Engineer education and attitudes toward mathematics: a comparative study

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ABSTRACT

Research addressed the importance of high ability in mathematics at the secondary school for the well preparation of engineering profession. However, factors like self-confidence in mathematics learning (SCM), values on mathematics (SVM), and positive attitudes toward mathematics (PATM) received less attention. This paper utilized TIMSS 2007 data to conduct a global comparative analysis on factors influencing mathematics performance at varied International Benchmark levels. TIMSS report showed that remarkable percentages of Asian students (Chinese Taipei, Korea and Singapore) reached Advanced International Benchmark. However, the report also showed that students from Chinese Taipei and Korea tended to have lower levels of SCM, SVM, and PATM. This paper aimed to provide comparative study on how the eighth-grade students of the top three Asian countries and the United States were allocated at the International Benchmark levels and the three factors at different International Benchmark categories. Results showed that compared with Chinese Taipei and Korea, Singapore students tend to have high level of PATM, SCM and SVM. In Chinese Taipei and Korea, students in categories lower than Advanced International Benchmark tend to have low SCM, SVM and PATM. United States students, although not ranked high in average mathematics achievement, tend to place good values on mathematics, have self-confidence in learning and have positive attitudes toward mathematics.

Keywords*: International Benchmark, Index of Students' Positive Affect Toward Mathematics, Index of Students Valuing Mathematics, Index of Students' Self-Confidence in Learning Mathematics*

INTRODUCTION

Recently, many countries have experienced a decline in the number of graduating engineers as well as a decline in the percentages of freshmen choosing to enter mathematics- and-science related majors (Seymour, 2002; Dawes & Rasmussen, 2007). Researchers also found that undergraduate students arrived with less adequate mathematical ability to do engineering courses and an overall poor preparedness for engineering studies (Reed, n.d.).

Research also indicated that it is important to increase students' perception of engineering as a career path and to have better understanding of the link between engineering and related subjects, especially mathematics, at a younger age (English, Dawes, Hudson, & Byers, 2009). The secondary school has been identified as a crucial period to encourage students' participation, develop positive attitudes toward mathematics and interest in engineering as a profession (Brophy, Klein, Portsmore, & Rogers, 2008; Dawes & Rasmussen, 2007). It is a broad question about how to improve the overall adequacy of middle-school mathematics and engineering education. Both fields require students to have fluent reasoning skills, generalization skills, and the ability to solve complex real-world problems. Engineering and mathematics are interdisciplinary knowledge. For example, a well-designed engineering education presence within the K-12 curriculum provides a rich and authentic base for the learning mathematics concepts (Custer, Daugherty, Meyer, n.d.). Mathematics in terms is helpful for solving a variety of relatively complex engineering situations. Research addressed the importance of high ability in mathematics at the secondary school for the well preparation of engineering profession. The issues including curriculum, educational resource, pedagogy, teacher pre-service, professional development, and learning assessment have been widely discussed. Previous studies also indicated that students' mathematics achievement was related to students' activities and attitudes (Mullis, Martin, Gonzalez, & Chrostowski, 2004). These attitudes have great impact on mathematics learning in terms of an essential on engineering education. However, factors like self-confidence in mathematics learning, values on mathematics, and attitudes toward mathematics received less attention. This paper utilized TIMSS 2007 data to conduct a global comparative analysis on these factors influencing mathematics performance at varied International Benchmark levels. The countries in comparison are Chinese Taipei, Korea, Singapore and United States. The three Asia countries ranked high continuously on international mathematics assessments and the United States experienced a decline in the number of freshmen selecting engineering or engineering-related majors.

TIMSS (Trends in International Mathematics and Science Study) is a global assessment of international student achievement in mathematics and science. It is a project of the International Association for the Evaluation of Educational Achievement (IEA), and is directed by the TIMSS & PIRLS International Study Center. TIMSS is conducted on a 4-year cycle (in 1995, 1999, and 2007 with planning underway of 2011). TIMSS provides trends in mathematics and science

at fourth and eighth grades. It assesses achievement in countries all over the world and collects rich information about the educational contexts, gender performance, students' background, home environment, resource availability, curriculum and instructional approaches, and teacher preparation in math and science. TIMSS 2007 involved more than 60 countries with 425,000 students assessed. Each country sampled approximately 4,000 students in 150 schools (Olson, Martin, & Mullis, 2008) .

