# AC 2010-1691: MEASUREMENT OF HANDS-ON ABILITY

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## Measurement of Hands-On Ability

### Introduction

"Practical ingenuity," according the National Academy of Engineering, is a necessary attribute for the engineer of 2020[1]. Hands-on ability is considered an important characteristic of practical ingenuity[2]. Two of the ABET criteria address hands-on skills: 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)[3]. Employers value hands-on ability and routinely ask recruits about hands-on experiences outside of classes[4]. A "tinkering deficit" has also been identified that puts females at a disadvantage in the workplace[5].

Hands-on ability is a critical component of a successful engineer, but can it be measured? A measure could be useful in several ways. As an assessment measure, it would provide the feedback necessary to improve the teaching of hands-on ability. By observing how students with high and low hands-on ability carry out hands-on tasks, we can identify differences in their strategies, developing a list of attributes that help define hands-on ability. By surveying students of high and low hands-on ability about their prior experiences, we can learn where hands-on ability comes from. By surveying students of varying hands-on ability about their attitude toward engineering, we can learn how hands-on ability and students' views on engineering are related.

This paper describes our efforts to measure hands-on ability and to use that measure to explore relationships with prior experiences and student attitudes and emotions.

### Data Collection

We attempted to devise a hands-on test that measures hands-on ability. Initially, we recruited eight mechanical engineering students and eight electrical engineering students for a pilot study. All students were sophomore level engineers at our institution. We devised both "easy" and "hard" hands-on tasks for the mechanical and electrical engineering students. For the mechanical engineering students, the "hard" task involved the measurement of pressure on a pipe rig used in a fluids lab course, and the "easy" task involved the centering of a cylindrical part on a roundness tester. For the electrical engineers, the "hard" task involved troubleshooting a circuit that was malfunctioning. The "easy" task asked the students to construct a circuit to illuminate a light emitting diode given a power supply and several components. Four students were assigned to each task, with each student only performing one task. Students were videotaped while doing the tasks, and two raters coded each video. The students were given documentation stating a goal of the task and basic instructions to complete the task. Each student performed the task individually on separate occasions. There was a single lab assistant present for each task. One lab instructor supervised all mechanical engineering tasks and another supervised all electrical engineering tasks. For the mechanical engineering task, the lab instructor was the female and for the electrical engineering task the instructor was male. The lab instructor was intentionally preoccupied with work, but stated they were available for questions. Typically, the lab assistant would only become involved if the student asked a question.

