AC 2010-1652: CORRELATIONS BETWEEN MECHANICAL APTITUDE, PRIOR EXPERIENCES, AND ATTITUDE TOWARD ENGINEERING

Michele Miller, Michigan Technological University

Dr. Michele Miller is an Associate Professor in mechanical engineering. She teaches classes on manufacturing and controls and does disciplinary research on microelectromechanical systems and precision machining. Her educational research interests include problem solving in the lab and informal engineering education.

Anna Pereira, Michigan Technological University

Anna Pereira is a graduate student in mechanical engineering. Her research interests include human factors, ergonomics, and engineering education.

Margot Hutchins, Michigan Technological Universtiy

Margot Hutchins is a Ph.D. candidate in Mechanical Engineering and a Graduate Scholar of the Sustainable Futures Institute. The primary objective of her research is to develop a model that addresses the relationship between decision alternatives and sustainability, especially the societal dimension. Other research interests include life cycle assessment, decision making, and engineering education.

William Helton, Michigan Technological University

Dr. William Helton is an Associate Professor in cognitive and learning sciences. He teaches classes in human factors and educational psychology and does disciplinary research on attention, expertise, and stress. His educational research interests include cognitive load theory, expertise development, and psychometrics.

Leonard Bohmann, Michigan Technological University

Dr. Leonard Bohmann is a faculty member in electrical engineering and presently serves as the Associate Dean of Engineering. His disciplinary research interests are in expanding the use of renewable energy in electric power systems. He has research interests in gender differences and how they relate to engineering education as well as methods to increase the participation of women in engineering.

Chris VanArsdale, Michigan Technological University

Christopher Van Arsdale is a graduate student in mining engineering. His interests include power systems, controls, and mining.

Correlations Between Mechanical Aptitude, Prior Experiences, and Attitude Toward Engineering

Introduction

Most engineering educators would agree that hands-on skills are important for success as an engineer. Two of the ABET criteria[1] address hands-on skills to some extent: ability to design and conduct experiments and interpret data (criteria b); and ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (criteria k). Six of the thirteen laboratory objectives described by Feisel and Rosa[2] address hands-on skills: Instrumentation, Experiment, Data Analysis, Design, Psychomotor, and Sensory Awareness. While the emphasis in the early part of the 20th century was on the practical, it shifted to the theoretical in mid-century because it was believed that scientifically trained engineers would create more revolutionary products[3]. The pendulum has more recently shifted back to the practical with greater emphasis on project-based learning[4]. Even as engineering work becomes increasingly sophisticated, practical ability and intuition about physical phenomenon remain important.

In addition to grade point average, employers pay attention to practical experience. Recruiters routinely ask about hands-on experiences outside of classes during the interview process. There seems to be something transferable about practical hands-on abilities[5]. In other words, even if a new hire won't be operating machine tools in their engineering job, employers seem to believe that the skills a student acquired by working in a machine shop transfer to better ability to tackle engineering problems. Surveys of industry representatives, academics, and students have found that "engineering practice" knowledge and skills and hands-on skills are highly valued by industry[6,7].

Based on surveys of 406 graduates in mechanical and electrical engineering, McIlwee and Robinson[8] conclude that mechanical know-how is more important to success on the job than to success in college (where math skills are especially important). "Whether or not they actually build prototypes or tinker with equipment on the job, they need to be able to present themselves as someone who is capable of doing so". They further identify a "tinkering deficit" that puts women at a disadvantage in the workplace.

Students in engineering have vastly different levels of hands-on ability. Most of this ability seems to be learned outside of school in work and hobby experiences. Lab and project courses provide an opportunity to develop these abilities, but they can fall short in many ways: labs are cookbook and thus do not challenge students to figure out new approaches; labs are often done with partners or teams, and some students do not get hands-on experience; faculty hand off the teaching of labs to graduate students and do not invest a lot of effort in improving them; lab activity is designed to support the learning of theoretical concepts rather than to support the learning of hands-on ability. Given these shortcomings, what type of lab activities would support the learning of hands-on ability? As a first step toward developing such activities, we wish to identify the prior experiences that contribute to hands-on ability.

