working in the field. Thus, for female high school students, an expansion of female gender role beliefs and an increase in female engineer role models would enhance personal STEM self-efficacy and would further affect their selection intention for the engineering profession. In other words, in the model of professional commitment to engineering among female high school students, the variables in female gender role beliefs, female engineer models, and STEM self-efficacy have good explanatory power. The cross-theoretical model developed in this study can indeed use female gender role beliefs and female engineer role models to predict STEM self-efficacy and professional commitment to engineering among female students.

Suggestions

The professional commitment to engineering model for female high school students shows that STEM self-efficacy is an important factor that would affect girls' intentions in choosing the engineering profession. After female students undergo STEM project-based learning, their abilities in STEM increased. Therefore, promotion of STEM project-based learning is very important. This study suggests that STEM project-based learning should be promoted so that students can use group collaboration in order to achieve learning tasks in STEM. Methods of investigation, experimentation, deduction, assembly, manufacturing, testing, and improvement should all be used to cultivate STEM knowledge and capabilities in students. They should also gain diverse abilities in team work, communication and coordination, internet usage, and report-writing, which can connect to higher levels of learning activities.

Further, the model in this study shows that female engineer role models in the proximity of female students can enhance their enthusiasm and confidence in the engineering field, in turn elevating their STEM self-efficacy and professional commitment to engineering. Currently, the field of engineering is deficient in female participation. It is necessary to effectively integrate female engineer role models into STEM project-based learning for female students. It is suggested that the project platform can include media reports and videos about female engineer role models; students should read their biographies, and teachers should arrange for interviews with female engineer role models relevant to projects or collaborate with local research institutions to invite more female scholars to participate in STEM project activities. Such actions would create positive interaction with female students so that female students can accumulate successful experiences from models, which should enhance their self-efficacy in STEM, effectively inspiring their future involvement in the professional field of engineering.

Due to time constraints, this study was unable to obtain large-scale random samples. It is suggested that in the future there should be STEM project-based courses designed for wide promotion to various schools, which would allow for the collection of data from large samples. Different groups of students should undergo group comparisons so that their differences can be understood. It would also be possible to use case interviews or focus group interviews to explore the formation factors and to use qualitative research methods to analyse and summarise the results to provide a reference for future studies relating to STEM.

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