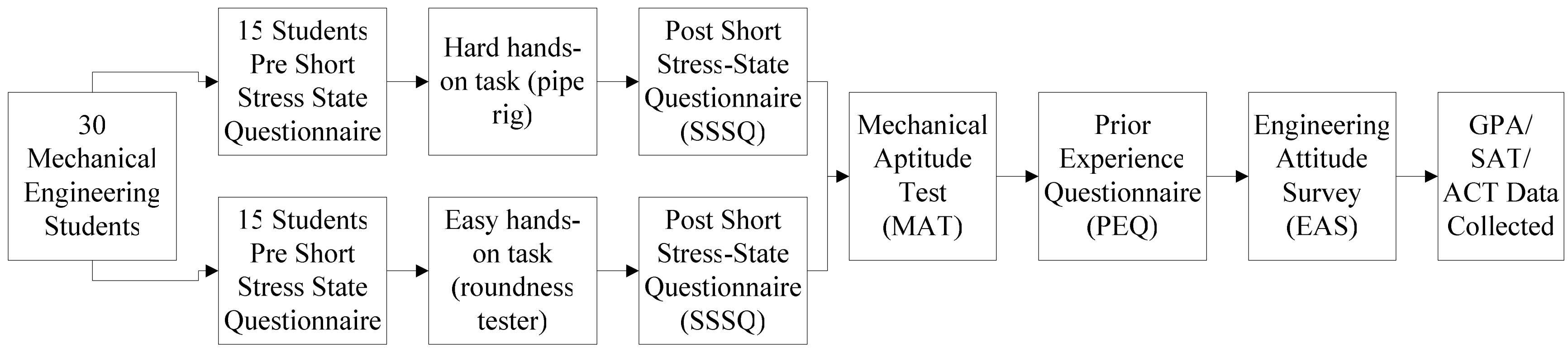


**Figure 1: Mechanical Engineering Study Flow Chart**

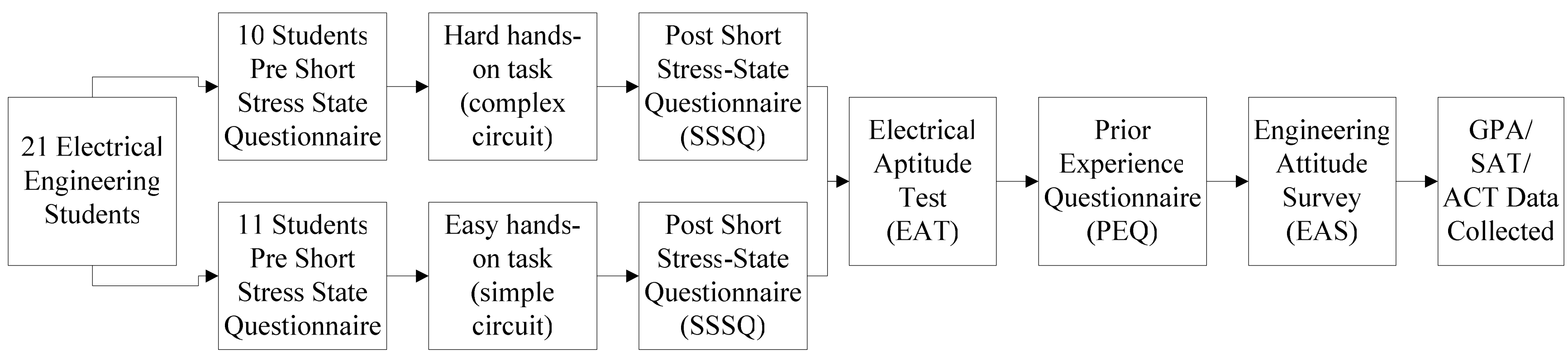


**Figure 2: Electrical Engineering Study Flow Chart**

However, if the student detoured significantly from the lab procedures the lab assistant intervened. The students were not given any preparation before they arrived. At the start of the task the only information given to the student outside the documentation was location of equipment and safety precautions. No orientation to the equipment was provided verbally. Since the tasks were relatively complex, students were randomly selected for hard or easy task. Communication between students was not a large concern because there was a large sample pool. However, lab assistants were observant for signs, both verbal and methodological, of student communication concerning lab solutions.

Based on the pilot study, we modified the two tasks slightly and greatly simplified the video coding procedure. We recruited an additional 30 mechanical engineering and 21 electrical engineering students to take the hands-on tests. In addition to the task, each student completed a short stress-state questionnaire (SSSQ) just before and just after the task which examined engagement, distress, and worry. For each of the SSSQ categories for each student, averages were calculated for pre, post, and change in score[6]. From the pilot study three possible qualities from the videos emerged as measures of hands-on ability: time to complete the task, number and type of questions asked, and a subjective expertise rating ascribed by the raters. Behaviors like use of written directions, dealing with mistakes, and conceptual understanding influenced the expertise rating. In addition to the expertise ratings the raters made a subjective rating of anxiety. We were interested in determining if observable anxiety significantly correlated with other data. Anxiety ratings were determined by noting nervous gestures, vocal cues, and facial cues. Raters coded each video individually and then met to compare scores and come to consensus on final scores. Student questions were classified into three types: confirming, seeking, and instruction. The number of questions of each type were recorded for each student.

At a different time, each student also took a mechanical or electrical aptitude test (MAT[7] or EAT), a prior experience questionnaire (PEQ[8]), and an engineering attitude survey (EAS[9]). With their permission we obtained GPA and ACT scores for each student. A summary of the process is shown in figures one and two. By analyzing correlations in this data and lab task data, we are able to report on the following: 1) the relationship between the paper and pencil aptitude tests and performance on an actual hands-on test; 2) differences in engagement, worry and distress associated with gender, hands-on ability, and task difficulty; 3) the prior experiences that correlated with hands-on ability; 4) correlations between hands-on ability and attitude toward engineering.

