AC 2011-1489: EARLY ENGINEERING INTERESTS AND ATTITUDES: CAN WE IDENTIFY THEM?

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A team of multidisciplinary university researchers are engaged in a project to measure changes in young students' (grades 3-5) STEM interests, achievement, and attitudes over three years and relate these changes to identifiable parent/teacher influences. This research follows a modified intersectional theory approach to consider the interdependence of school and home cultures on attitudes and interests in science and math. The main objective of this project is to determine significant predictors of students' early interests in STEM and to provide new guidance for classroom practices that encourage young girls' STEM interests. The targeted school region includes large numbers of low, socio-economic status (SES) students (those eligible for free and reduced-price meals) and American Indians (AI). The study includes 584 students (with approximately 50% AI students) with similar numbers of girls and boys at each level.

In this paper, we explore identification of elementary children's engineering interests and perceptions (as to who should do engineering). Within the context of the engineering design cycle, we would like to organize and analyze school children's thoughts as to what activities they do that are related to engineering as well as for them to consider whether girls, boys or both should engage in these activities.

Background and Theoretical Framework

We know very little about how young girls develop expectations for themselves with regard to STEM learning – and even less about these processes among low-income, American Indian children in rural schools. It seems that girls have already developed expectations about their STEM interests and abilities before they enter middle school. Little research explores the ways in which parents and elementary teachers, whose science and math skills are often lacking, might subtly (or explicitly) influence children's interest and achievement in science and math. Research and intervention projects since *How Schools Shortchange Girls*[1] indicate patterns of progress in improved instruction and innovative learning opportunities.[2] Still, many bright students, particularly women and minorities, choose not to pursue engineering careers.[3] As Halpern et al.[4] assert the differences in male and female expectations and choices regarding STEM learning are much more complex than previously assumed. So too, the perceived gender gap may well be exacerbated by self-perceptions and ethnicity.[5] This study aims to delineate the cultural ways in which rural, American Indian girls and boys develop their interests and attitudes about STEM learning in grades 3-5.

Gender, culture achievement gap. Though the gap between boys' and girls' interest in science appears to grow during middle school,[6] the gap begins in elementary school.[7] Continuing assumptions of science and math success as a *gift* particularly lead women to lose confidence and motivation.[8] These lowered self-beliefs may lead to a self-fulfilling prophecy and partially account for fewer women in STEM fields.[9] Given the additive effects of both gender and ethnicity, rural, American Indian (AI) girls may be in a double bind. For American Indians, who often place family and community concerns ahead of academic concerns, school achievement can be a metaphor for assimilation and "becoming White".[10] As well, lower-income parents are less likely to object to their children being shuffled into a lower-track curriculum.[11] It is no surprise that 40% of American Indians drop out before attaining their high school diploma; the post-secondary retention rate may be as low as 15%.[12] To be successful in school (and in the larger world outside their usually rural home environment), AI students need to actively construct their own knowledge, engage in varied activities in and out of school, and be encouraged to maintain their native identity to be successful in school and professionally.[13]

Parent and teacher influence. Gender schemas are generally understood as assumptions about what it means to be male or female. While researchers can explain *what* gender schema children learn from birth, there is much to learn about *how* children learn about gender. Parents have a large impact on children's developing perceptions of self-competence.[14] Fouad[15] determined girls' feelings of self-confidence, instilled by parents and supported by teachers, are a precursor to girls' interests in science and math. Girls may feel competent in math, but they are less likely to report finding it interesting and girls' parents are less likely than boys' parents to create math promotive environments for them.[14] Elementary teachers are generally known to exhibit low science/math confidence – suggesting they have bought into the idea that science and mathematics are for boys.[16] These teachers' gender schemas subtly influence children's STEM achievement.[17] Elementary teachers may also not recognize the need or have the training to connect STEM subjects to Native language and cultural traditions.[18]