TIMSS 2007 data provides international benchmarks that can be used to conduct global comparative studies of students' in mathematics and science at fourth and eighth grades. TIMSS uses four-point scale as international benchmark to describe students' performance on the test items. The Advanced International Benchmark is 625, the High International Benchmark is 550, the Intermediate International Benchmark is 475, and the Low International Benchmark is 400 (Olson, et al., 2008). TIMSS uses scale anchoring to describe students' performance at different International Benchmark levels in terms of the types of item students answered correctly. For example, at eighth grade, students at the Advanced International Benchmark can organize and draw out conclusions from given information, make generalization, and solve non-routine problems. Students at High International Benchmark can apply their understanding and knowledge in a variety of relatively complex situations. While students at Low International Benchmark have some knowledge of whole numbers and decimals, operations and basic graphs (Mullis, Martin, & Foy, 2008, p.69). TIMSS report (Mullis, et al., 2008) showed that remarkable percentages of Asian students (Chinese Taipei, Korea and Singapore, three highest average mathematics achievement at the eighth grade) reached the Advanced International Benchmark, which requires the ability to solve items involving complex topics and making generalization. However, the report also showed that students from Chinese Taipei and Korea tend to have lower levels of self-confidence, value of mathematics, and positive attitudes toward mathematics. Positive attitudes toward mathematics, values placed on mathematics and self-confidence in learning mathematics are important factors associated with higher achievement in mathematics. They are important in interpreting the achievement results. This paper aimed to investigate how the eighth-grade students of the top three Asian countries and the United States are allocated at the International Benchmark levels and the their attitudes toward mathematics. The goal of this study is to provide comparative information about mathematics achievement and attitudes toward mathematics across these four countries for educators to consider the implication in instructional practices and improve learning in mathematics and engineering education. The dataset used to do this analysis is from TIMSS 2007 website: http://timss.bc.edu/TIMSS2007/idb_ug.html.

INTERNATIONAL BENCHMARKS COMPARISON

At eighth grade, the top three countries with average mathematics achievement are Chinese Taipei, Korea, and Singapore (Mullis, Martin, & Foy, 2008). United States is at the ninth place. There was a substantial gap in average mathematics achievement between these three Asia countries and the United States. In the benchmark studies, this result also revealed that these three Asia countries have very high percentages of students reaching or above the Advanced International

Benchmark for mathematics. Table 1 showed that the percentages in Advanced International Benchmark for mathematics at eighth grade of Chinese Taipei, Korea, Singapore and the United States are 45%, 40% and 40% and 6% respectively.

The percentages in Low Benchmark for mathematics at the eighth grade of Chinese Taipei, Korea, Singapore and the United States are 14%, 10%, 12% and 34% respectively. However, Table 2 displayed that the percentages in Low Benchmark for mathematics at the fourth grade for Chinese Taipei, Singapore and United States are 8%, 8% and 25% respectively. These statistics revealed that when students grow older, they became less competent in mathematics. The percentages of Advanced International Benchmark for mathematics at fourth grade of Chinese Taipei, Singapore and United States are 24%, 40% and 10% respectively. This fact showed that students of Chinese Taipei make remarkable progress on mathematics achievement. However, the statistics on Advanced International Benchmark and low International Benchmark at 4^{th} and 8^{th} grades for Chinese Taipei revealed that the percentage of high-level students and low-level students on mathematics both increased. That gives an "M" distribution on average mathematics achievements.

Table 1: Percentages of Three Asia Countries and USA on Advanced and Low International Benchmark at 8^{th} Grade.

Benchmark	Chinese Taipei	Korea	Singapore	United States
Advanced	45%	40%	40%	6%
Low	14%	10%	12%	34%

Note. From *TIMSS 2007 International Mathematics Report: Findings from IEA's Trends in International Mathematics and Science Study at the Fourth and Eighth Grades* (p.71) , by Mullis, I.V.S., Martin, M.O., & Foy, P. (with Olson, J.F., Preuschoff, C., Erberber, E., Arora, A., & Galia, J.), 2008, Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

Table 2: Percentages of Two Asia Countries and USA on Advanced and Low International Benchmark at 4^{th} Grade.

Benchmark	Chinese Taipei	Singapore	United States
Advanced	24%	40%	10%
Low	8%	8%	25%

Note. From T*IMSS 2007 International Mathematics Report: Findings from IEA's Trends in International Mathematics and Science Study at the Fourth and Eighth Grades* (p.70) , by Mullis, I.V.S., Martin, M.O., & Foy, P. (with Olson, J.F., Preuschoff, C., Erberber, E., Arora, A., & Galia, J.), 2008, Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

ATTITUDES INDICES TOWARD MATHEMATICS

In addition to International Benchmark statistics, TIMSS also provides information regarding students' attitudes toward mathematics, which is important in interpreting achievement results.