Data Collection and Analysis

For four semesters, students from a required mechanical engineering sophomore course have been recruited to participate in our study. The students take a sixteen question mechanical aptitude test (MAT) that serves as a measure of hands-on ability. They also complete a 147-question prior experience questionnaire (PEQ) and a 50-question engineering attitude survey (EAS). All participating students signed a consent form releasing their ACT/SAT scores and MTU grade point average (GPA). We have data for 168 students though not all students completed all items. We looked at correlations across all five items (MAT, PEQ, EAS, GPA, and SAT/ACT scores).

Prior Experience and Mechanical Aptitude

The MAT was adapted from mechanical aptitude practice tests[9] that serve as preparation for civil service, military and trade exams. It has questions about gears, pipes, linkages, and other mechanisms. The types of questions suggest that mechanical aptitude encompasses physical intuition and spatial visualization. The PEQ was adapted from an existing Spatial Experience Inventory[10]. Questions relating more specifically to hands-on experiences were added. Questions were also deleted or combined to reduce the time needed to complete the survey. Questions were grouped into several chronological categories: pre-school years experiences (PS), elementary school years experiences (ES), middle school years academic experiences (MS), high school years academic experiences (HS), middle and high school years non-academic experiences (M/HS), post high school academic experiences (postHS). Respondents indicated the extent of their participation on a four-point scale. For most of the questions the scale choices were: never, seldom, occasionally and frequently. For the questions that involved course work, the choices were: no courses, one course, two courses, and more than two courses. One hundred fifty-six students completed both the MAT and the PEQ.

Table 1 shows the prior experiences that correlated most highly and positively with MAT score. The list is limited to the activities that had statistically significant correlation (with $p<0.05$). Some themes are apparent: working with tools, outdoor activities, and instrumental music. Note that the correlation coefficients are quite low which is likely due to the large number of possible prior experiences. In other words, a student comes to engineering school with a wide array of prior experiences, and many different prior experiences contribute to mechanical aptitude. A correlation coefficient near one for one of the prior experiences would mean that all students scoring high on the MAT shared that prior experience, and that all students with that particular prior experience would score high on the MAT. We did not expect to find one or two prior experiences that are absolutely necessary for mechanical aptitude, and thus the seemingly low correlation coefficients make sense. We are relying on the *p* values to indicate significance and not the size of the correlation coefficient.

Table 1: Positive correlations between MAT score and prior experiences with $p<0.05$ ($N=156$)

Activity	Correlation Coefficient, *r*	Significance, *p*
M/HS: used hand tools	0.290	0.0002
M/HS: target shooting	0.284	0.0003
M/HS: canoeing	0.259	0.0011
M/HS: repaired equipment	0.243	0.0023
M/HS: used power tools	0.229	0.0041
HS: woodworking courses	0.223	0.0052
M/HS: repaired bicycles	0.212	0.0079
M/HS: archery	0.208	0.0090
postHS: electronics courses	0.207	0.0103
M/HS: carpentry projects	0.201	0.0118
HS: small engines courses	0.191	0.0167
M/HS: repaired automobiles	0.190	0.0178
M/HS: operate machinery	0.185	0.0242
M/HS: instrumental music	0.172	0.0318
M/HS: marching band	0.170	0.0337
M/HS: hunting	0.167	0.0375
M/HS: knot tying	0.165	0.0393
HS: metalworking courses	0.160	0.0465

Tables 2 and 3 list the prior experiences with the highest positive correlations for male and female students, respectively. The tables have a number of overlapping activities, but there are some differences. For example, the female list (but not the male list) includes post high school classes in manufacturing technology, pneumatics/hydraulics and metalworking. The male list (but not the female list) includes activities related to hunting, engines, and automobiles.

Table 2: Positive correlations between MAT score and prior experiences with $p<0.10$ for male students (N=138)

Activity	**Correlation Coefficient, *r***	**Significance, *p***
M/HS: target shooting	0.268	0.0015
HS: woodworking courses	0.246	0.0037
M/HS: used hand tools	0.237	0.0051
M/HS: canoeing	0.230	0.0068
M/HS: used power tools	0.215	0.0112
post HS: electronics courses	0.204	0.0175
M/HS: archery	0.203	0.0169
M/HS: repaired equipment	0.196	0.021
M/HS: marching band	0.190	0.026
HS: small engines courses	0.168	0.0486
M/HS: knot tying	0.160	0.0602
M/HS: hunting	0.158	0.0654
M/HS: instrumental music	0.155	0.0695
M/HS: sailing	0.154	0.0715
M/HS: carpentry	0.152	0.0744
M/HS: operate machinery	0.147	0.0854
M/HS: repaired automobiles	0.142	0.0959