Young girls begin to form definite ideas about their personal science and math interests and abilities during their elementary school years. These early ideas (1) influence later decisions about science and math achievement in middle school and high school and (2 exacerbate the STEM workforce pipeline problem. The success of new initiatives for enabling women to pursue and succeed in STEM fields will depend on improved understandings about *how* children learn about gender roles and STEM. Others' research on girls' interest in science has focused on adolescent girls and has neglected the ways in which experiences of race and class may also contribute to girls' lack of participation in STEM.[19] To meet this need in the research literature, we focus on elementary-aged, low-income, rural and American Indian students and their teachers and parents. The dual objectives of this research are (1) to determine significant predictors of low-income, rural American Indian boys' and girls' early interests in science and mathematics and (2) to provide new guidance for classroom practices that encourage young girls' STEM interests. Once we understand the "red light" signals (or negative influences) we can provide recommendations about how to encourage STEM learning for both boys and girls. Though we have seen benefit from funded projects to increase women's options in STEM career fields, it is evident that traditional gender schemas – in families, classroom procedures, curricula design, and testing procedures – impress very young children. This elementary population is particularly important given Kurzweil and Hundt's report[20] on the essentialness of early interventions when it comes to helping American Indian students.

Theoretical framework. The larger study (NSF # HRD-0936672) follows a modified intersectional theory approach to consider the interdependence of school and home cultures on attitudes and interests in science and math. Modified intersectional theory frames this research to develop better understanding about early influences on boys' and girls' pursuit of STEM tracks.[19,21] Intersectional theory holds that discrete forms or expressions of oppression (such as race, class and gender) actually shape, and are shaped by, one another.[22] This study follows an *open systems model*[23] to guide our research questions and design. Like any social system, school systems comprise varied components (the school organization, the **e**nvironment, input, output, and feedback). The *open systems model* focuses on both micro- and macro- levels. *Micro-level analysis* includes classroom interactions and experiences. At the *macro-level of analysis*, research methods link individuals and small groups to larger educational systems using functionalist and conflict theories of education.[24] This model, and our mixed-methods research approach, leads us to examine schools as open rather than closed systems. Thus we are able to examine daily interactions that maintain or strengthen gendered interactions[25] in relationship to girl's STEM potential. This conceptual framework is dynamic, not static. It considers girls' STEM potential as both a result and a product of interactions within the organizational structure of school.

Engineering design cycle. Our research question is organized by a five-step engineering design cycle (developed by Alan Cheville at Oklahoma State University). These steps are distilled from the ABET (Accreditation Board for Engineering and Technology) who judges the quality of a university's degree program (key words are underlined):

> *Engineering design is the <u>process</u> of devising a system, component, or process to meet desired needs. It is a <u>decision-making</u> process (often <u>iterative</u>), in which the basic <u>science and mathematics</u> and engineering sciences are <u>applied</u> to convert resources <u>optimally</u> to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation.*

Beginning with "Researching" and ending with "Communicating," engineers go through five steps in a generally linear fashion with jumps back and forth as needed. The more experienced the designer, the more they consider the impact of earlier and later steps in the cycle.

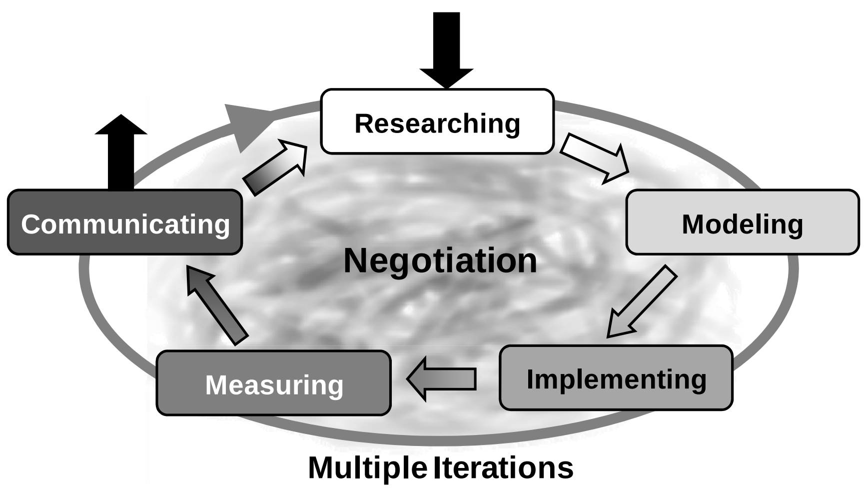

Figure 1. The Design Cycle

<u>*Research*</u> is the first step of engineering design. We all do research every day of our lives. While the term "research" sounds deep and difficult, it is a skill we are all familiar with. According to Wikipedia, "*Research can be defined as the search for knowledge or any systematic investigation to establish facts. The primary purpose for applied research (as opposed*

to basic research) is discovering, interpreting, and the development of methods and systems for the advancement of human knowledge..."