Despite the high performance on mathematics, Asian students tend to show low scores in their attitudes toward mathematics. TIMSS created three indices to measure students' attitudes toward mathematics: Index of Students' Positive Affect Toward Mathematics (PATM), Index of Students Valuing Mathematics (SVM), and Index of Students' Self-Confidence in Learning Mathematics (SCM) (Foy, & Olson, 2008)

SCM is to investigate how students think about their abilities in mathematics. It was based students' responses on four questions: (1) I usually do well in mathematics, (2) Mathematics is harder for me than for many of my classmates, (3) I am not just good at mathematics, and (4) I learn things quickly in mathematics (Foy, & Olson, 2008). Table 3 displayed the cross tabulation of Index of Self-Confidence Learning Math (SCM) and International Benchmark categories of the 8th grade students of Chinese Taipei, Korea, Singapore and USA. In Chinese Taipei, students at or above Advanced International Benchmark have high percentage at the high level of self-confidence in learning mathematics, while students in other international benchmark categories have very high percentages in the lowest level of SCM. For example, the percentages at lowest level of SCM in the categories of "at or above 400 but below 475", "at or above 475 but below 550" and "at or above 550 but below 625" are 81.6%, 78.6% and 53.5% respectively. These statistics revealed that although Chinese Taipei students ranked first in average international mathematics achievement, most students don't think they have good mathematic learning abilities. There was a negative relation between self-confidence in learning mathematics and mathematics achievement of the 8th grade Chinese Taipei students. The same phenomenon can be found in Korea. However, the situation "High performance with low self-confidence" was completely reversed in the US. Most of the 8th-grade USA students other than those in the "below 400" category showed high or medium self-confidence in learning mathematics. Most USA students are self-confident mathematics learners. For the 8th grade students of Singapore, it can be found that high performance students tend to have high level of self-confidence in learning mathematics. The association between self-confidence in learning mathematics and mathematics achievement for Singapore students is positive.

In addition to self-confidence in learning mathematics, students were also asked if they have motivation in learning mathematics and if they perceived that good mathematics achievement gives advantages in perusing higher education and getting into the society. The Index of Students Valuing Mathematics (SVM) is based on students' responses on four questions: (1) I think learning mathematics will help me in my daily life, (2) I need mathematics to learn other school subjects, (3) I need to do well in mathematics to get into university of my choice, and (4) I need to do well in mathematics to get the job I want (Foy, & Olson, 2008). Table 4 presented the cross tabulation of SVM and International Benchmark categories for the 8th grade students of Chinese Taipei, Korea, Singapore and the US. Most students from Singapore and the United States

generally had high value on mathematics across all categories of International Benchmark. Most Korea students valued mathematics at high or medium levels. The responses on SVM for Chinese Taipei were very diverse. Most students in upper two International Benchmark categories placed high or medium values on mathematics, while most students in "below 400" category were at the low level of the valuing mathematics index (45.5%). It seemed that most low mathematics performance of Chinese Taipei students have given up mathematics and mathematics means less to them.

Educators emphasize the importance of developing positive attitudes in learning. TIMSS created an Index of Students' Positive Affect Toward Mathematics (PATM). PATM is based on the responses of students on three statements: (1) I enjoy learning mathematics, (2) Mathematics and (3) I like mathematics (Foy, & Olson, 2008). For Chinese Taipei, only the students in at or above Advanced International Benchmark had high percentages at the high level of PATM (56.9%). In other International Benchmark categories, most students were at the low level of positive affect toward mathematics. For example, the percentages at lowest level of PATM in the categories of "below 400", "at or above 400 below 475", "at or above 475 below 550" and are 83.7%, 79.1% and 68.9% , respectively. The same conclusion can be found in Korea. Again, these evidences showed that being a well-performed student does not necessarily mean being a happy learner or a confident learner in the mathematics region. In Singapore, most students in the "below 400" category had low PATM, but most students in the other International Benchmark categories were at high levels of PATM. In t he United States, students in the upper International Benchmark categories were at high levels of PATM while students in the lower International Benchmark categories had low level of positive attitudes toward mathematics.

CLOSING REMARKS

Chinese Taipei and Korea, though ranked top two, students in categories below Advanced International Benchmark tend to have low SCM, SVM and PATM. Students felt less able, less confident and possess negative attitudes toward mathematics. In contrast, Singapore students tend to have positive attitudes toward mathematics, place good values on mathematics as a way of improving their future and lives, and have self-confidence in learning mathematics. United States students tend to have self-confidence and positive attitudes toward mathematics.