Table 3: Positive correlations between MAT score and prior experiences with $p<0.10$ for female students (N=18)

Activity	**Correlation Coefficient, *r***	**Significance, *p***
post HS: mfg tech courses	0.750	0.0079
M/HS: camping	0.605	0.0488
HS: physics courses	0.584	0.0592
ES: instrumental music	0.553	0.0172
M/HS: operate machinery	0.525	0.0975
post HS: hydraulics/pneumatics courses	0.461	0.0625
post HS: metalworking	0.451	0.0691
M/HS: read blueprints	0.444	0.065
ES: worked puzzles	0.427	0.0771
M/HS: scouting	0.407	0.0934
MS: construction courses	0.403	0.0969

A number of prior experiences negatively correlate with MAT score. Table 4 summarizes the experiences with the largest negative correlations. A negative correlation probably does not mean that these activities subtract from mechanical aptitude. Rather, it might mean that these activities do not add to mechanical aptitude and the time spent on them reduces the time available for activities that do contribute to mechanical aptitude.

Table 4: Negative correlations between MAT score and prior experiences with $p<0.05$ (N=156)

Activity	Correlation Coefficient, *r*	Significance, *p*
M/HS: newspaper layout	-0.321	0.0000
M/HS: dance choreography	-0.291	0.0002
postHS: interior design	-0.282	0.0004
ES: dance	-0.243	0.0023
M/HS: racquetball	-0.239	0.0027
PS: dance	-0.238	0.0028
M/HS: computer drawing/graphics	-0.219	0.0060
M/HS: gymnastics	-0.217	0.0064
M/HS: tennis	-0.215	0.0071
postHS: construction technology	-0.203	0.0112
ES: played with doll houses	-0.201	0.0121
M/HS: dance	-0.200	0.0121
HS: photography classes	-0.193	0.0183
HS: studio art classes	-0.189	0.0183
M/HS: interior decorating	-0.186	0.0234
M/HS: soccer	-0.181	0.0240

There are many possible "prior experiences," and Table 1 suggests no one or two experiences is vital for developing hands-on ability or mechanical aptitude. We took the analysis a step further to try and identify a *set* of experiences that would develop this ability. As such, we selected 20 items with $|r| > 0.20$. We then performed an exploratory factor analysis with varimax rotation on these items. Based on both intelligibility of the factor solution and criteria regarding the amount of variance accounted for, we determined a reasonable 5-factor solution accounting for 58% of the variance. These 5 factors were (a) prior tool usage (7 items), (b) formal dance training (4 items), (c) outdoors skills (3 items), (d) racket sports (2 items), and (e) post-high school occupational training (4 items).

Table 5 describes the correlations between the five factors and MAT score. We also looked at the correlations for men and women separately. Note that the *p*-value is quite high for the female correlations as there were only 18 students. Overall, tool usage and outdoors skills correlate positively with MAT, and they correlate positively for both women and men. This makes sense and the specific activities may suggest educational activities for improving hands-on ability. Dance training correlates negatively for men and may be irrelevant for women. Racket sports correlate negatively for both women and men. Perhaps the time spent on dance training and racket sports reduces the time available for the things that correlate positively. Finally, post high school occupational training correlates positively for women (albeit with high *p* value) and negatively for men. Perhaps, for men, these courses are remedial: they take a post-high school course in electronics, for example, because they have had few prior experiences in that area.

Table 5: Correlations between primary factors and MAT, for all students (N=156), for females (N=18), and for males (N=138)

Factor	Gender	Correlation Coefficient, *r*	Significance, *p*
Tool usage	all	0.236	0.003
	F	0.158	0.530
	M	0.182	0.033
Dance training	all	-0.305	0.000
	F	0.053	0.834
	M	-0.261	0.002
Outdoors skills	all	0.340	0.000
	F	0.231	0.356
	M	0.317	0.000
Racket sports	all	-0.262	0.001
	F	-0.280	0.261
	M	-0.229	0.007
Post HS occupational training	all	-0.180	0.026
	F	0.191	0.463
	M	-0.181	0.035

In addition, we looked at gender differences for MAT score and the prior experiences that correlate most highly with MAT. As shown in Table 6, male students as a group scored higher than female students. In terms of relevant prior experiences, men have more experiences using hand tools, target shooting, and repairing equipment. Women have more experience with dance, dance choreography, and newspaper layout. These differences in prior experience between male and female students may help to explain the difference in MAT scores.