**Mechanical Engineering Video Results Discussion**

During fall of 2009, 30 mechanical engineering completed hard and easy hands-on tasks. The easy task involved centering a cylinder on a roundness tester in preparation for making a measurement. For the hard task students manipulated a water flow path in a pipe rig. They used pressure transducers to observe pressure drops throughout the rig. The students were videotaped while doing the task, and various aspects of the videos were coded and analyzed. Each student received a one through four score for anxiety and expertise according to the definitions shown below in Table 1. Seeking questions were defined as questions in which the student sought assistance with the lab. Anxious movements included repeated movement such as adjusting their glasses repeatedly.

**Table 1: Scoring rubric for expertise and anxiety**

| **Expertise Score** | **Definition** |
|---|---|
| 4 | Primarily self-sufficient, demonstrated high levels of understanding, no major mistakes, one or two seeking questions, and completed the task below average time |
| 3 | Relatively self-sufficient, demonstrated understanding of the task, few mistakes, and few seeking questions |
| 2 | Slightly self-sufficient, demonstrated some understanding of the task, asked multiple seeking questions |
| 1 | Not self-sufficient, did not demonstrate understanding of the task, asked seeking questions frequently |
| **Anxiety Score** | **Definition** |
| 4 | No more than one or two anxious movements, no anxious statements |
| 3 | Few anxious movements and/or anxious statements |
| 2 | Multiple anxious movements and/or anxious statements |
| 1 | Frequent anxious movements and/or anxious statements |

Table 2 summarizes key information for each student. The video ratings represent the final consensus score for the two raters. The expertise and anxiety ratings were rated on a skill of one to four. An expertise score of one was assigned to students who had to ask questions for a majority of the procedures, did not learn from previous steps, and made multiple significant mistakes. The MAT score is percent correct for the sixteen question aptitude test. The SSSQ scores used a 1-5 rubric with 1 not at all representing students' feelings and thoughts and 5 extremely representing students' feelings and thoughts. The final column shows the number of questions asked of each type (confirming, seeking, and instructional).

**Table 2(a): Mechanical engineering student summaries for easy test**

| | | Video Ratings | | MAT | SSSQ Post Avgs | | | Q's | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Time*** | **M/F** | **Exp** | **Anx** | **(%)** | **Engage** | **Stress** | **Worry** | **C** | **S** | **I** |
| 14:06 | M | 4 | 3 | 88 | 3.13 | 4 | 3.25 | 0 | 0 | 0 |
| 17:00 | M | 3 | 2 | 88 | 4.13 | 1 | 2.25 | 0 | 0 | 1 |
| 22:40 | F | 1 | 2 | 63 | 2.75 | 1.5 | 1.875 | 0 | 0 | 0 |
| 22:40 | M | 4 | 1 | 94 | 4.13 | 1.5 | 1.5 | 1 | 0 | 4 |
| 24:50 | F | 3 | 1 | 69 | 3.75 | 1.75 | 2.5 | 0 | 0 | 2 |
| 27:40 | M | 2 | 2 | 75 | 2.88 | 1.25 | 2.63 | 0 | 1 | 1 |
| 29:30 | M | 1 | 2 | 38 | 4 | 1.38 | 1 | 0 | 0 | 0 |
| 30:00 | M | 2 | 2 | 94 | 4.13 | 1.38 | 2.13 | 0 | 1 | 1 |
| 31:50 | M | 2 | 3 | 88 | 2.63 | 2.13 | 3 | 0 | 1 | 1 |
| 34:39 | M | 2 | 3 | 88 | 2.88 | 1.38 | 1.88 | 0 | 0 | 1 |
| 35:58 | M | 3 | 1 | 63 | 4 | 1.5 | 1.88 | 0 | 0 | 0 |
| 36:48 | M | 3 | 3 | 81 | 4.63 | 1.5 | 1.88 | 0 | 0 | 1 |
| 39:25 | M | 1 | 3 | 69 | 3.13 | 1.13 | 2.88 | 0 | 3 | 2 |
| 40:58 | M | 2 | 3 | 69 | 3.13 | 3 | 3.125 | 0 | 1 | 1 |
| 42:30 | F | 2 | 2 | | 3.25 | 2 | 1.13 | 0 | 0 | 1 |
| Averages | | | | | | | | | | |
| 30:02 | 15M 4F | 2.33 | 2.20 | 76.2 | 3.50 | 1.76 | 2.19 | 0.07 | 0.47 | 1.07 |