Table 3: Cross Tabulation of Index of Self-Confidence Learning Math (SCM) and International Benchmark for Chinese Taipei, Korea, Singapore and United States.

	Chinese Taipei				Korea			
	HIGH	MEDIUM	LOW	TOTAL	HIGH	MEDIUM	LOW	TOTAL
below 400	12	44	122	178	2	14	78	94
	6.74 %	24.71%	68.53 %	100%	2.12 %	14.89%	82.97 %	100%
at or above 400 below 475	4	62	292	358	3	52	265	320
	1.11 %	17.31%	81.56 %	100%	0.93 %	16.25%	82.81 %	100%
at or above 475 below 550	19	107	463	589	37	218	539	794
	3.22 %	18.16%	78.60 %	100%	4.65 %	27.45%	67.88 %	100%
at or above 550 below 625	159	304	533	996	223	531	512	1266
	15.96 %	30.52%	53.51 %	100%	17.61 %	41.94%	40.44 %	100%
at or above 625	920	557	427	1904	948	616	195	1759
	48.31 %	29.25%	22.42 %	100%	53.89 %	35.01%	11.08 %	100%
TOTAL	1114	1074	1837	4025	1213	1431	1589	4233
	27.67 %	26.68%	45.63 %	100%	28.65 %	33.80%	37.53 %	100%

	Singapore				United States			
	HIGH	MEDIUM	LOW	Total	HIGH	MEDIUM	LOW	Total
below 400	9	64	63	136	151	229	239	619
	6.62 %	47.06%	46.32 %	100.00 %	24.39 %	37.00%	38.61 %	100.00 %
at or above 400 below 475	51	191	168	410	616	680	582	1878
	12.44 %	46.59%	40.98 %	100.00 %	32.80 %	36.21%	30.99 %	100.00 %
at or above 475 below 550	204	325	342	871	1357	795	457	2609
	23.42 %	37.31%	39.27 %	100.00 %	52.01 %	30.47%	17.52 %	100.00 %
at or above 550 below 625	488	522	425	1435	1369	311	89	1769
	34.01 %	36.38%	29.62 %	100.00 %	77.39 %	17.58%	5.03 %	100.00 %
at or above 625	1090	459	188	1737	360	30	12	402
	62.75 %	26.42%	10.82 %	100.00 %	89.55 %	7.46%	2.99 %	100.00 %

Total	1842	1561	1186	4589	3853	2045	1379	7277
	40.14 %	34.02%	25.84 %	100.00 %	52.95 %	28.10%	18.95 %	100.00 %

Chinese Taipei and Korea have similar cultures. Both countries have strong emphasis on the importance of higher education. Parents/ teachers have high expectation in their children/students achievements. Parents/teachers also ask their children/students have serious attitudes toward learning. Under high academic pressure and expectations, students lack positive attitudes, self-confidence, and do not enjoy learning. American students have positive attitudes and self-confidence in learning. How to improve mathematics education has always been a big issue. It appears that Singapore does well in mathematics education. Singapore students continuously rank high in global assessment, place great value on mathematics and show self-confidence and positive attitudes toward mathematics.

It is crucial that mathematics education in middle-school is sufficient in preparing for engineering fields in college. Mathematical competence plays an important role in engineering profession. A solid foundation in mathematics can give an easier transition to engineering learning. In addition to addressing the importance in new modes of curriculum, pedagogy, and learning assessments, educator and researchers should also investigate students' self-confidence, values and attitudes toward mathematics and engineering. In terms of mathematical learning at middle-school level, students should enjoy their classes in mathematics, consider it is important to perform well in its related subjects, and achieve a good living standard.

Table 4: Cross Tabulation of Index of Students Valuing Mathematics (SVM) and International Benchmark for Chinese Taipei, Korea, Singapore and United States.