Table 6: Items of statistically significant difference between men and women (note that the Mann-Whitney values are adjusted for ties)

Activity or Measure		Male	Female	p-value	
MAT	N	149	19	0.0000	t-test
	Mean	73.1%	61.0%		
	Std Dev	13.7%	8.9%		
M/HS: used hand tools	N	138	18	0.0012	Mann-Whitney test
	Median	frequently	occasionally		
M/HS: target shooting	N	138	18	0.0263	Mann-Whitney test
	Median	seldom	never		
M/HS: repaired equipment	N	138	18	0.0018	Mann-Whitney test
	Median	occasionally	never		
PS: dance	N	137	18	0.0000	Mann-Whitney test
	Median	never	seldom		
M/HS: dance choreography	N	138	18	0.0000	Mann-Whitney test
	Median	never	never		
M/HS: newspaper layout	N	138	18	0.0018	Mann-Whitney test
	Median	never	never/seldom		

Other Predictors of Mechanical Aptitude

Besides prior experiences, we investigated other predictors of mechanical aptitude, such as GPA, ACT scores (comprehensive, English, math, reading, and science), SAT scores (verbal, math, writing), and attitude about engineering (as measured with the 50 question Pittsburgh Freshman Engineering Survey[11]). Out of these 59 items, the number with a statistically significant correlation to MAT is small. Table 7 summarizes the results for items with $p<0.05$. All four items make sense. The first and third items might indicate that the MAT questions have some similarity to those addressed in physics classes or on standardized science tests. The second item indicates that students who "enjoy figuring out how things work" have a high mechanical aptitude. The fourth item suggests that student can self-evaluate their mechanically ability with some accuracy. Notably there was not a correlation with grade point average.

Table 7: Items from the attitude survey and college entrance test scores that correlate with MAT score

Attitude Survey Statements or Test Scores	***r***	***p***
Confidence in physics abilities	0.260	0.010
I am studying engineering because I enjoy figuring out how things work	0.251	0.013
ACT science score	0.242	0.008
I consider myself mechanically inclined	0.240	0.018

Prior Experience and Attitude about Engineering

The final way in which we viewed the collected data was to look for prior experiences that correlate highly with a positive attitude about engineering. The attitude survey's 50 questions measure attitude along 13 sub-scales. One of those sub-scales (addressed by 9 of the questions[12]) is "general impressions of engineering." We looked for the prior experiences that correlated positively with this sub-scale. Table 8 lists the prior experiences that correlated most positively with "general impressions of engineering." The majority of these are hands-on activities or design activities.

Table 8: Prior experiences that correlate most positively with a high general impression of engineering

Activity	**r**	**p**
M/HS: repaired equipment	0.261	0.010
M/HS: bicycling	0.231	0.024
M/HS: carpentry	0.226	0.027
postHS: product design courses	0.226	0.028
postHS: CAD courses	0.224	0.030
M/HS: computer drawing and graphics	0.214	0.036
postHS: mechanical drawing/drafting	0.213	0.038
M/HS: camping	0.207	0.043
M/HS: repaired bicycles	0.202	0.049
M/HS: built model cars, planes, …	0.200	0.050

Conclusions

The data collected thus far has given us some insight into where hands-on ability comes from. A mechanical aptitude test was used as the measure for hands-on ability. Activities involving the use of tools or outdoors skills correlated most highly with MAT scores. Male students engaged in these activities more often than female students, which may explain why women as a group scored lower than men on the MAT.

In terms of academic predictors of MAT score, the ACT science score was the only one that correlated to a significant extent. From the attitude survey we learned that students who like figuring out how things work or consider themselves mechanically inclined tend to score better on the MAT.

The dataset also gave us the opportunity to identify prior experiences that might lead to more positive attitudes about engineering. The list of activities with statistically significant correlation was dominated by hands-on and design activities. This type of information may be relevant for attracting more young people to the engineering field.

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