*Time = min:sec

#C = confirming, S = seeking, I = instructional

**Table 2(b): Mechanical engineering student summaries for hard test**

| | | Video Ratings | | MAT | SSSQ Post Avgs | | | Q's | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Time* | M/F | Exp | Anx | (%) | Engage | Stress | Worry | C | S | I |
| 23:07 | M | 3 | 2 | 81 | 4.63 | 1.63 | 2.75 | 0 | 1 | 0 |
| 26:03 | M | 1 | 3 | 88 | 4 | 1.63 | 1.75 | 0 | 11 | 2 |
| 28:28 | M | 4 | 1 | 50 | 5 | 2 | 3.5 | 1 | 2 | 4 |
| 28:55 | M | 3 | 2 | 69 | 4.5 | 1 | 2.5 | 1 | 9 | 0 |
| 31:50 | F | 2 | 3 | 50 | 3.13 | 2 | 2.13 | 0 | 17 | 1 |
| 32:20 | M | 2 | 3 | 94 | 3.63 | 1 | 1 | 2 | 2 | 2 |
| 33:22 | M | 2 | 2 | 63 | 2.83 | | 4 | 0 | 8 | 1 |
| 34:40 | F | 3 | 2 | 75 | 2.88 | 1.63 | 2.5 | 0 | 10 | 1 |
| 36:42 | M | 1 | 2 | 69 | 4.38 | 1 | 2.25 | 2 | 14 | 5 |
| 37:20 | M | 1 | 3 | 81 | 3.5 | 1.13 | 1.38 | 2 | 23 | 2 |
| 39:54 | M | 1 | 3 | 75 | 3.88 | 1.25 | 1.75 | 0 | 11 | 2 |
| 41:36 | M | 1 | 3 | 44 | 3.13 | 1.38 | 1.5 | 0 | 15 | 0 |
| 42:08 | M | 1 | 3 | 56 | 2.25 | 1.25 | 3 | 1 | 29 | 4 |
| 44:53 | M | 1 | 1 | 56 | 3.63 | 1.75 | 1.75 | 2 | 2 | 2 |
| 45:00 | F | 1 | 3 | 56 | 4.38 | 1 | 2.38 | 1 | 6 | 1 |
| Averages | | | | | | | | | | |
| 35:05 | 15M 3F | 1.80 | 2.40 | 67.1 | 3.78 | 1.40 | 2.28 | 0.8 | 10.7 | 1.8 |

We first assessed whether there was statistical difference between the hard and easy tasks in terms of the expertise and anxiety ratings. The average expertise ratings were 2.33 and 1.80 for the easy and hard tests, respectively. However, a Mann-Whitney test revealed no statistically significant difference. The Mann-Whitney test was used instead of a t-test because the data is not believed to be normal. There was also no significant difference in anxiety rating for the hard and easy tasks.

The MAT paper and pencil aptitude was compared to the lab expertise rating. First, the MAT scores were tested and found to be normally distributed using the Anderson-Darling test. Also, a t-test showed no significant difference between MAT scores for students that performed hard lab tasks compared to easy lab tasks. There was a positive correlation between MAT and expertise rating using a significance level of $\alpha = 0.1$. For the easy task, the correlation coefficient was 0.556, with a $p$-value of 0.039. For the hard task, the correlation coefficient was 0.007 with a $p$-value of 0.982. A larger sample size is needed to make a stronger conclusion about the ability of the MAT to describe hands-on ability. There was no significant correlation between task completion time and MAT score.

The SSSQ categories were used to study the interrelationships among of gender, hands-on ability, task difficulty, engagement, worry, and distress. To determine if there was a difference between male and female students, with respect to the engagement, stress, and worry, SSSQ post scores and Mann-Whitney Test was used. There did not appear to be a difference in SSSQ post scores for engagement, stress, and worry for the male students compared to the female students. However, only six females completed the lab tasks, which is a small sample size, and conclusions should be considered cautiously. There does not appear to be a relationship between anxiety score and SSSQ post score for engagement, distress, and worry. This would imply that the anxiety score does not reflect stress or worry as assessed by the SSSQ as was expected. There appears to be a significant ($p < 0.05$) relationship between the expertise score and the SSSQ distress score. The relationship is positive, indicating that an increase in distress is correlated with an increase in expertise score (a surprising result). There does not appear to be a relationship between expertise score and change in SSSQ score for engagement and worry. It should be noted that the hard and easy tasks were not analyzed separately.