	Chinese Taipei				Korea			
	HIGH	MEDIUM	LOW	TOTAL	HIGH	MEDIUM	LOW	TOTAL
below 400	52	45	81	178	35	39	19	93
	29.21%	25.28%	45.51%	100.00%	37.63%	41.94%	20.43%	100.00%
at or above 400 below 475	112	140	106	358	112	148	60	320
	31.28%	39.11%	29.61%	100.00%	35.00%	46.25%	18.75%	100.00%
at or above 475 below 550	193	246	151	590	333	336	125	794
	32.71%	41.69%	25.59%	100.00%	41.94%	42.32%	15.74%	100.00%
at or above 550 below 625	403	417	175	995	624	506	136	1266
	40.50%	41.91%	17.59%	100.00%	49.29%	39.97%	10.74%	100.00%
at or above 625	1042	714	153	1909	1153	523	84	1760
	54.58%	37.40%	8.01%	100.00%	65.51%	29.72%	4.77%	100.00%
TOTAL	1802	1562	666	4030	2257	1552	424	4233
	44.71%	38.76%	16.53%	100.00%	53.32%	36.66%	10.02%	100.00%

	Singapore				United States			
	HIGH	MEDIUM	LOW	TOTAL	HIGH	MEDIUM	LOW	TOTAL
below 400	82	30	22	134	491	85	39	615
	61.19%	22.39%	16.42%	100.00%	79.84%	13.82%	6.34%	100.00%
at or above 400 below 475	282	84	42	408	1538	268	74	1880
	69.12%	20.59%	10.29%	100.00%	81.81%	14.26%	3.94%	100.00%
at or above 475 below 550	664	159	48	871	2108	391	111	2610
	76.23%	18.25%	5.51%	100.00%	80.77%	14.98%	4.25%	100.00%
at or above 550 below 625	1128	256	49	1433	1538	197	36	1771

	78.72 %	17.86%	3.42 %	100.00 %	86.84 %	11.12%	2.03 %	100.00 %
at or above 625	1386	319	34	1739	357	37	8	402
	79.70 %	18.34%	1.96 %	100.00 %	88.81 %	9.20%	1.99 %	100.00 %
TOTAL	3542	848	195	4585	6032	978	268	7278
	77.25 %	18.50%	4.25 %	100.00 %	82.88 %	13.44%	3.68 %	100.00 %

Table 5: Cross Tabulation of Index of Students' Positive Affect Toward Mathematics (PATM) and International Benchmark for Chinese Taipei, Korea, Singapore and United States.

	Chinese Taipei				Korea			
	HIGH	MEDIUM	LOW	TOTAL	HIGH	MEDIUM	LOW	TOTAL
below 400	7	22	149	178	8	18	68	94
	3.93 %	12.36%	83.71 %	100.00 %	8.51 %	19.15%	72.34 %	100.00 %
at or above 400 below 475	21	54	284	359	12	44	265	321
	5.85 %	15.04%	79.11 %	100.00 %	3.74 %	13.71%	82.55 %	100.00 %
at or above 475 below 550	78	105	405	588	107	171	517	795
	13.27 %	17.86%	68.88 %	100.00 %	13.46 %	21.51%	65.03 %	100.00 %
at or above 550 below 625	302	196	498	996	335	356	575	1266
	30.32 %	19.68%	50.00 %	100.00 %	26.46 %	28.12%	45.42 %	100.00 %
at or above 625	1086	365	456	1907	932	374	453	1759
	56.95 %	19.14%	23.91 %	100.00 %	52.98 %	21.26%	25.75 %	100.00 %
TOTAL	1494	742	1792	4028	1394	963	1878	4235
	37.09 %	18.42%	44.49 %	100.00 %	32.92 %	22.74%	44.34 %	100.00 %

	Singapore				United States			
	HIGH	MEDIUM	LOW	TOTAL	HIGH	MEDIUM	LOW	TOTAL
below 400	41	27	68	136	197	147	277	621
	30.15 %	19.85%	50.00 %	100.00 %	31.72 %	23.67%	44.61 %	100.00 %

at or above 400 below 475	144	129	137	410	619	434	825	1878
	35.12 %	31.46%	33.41 %	100.00 %	32.96 %	23.11%	43.93 %	100.00 %
at or above 475 below 550	417	198	256	871	1068	623	920	2611
	47.88 %	22.73%	29.39 %	100.00 %	40.90 %	23.86%	35.24 %	100.00 %
at or above 550 below 625	828	310	296	1434	877	459	433	1769
	57.74 %	21.62%	20.64 %	100.00 %	49.58 %	25.95%	24.48 %	100.00 %
at or above 625	1317	263	158	1738	222	93	86	401
	75.78 %	15.13%	9.09 %	100.00 %	55.36 %	23.19%	21.45 %	100.00 %
TOTAL	2747	927	915	4589	2983	1756	2541	7280
	59.86 %	20.20%	19.94 %	100.00 %	40.98 %	24.12%	34.90 %	100.00 %

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