> The second step in the engineering design cycle is *modeling* the problem. The word "model" means different things to different people. You may think of a model in terms of a tiny reproduction, such as a model ship or model car. An architect might define a model as a set of blueprints while a computer programmer considers a model to be a flowchart explaining how code functions. Engineers may think of a numerical model, which is a representation of a system on a computer; these are also called simulations. Models are also sets of mathematical equations that describe a system and can be used to predict how it will behave. All of these types of models are used in engineering.

After engineers have explored a problem by doing research, and made models to make sure their ideas will work, the next step in design is to actually *implement* their design. It may seem odd use the word "implement" rather than "build" or "make", but the term implement reflects the many ways engineer take designs from ideas to reality. Many engineers do build designs using a broad array of techniques. Perhaps one of the biggest differences between engineering disciplines is the specialized methods and technologies they use to implement designs. However some engineers implement ideas through manipulation of information, such as designing computer software or producing plans. Here the real value is the information in the blueprint or code, not the medium (paper or magnetic disk) that contains the information. Another option for implementing a design is to contract another company to build it. In this case the engineer works with the company to ensure the work is done properly.

The fourth step of the engineering design cycle is to make *measurements* that determine whether or not the design that was implemented words properly. In order to determine if the design functions, engineers compare measurements of design performance with the results of the models done in the modeling step of the design cycle. Engineers are very aware of the fact that engineering devices never function perfectly, and characterizing the actual performance of a device is a critical step in improving the performance. By comparing how a device really works to how the device should work allows engineers to improve the performance.

The fifth step, *communicating*, is a critical part of engineering design since it is how you share information between the members of a design team, inform managers and customers of your progress, and provide information to those who use your products.

Hypotheses and Research Questions

In the larger study, we hypothesized that science and mathematics attitudes/interests are gendered, socially constructed and evident as early as 3rd grade. We have come to expect that engineering attitudes/interests are also gendered, socially constructed and evident as early as 3rd grade. Thus, we assume that teachers and parents influence children's interests in engineering. In this research, we explored a possible relationship between parent, child, and teacher responses on engineering-related survey items. This paper explores the following research question: Within the context of the engineering design cycle and previously-selected instruments, is it possible to determine a relationship between parent, teacher, and child responses regarding the appropriateness of girls' and boys' engagement in engineering activities?

Demographics

In the first year of this study, research participants included 3rd grade students (and their consenting parents and teachers) enrolled in 22 rural schools within three Indian Nation regions. There were 277 boys and 307 girls; 316 parents, and 62 teachers in the study. Further, student participants were 51% American Indian. All teachers but one were female and 24% were American Indian. Parents were mainly mothers (N = 265) or other female caretaker (N = 23) and were 24% American Indian; less than 5% of the sample had less than a high school education. The school districts students were sampled from were 72% are on free-or-reduced lunch. While our state is home to 39 federally recognized tribal nations encompassing separate and unique jurisdictional areas, there are no Indian Reservations per se in our state.

Survey Instruments

Parents', teachers', and students' completed parallel surveys. As part of a larger study, they completed the short form of the *Occupations, Activities, and Traits Scale—Preference Measure*[26] (OATS) which assessed beliefs and attitudes toward stereotypically masculine and feminine activities. There are 10 typically feminine items, 10 typically masculine items, and 5 neutral items on each scale. Items were classified as feminine or masculine based on how stereotypical they were viewed in pilot testing by the measure authors (items viewed as least stereotypical were the neutral items). Although most all of the items on the child and adult versions overlap, there are some items that are unique to each population. Participants were asked two sets of questions, one asking who should do a series of activities (WHO SHOULD) and the other asking what they do in their free time (FREE TIME). On the WHO SHOULD scale, participants can answer boys only, girls only, or both and girls (men and women for adults). A participant gets a 1 if they answered both boys and girls – termed the egalitarian response, else they received a 0 (note for adults scale the mainly men, sometimes women type responses were coded as a 0). Sample items are drawing cars/rockets (M), building with tools (M), wash clothes (F), sew from a pattern (F), play cards (N). The FREE TIME measure has similar items and is scored on a 1 (none) to 4 (Often or Very Often). Sample items are cook dinner (F), shoot a bow and arrow (M), play cards (N). Normally a difference score is calculated by subtracting feminine subscale score minus masculine to obtain an overall measure of egalitarianism in ones free time activities (see next section for how scored in this study).