The number of questions each student asked were totaled. Using the totals, the Mann-Whitney Test did not show a significant difference in the number of questions males asked compared to the number of questions that females asked. Once again, it should be noted that there are only six females in the sample.

Two repeated measures analysis of variance (ANOVAs) were performed on the change in state of the SSSQ. The first ANOVA examined the change in scores. By creating a confidence interval, a significant scale for engagement, distress, and worry by hard and easy test interaction was established. Table 3 shows the results.

**Table 3: Scale of engagement, distress, and worry by hard or easy test interaction**

| Test | Scale | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound |
| Easy Test | Engage | -.158 | .182 | -.531 | .215 |
| | Distress | .558 | .128 | .296 | .821 |
| | Worry | -.083 | .148 | -.386 | .219 |
| Hard Test | Engage | .223 | .188 | -.163 | .609 |
| | Distress | -.013 | .132 | -.284 | .259 |
| | Worry | -.116 | .153 | -.429 | .197 |

By examining the confidence intervals it is apparent that distress went down in the hard test slightly and up in the easy. The other traits, worry and engagement, are different but not significantly so. A possible explanation for the results is that the students found the easy task boring. The students dropped in engagement in the easy task but went up in the hard, although not significantly. This trend suggests the easy task was boring (unengaging) and that the distress going up in the easy task might reflect an unengaging task.

The second ANOVA was performed on the pre-SSSQ scales and is summarized below in Table 4. The purpose of the second ANOVA is to determine if there is significant difference between the two test groups initially (on the pre-SSSQ). The table shows there is no significant difference between the two groups initially. Calculated F values are relatively small; therefore the null hypothesis that the two groups derive from the same population cannot be rejected.

**Table 4: ANOVA test of initial groups**

| Source of Variation | | Type III Sum of Squares | df | Mean Square | F | P. |
|---|---|---|---|---|---|---|
| Between treatments | Sphericity Assumed | .460 | 2 | .230 | .838 | .438 |
| | Greenhouse-Geisser | .460 | 1.918 | .240 | .838 | .434 |
| | Huynh-Feldt | .460 | 2.000 | .230 | .838 | .438 |
| | Lower-bound | .460 | 1.000 | .460 | .838 | .368 |

To discover traits that are linked to students' hands-on ability, the expertise rating was correlated with attitude toward engineering and prior experiences. The data was obtained from the two surveys, EAS and PEQ, respectively. The EAS survey asked students to rate their agreement with 50 statements on a one to four Likert scale, one being strongly disagree and four being strongly agree. The PEQ survey required the students to report their level of participation in 147 different activities, on a one to four scale, with one being never and four frequently. ACT math, ACT composite score, and GPA were also examined. The results can be seen below in Table 5. For the PEQ questions and EAS questions a cut off $p$-value of 0.05 was used. The influence of GPA, gender, difficulty of task, MAT score was not considered in the analysis.

**Table 5: Expertise score of combined tasks correlated to PEQ, EAS, ACT, and GPA**

| Question Topic | Source | Correlation | *p*-value |
|---|---|---|---|
| Formal post-high school education: hydraulics/pneumatics | PEQ | 0.505 | 0.005 |
| Formal high school education: construction | PEQ | 0.482 | 0.008 |
| Formal post-high school education: electronics | PEQ | 0.465 | 0.011 |
| Formal junior high school education: construction | PEQ | 0.467 | 0.011 |
| Formal post-high school education: construction tech | PEQ | 0.449 | 0.015 |
| Formal post-high school education: woodworking/wood tech | PEQ | 0.439 | 0.017 |
| I am studying engineering because it will provide me with a lot of money. | EAS | 0.429 | 0.02 |
| Pre-school years activities: attended pre-school | PEQ | -0.425 | 0.022 |
| High school sports: tennis | PEQ | -0.413 | 0.026 |
| Formal high school education: woodworking | PEQ | 0.411 | 0.027 |
| Studying in a group is better than studying by myself. | EAS | -0.387 | 0.038 |
| High school non-academic experiences: plumbing | PEQ | 0.379 | 0.042 |
| I will have no problem finding a job when I have obtained an engineering degree. | EAS | -0.377 | 0.044 |
| Formal post-high school education: photography | PEQ | 0.370 | 0.048 |