For this study, in an attempt to measure the development of gender stereotyping of activities that are most closely related to engineering, we examined the OAT for items that reflect what engineers typically do. In doing so, we approached this from the five- step engineering design described above. In examining the OAT items, the majority of the relevant items to engineering fall in the Modeling stage, with additional items in the Implementing stage. This comes from the examination of the questions and the recognition that many of the items that are in the OAT are the more typically active skills that engineers engage in, such as building, and that there are not questions that get at children's interest in or deciding who should do activities that are more about Research, Communication, or Measuring, since these are not skills typically thought of that children do in their free time. This is something the authors will address in newly developed measures that engage all components of the design cycle. The individual items that were selected do not necessarily represent things that practicing engineers do, but involve engineering skills.

Child Measure. The WHO SHOULD scores were calculated as per above in that the egalitarian response received a 1 and the non-egalitarian received a 0. A mean score was then calculated, thus scores could range from 0 to 1. Cronbach's α was .73. Items in this category were (the numbers correspond to the item number in the OAT instrument, a rationale for the item as an engineering task in the particular design cycle step is also given):

Modeling

- 9 Play cards – Involve predictions about how the "system" will behave, how the other players will play their cards, what cards have already been played, etc.
- 10. Shoot pool – This involves an understanding and application of physics to be able to have the ball go where it needs to go. There is also some predictions of how the ball will behave the next time it is shot.
- 13. Play darts - This involves an understanding and application of physics to be able to have the dart go where it needs to go. There is also some predictions of how the dart will behave the next time it is thrown.
- 17. Play video games – Models and simulation of the models are accomplished in video games. There is a continual predictive part of playing these games.
- 18. Draw (or design) buildings – This is a reproduction of physical system.
- 20. Sketch (or design) clothes – This is a reproduction of a physical system.
- 22. Draw (or design) cars/rockets – This is a reproduction of a physical system.

Implementing

- 3. Sew from a pattern – Takes a clothing "plan" from idea to reality.
- 8. Build with tools –This is a skill that is needed to effectively implement engineering designs.
- 12. Fix bicycles – Takes an idea about how to solve a problem and makes it a reality.
- 24. Build model airplanes – Takes a plan and makes it a reality.

The FREE TIME mean score was calculated, scores could range from 1 to 4, with high scores reflecting they reported doing that activity more in their free time; α was .68. Items included were:

Modeling

- 4. Paint pictures – Represents physical reality, is a reproduction.
- 12. Play pool – (see above)
- 23. Shoot a bow and arrow - This involves an understanding and application of physics to be able to have the arrow go where it needs to go. There is also some predictions of how the arrow will behave the next time it is shot.
- 25. Draw (or design) cars or rockets (see above)

Implementing

3. Build forts – Requires planning and then implementation of the plan to make sure everything turns out well.
8. Fix a car – Requires mechanical skills that are needed for implementing engineering designs
10. Build with tools (see above)
11. Cook dinner – Requires some planning and then implementation of the plan to make sure everything turns out well.
22. Hunt - Requires some planning and then implementation of the plan to make sure everything turns out well.

Adult Measure. The WHO SHOULD scores in this measure were calculated as per above in that the egalitarian response received a 1 and the non-egalitarian received a 0. A mean score was then calculated, thus scores could range from 0 to 1. Cronbach's α was .83 for parents and .81 for teachers. The following items were considered part of the engineering scale:

Modeling

2. Knit a sweater – Unlike sewing from a pattern, knitting requires some prediction and adjustment to make the sweater come out as desired. The plan evolves as the sweater is knitted.
8. Play cards (see above)
9. Shoot pool (see above)
18. Shoot a bow and arrow (see above)
20. Sketch (or design) clothes (see above)
22. Draw (or design) cars (see above)

Implementing

3. Sew from a pattern (see above)
6. Fix a car (see above)
7. Build with tools (see above)
11. Fix bicycles (see above)
23. Build model airplanes (see above)

The FREE TIME mean score was calculated, thus scores could range from 1 to 4, with high scores reflecting they reported doing that activity more in their free time; α was .62 for parents and for .76 for teachers. The following items were considered part of the engineering scale.