The PEQ had 11 significant questions and the EAS had three significant questions. The highest correlation, formal post-high school education of hydraulics/pneumatics is most likely attributed to the hard test being comprised of a pipe rig that students had to manipulate to run an experiment. Formal post-elementary coursework in construction and electronics accounted for the majority of the stronger correlations with hands-on ability,, which were all positive. Significant negative correlations included attending pre-school, preference for group study, and confidence in finding a job. ACT math, ACT composite and GPA were not significant correlations, with *p*-values of 0.689, 0.848, and 0.836 respectively.

**Electrical Engineering Video Results Discussion**

Twenty one electrical engineering students, 17 males and 4 females, also performed hard and easy lab tasks. The easy task asked students to construct a circuit to illuminate a light emitting diode given a power supply voltage, and several components. The hard task involved troubleshooting a relatively complex circuit that was malfunctioning. The same correlations and significances were examined as those examined for the mechanical engineering students. Below in Table 6 are the student summaries for electrical engineering. The video ratings reported are the final consensus ratings. The SSSQ results reflect the post average responses to each category. The final column represents the quantity and type of questions asked by confirming, seeking, and instructional question type.

**Table 6(a): Electrical engineering student summaries for easy test**

| | | Video Ratings | | | SSSQ Post Avgs | | | Q's | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Time** | **M/F** | **Exp** | **Anx** | **EAT** | **Engage** | **Stress** | **Worry** | **C** | S | I |
| 0:00 | M | 3 | 3 | 63 | 3.83 | | 2.63 | 0 | 1 | 2 |
| 0:00 | M | 2 | 3 | 89 | 2.75 | 1.13 | 1 | 0 | 2 | 2 |
| 1:51 | F | 4 | 1 | 63 | 3.63 | 1 | 2.75 | 0 | 0 | 0 |
| 1:54 | F | 3 | 1 | 89 | 4.88 | 1.63 | 2.88 | 0 | 0 | 0 |
| 3:18 | M | 3 | 2 | 95 | 4 | 1.13 | 2.75 | 0 | 0 | 0 |
| 5:17 | M | 3 | 1 | 74 | 3.5 | 1 | 2.13 | 0 | 0 | 0 |
| 5:17 | M | 3 | 1 | 79 | 4.63 | 1 | 1.25 | 0 | 0 | 0 |
| 14:00 | M | 3 | 1 | 1 | 4.13 | 1.25 | 1 | 2 | 0 | 0 |
| 18:00 | M | 2 | 2 | 79 | 4.25 | 1 | 1.25 | 0 | 0 | 0 |
| 19:00 | M | 2 | 2 | 84 | 3.25 | 1.88 | 1.88 | 0 | 1 | 2 |
| 24:00 | M | 0 | 0 | 58 | 3.88 | 1 | 3.25 | 0 | 2 | 0 |
| Averages | | | | | | | | | | |
| 8:25 | 9M 2F | 2.55 | 1.55 | 70.4 | 3.88 | 1.20 | 2.07 | 0.2 | 0.5 | 0.5 |

**Table 6(b): Electrical engineering student summaries for hard test**

| | | Video Ratings | | | SSSQ Post Avgs | | | Q's | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Time** | **M/F** | **Exp** | **Anx** | **EAT** | **Engage** | **Stress** | **Worry** | **C** | **S** | **I** |
| 1:00 | M | 4 | 1 | 95 | 4.75 | 1.13 | 2 | 0 | 0 | 0 |
| 6:00 | M | 4 | 1 | 74 | 5 | 1 | 2.88 | 0 | 0 | 0 |
| 7:30 | M | 4 | 1 | 95 | 4.75 | 1 | 2.13 | 0 | 0 | 0 |
| 13:00 | F | 4 | 2 | 90 | 3.88 | 1 | 1.63 | 2 | 0 | 1 |
| 14:36 | M | 3 | 2 | 95 | 4.13 | 2 | 2.5 | 0 | 0 | 0 |
| 17:00 | F | 3 | 3 | 79 | 3.88 | 1 | 1.75 | 0 | 0 | 0 |
| 21:00 | M | 3 | 3 | 68 | 2.75 | 2.13 | 3.5 | 0 | 1 | 3 |
| 29:00 | M | 3 | 2 | 84 | 3.63 | 1 | 2.25 | 0 | 0 | 0 |
| 57:00 | M | 3 | 2 | 79 | 3.13 | 1.25 | 1.38 | 0 | 0 | 0 |
| 73:00 | M | 2 | 3 | 68 | 3.5 | 2.13 | 1.88 | 0 | 0 | 1 |
| Averages | | | | | | | | | | |
| 23:55 | 8M 2F | 3.30 | 2.00 | 82.7 | 3.94 | 1.36 | 2.19 | 0.2 | 0.1 | 0.5 |

A Mann-Whitney Test examined the possible difference between expertise and anxiety scores for students that performed the hard vs. easy tasks. The data was not believed to be normally distributed. This test revealed no statistically significant differences. However, students that performed the easy task on average received an expertise rating of 3.30 while students that performed the hard task on average received a 2.55 expertise rating. There was no difference in anxiety scores students received based on task difficulty.

The EAT and electrical engineering practicum was compared to expertise rating. The EAT scores were found to be normally distributed using the Anderson-Darling test. A t-test shows no significant difference between EAT scores for students that performed hard lab tasks compared to easy lab tasks. There was no significant relationship between EAT and expertise score for the hard or easy task. There was no significant correlation between lab completion time and EAT score. Finally, there was no significant correlation of lab practicum to expertise score.

The SSSQ categories were used to study the interrelationships among gender, hands-on ability, task difficulty, engagement, worry, and distress. Based on a Mann-Whitney Test, there did not appear to be a difference between male and female students in the post scores for engagement, stress, and worry. However, only four females completed the lab task, which is a small sample size, and conclusions should be considered cautiously. There appears to be a significant ($p < 0.01$) relationship between the anxiety score and the post-task SSSQ engagement score. It was a surprising result and the meaning is unknown. There may be a significant relationship between the anxiety score and the post-task SSSQ distress score, $p < 0.10$. The possible relationship between post-task SSSQ score and anxiety rating provides evidence that the anxiety score may be rating student distress. There does not appear to be a relationship between anxiety score and SSSQ score for worry. Unlike the mechanical engineering analysis, there does not appear to be a relationship between expertise score and post-task SSSQ score for engagement, distress, or worry. It should be noted that the hard and easy tasks were not analyzed separately.

The number of questions each student asked was totaled for the electrical tasks. Using the totals, the Mann-Whitney Test did not show a significant difference in the number of questions males asked compared to the number of questions that females asked. Once again, it should be noted that there are only four females in the sample.

Hands-on ability was correlated with attitude toward engineering and prior experience to discover traits that are linked to electrical engineering students' hands-on ability. The data was obtained from EAS and PEQ. ACT math, ACT composite score, and GPA were also examined. The results can be seen below in Table 7. For the PEQ questions and EAS questions a $p$ cut off value of 0.1 was used. The additional influence of GPA, gender, difficulty of task, EAT score was not considered on the correlations.

**Table 7: Expertise score correlated to PEQ, EAS, ACT, and GPA**

| **Question Topic** | **Source** | **Correlation** | ***p*-value** |
|---|---|---|---|
| High school sports: golf | PEQ | -0.608 | 0.003 |
| Elementary school years activities: video/computer games | PEQ | -0.603 | 0.004 |
| Technology plays an important role in solving society's problems. | EAS | 0.519 | 0.016 |
| I have strong problem solving skills. | EAS | 0.518 | 0.016 |
| Pre-school years activities: stay home with father | PEQ | -0.468 | 0.032 |
| Formal high school education: computer programming | PEQ | -0.449 | 0.041 |

As found in the ME correlations, ACT math, ACT composite and GPA were not significant correlations, with $p$-values of .0166, 0.848, and 0.879 respectively. The sample size was significantly smaller than the ME test which could have caused higher $p$-values and therefore fewer significant correlations. The PEQ had four significant questions and the EAS had two significant questions. However the EAS had higher correlation values than the ME and had two EAS questions in the top four. Formal post-elementary coursework showed much lower significance than with ME correlations, with only one category showing significant values. There were many more significant negative correlations; perhaps these activities reduce the time available to participate in activities with positive correlations.

**Discussion**

Significance was realized between the MAT and expertise lab score for the easy task, $p < .05$, but not for the hard task. The paper and pencil EAT and lab practicum did not have a significant relationship with the expertise lab score. The labs had to be divided into hard and easy tasks for analysis, which further lessened the sample size. Small sample size is very likely obscuring more solidifying results. It could also be possible that the MAT does relate to expertise score and the EAT does not. Future research will collect more samples and determine if EAT significantly relates to expertise score or if alterations to the EAT could improve correlations. If stronger correlations are realized between expertise lab score and MAT or EAT for ME students or EE students, respectively the paper and pencil tests could provide the same information as an expertise scoring using significantly less resources.

For both mechanical engineering and electrical engineering, ACT scores and GPA were not significantly correlated to lab expertise. It implies that lab expertise is not correlated to academic performance. It is also interesting to note that the mechanical engineering expertise score highly correlated to construction and other formal academic experiences, whereas electrical engineering positive correlations were related to engineering attitude. Another area of future research includes considering the influence of GPA, gender, ACT composite score, etc., in correlations with PEQ and EAS. Again, due to the small sample size it would not be useful to test for significant correlations with these constraints.

One possible reason that could have influenced the lack of correlation between hands-on ability and GPA could derive from student's original interest in engineering. Females typically come to engineering because they have strong math and science skills. They often lack hands-on experiences due to social stigmas. Males, on the other hand, come to engineering for a variety of reasons. Some pick engineering because they are strong in math and science but others pick it because it fits the male stigma and have spent time tinkering with machinery[5]. The initial difference in interest in engineering may explain why GPA and ACT scores are not correlated to hands-on expertise. A reason for adding lab experiences to curriculum is to complement content knowledge and computation skills that are highlighted in homework and lectures. This could also explain the lack of significant expertise lab score correlations for GPA and ACT.

The SSSQ post scores had three significant correlations. The significant score between anxiety and post-task SSSQ distress from the electrical lab procedures produces evidence that the anxiety score is measuring student emotions similar to distress. The second significant item from SSSQ post-task scores was distress, which was associated with expertise in the mechanical procedures. Thirdly, the anxiety score and SSSQ engagement post-task score was significant for the electrical procedures. However, the meanings of the last two relationships are unclear. Perhaps a correlation between expertise and distress signifies that students display more expert behaviors when they are distressed. As research progresses and more samples are collected higher levels of significance will hopefully reveal relationships between SSSQ results and lab results.

Few similarities were noticed between the mechanical engineering analysis and electrical engineering analysis. This in part may be due to the relatively small sample sizes. A possible trait that could become significant for both with increased sample size is gender and total questions asked. A possible trend can be seen below in Table 8.

**Table 8: Total questions asked by males and females**

| | EE test | | | ME test | | |
|---|---|---|---|---|---|---|
| | N | Mean | Median | N | Mean | Median |
| Male question total | 17 | 1.12 | 0 | 24 | 7.67 | 5 |
| Female question total | 4 | 0.75 | 0 | 6 | 6.67 | 5 |

From the above table it could be worthwhile to examine differences between males and females administering the test, differences in EE and ME, and/or differences in approach to administering the test. It is worth noting that the lab assistant to administer all the ME tests was female while the lab assistant to administer the EE tests was male.

## Conclusion

There is some evidence that the expertise lab score is related to the paper-and-pencil (MAT and EAT) scores. Similarly, there seems to be some relationship between the anxiety score students received while completing the hands-on lab activity and their distress/worry score on the SSSQ. This would imply that there is both validity to our approach and opportunities for improvement. Further analysis and exploration to determine why there is a correlation between MAT and expertise lab scores for the easy task but not for the hard task of both the MAT and EAT would be useful. Work in this area could include improvement of both assessment tools. Additionally, there seems to be an opportunity to consider how the gender of a teaching assistant effects student behavior and performance in a laboratory environment.

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