Modeling

3. Go bowling - This involves an understanding and application of physics to be able to have the ball go where it needs to go. There is also some predictions of how the ball will behave the next time it is thrown.
10. Play cards (see above)
11. Shoot pool (see above)
16. Play darts (see above)
21. Play video or computer games (see above)
23. Shoot a bow and arrow (see above)

Implementing

8. Build with tools (see above)
9. Cook dinner (see above)
22. Hunt (see above)

Results

Unfortunately, due to a low number of items, the modeling and implementing subscales had poor reliability. Conceptually, we are interested in predicting engineering interest as a whole and not in predicting particular parts of the process. The division described above allows us to describe which part of the design process our overall measure examines. The results presented here put all items into an engineering design scale.

Boys engaged in more engineering design activities (M = 2.23) than girls (M = 1.91), $F(1, 582) = 46.17$, $p = .001$. Girls had more egalitarian attitudes than boys ($M_{girls} = .42$ and $M_{boys} = .33$), $F(1, 582) = 18.98$, $p = .001$. There were no differences in responses of parents who had boys versus parents who had girls. ANOVAs were not run with teacher data because it would be the same teacher providing data for boys and for girls within their classrooms. There were no effects of child ethnicity (American Indian, Other) when looked at as a 1-factor ANOVA.

In 2-factor ANOVAs combining ethnicity and sex, for child FREE TIME, there was a main effect of gender (same effect as above) and a main effect of ethnicity ($M_{AI} = 2.12$ and $M_{non\text{-}AI} = 2.03$), $F(1, 582) = 3.78$, $p = .05$, with American Indian children engaging in more engineering design activities. For the child WHO SHOULD responses, only the main effect of gender were significant with the effect being the same as above. For parents' WHO SHOULD responses, there was a significant interaction, $F(1, 313) = 4.44$, $p = .04$. Specifically follow-up tests revealed that for boys there was no ethnicity differences, but for girls, American Indian girls had parents who scored significantly lower than parents of non-American Indian girls, M M_{AI} Girls = .55 and $M_{non\text{-}AIGirls} = .65$. No other effects were significant.

We were interested in understanding teacher and parental influence on children's gender stereotyping of engineering design activities. We found that as parental engagement in engineering activities increased, so did children's egalitarian views of engineering design activities, $r(314) = .12$, $p = .04$. In order to correlate teacher data with child data, since each classroom only had one teacher, each teacher was reproduced as many times as needed for each child in their class. While this is not ideal as it violates the independence assumption, general linear models are robust to this assumption. For teachers, as their egalitarian views increased, their students egalitarian views decreased, $r(541) = -.09$, $p = .02$. No other relations between parent and teacher and children's views of engineering activities were significant. Interestingly, both parent and teacher views of who should do and what they do were positively related, ($r(314) = .16$, $p = .001$ and $r(60) = .25$, $p = .05$, respectively) but for children were unrelated, $r(541) = -.04$, $p = .29$.

Conclusions, Recommendations, and Further Directions

The relationship between parent, child, and teacher and child attitudes about activities within the engineering design cycle are complex. It is interesting to note that parental engagement in activities was not related to their children's engagement in activities, but rather was related to them having a more egalitarian view of these activities. It will be important to look at these relations over time; it may be that, as children age, their own egalitarian views will influence the activities they engage in. It may also be that children are holding egalitarian views but are not acting on them for a variety of reasons. There is some evidence for this in our data in that girls are more egalitarian in their attitudes, but boys engage in the activities at a higher rate. What is perhaps particularly distressing about our findings is that parents of American Indian girls scored the lowest in their egalitarian attitudes. If parental attitudes have an effect over time, these girls are at particular risk of societal stereotypes related to engineering activities.

The relationship between teacher and child attitudes is less straightforward in that as teachers' egalitarian views increased, their students' views decreased. This finding may be an artifact of the way the data were analyzed, but it may also indicate that teachers are not clearly communicating their own views to their students or are even communicating views opposite to their own in an attempt to follow what they view as societal stereotypes, even though they do not hold these views personally.

Some of the limitations of the current study are that it is cross-sectional in nature and the large majority of parents and teachers were female. Its strengths are that the sample size is quite large and contains many American Indian children, a population here-to-for understudied.

In our long-view, we hope to expand on these survey items to further reflect the entire five step engineering design cycle. One major focus of future work will be to develop an instrument that measures students' involvement in all five components of the engineering design cycle. Additionally, we want this new instrument to evaluate egalitarian views of children for components of all of the design cycle. Ideally one would also assess these views over time as children move from elementary to middle school to high school and beyond.

Such an instrument would be useful in engineering curricula workshops for teachers to measure pre/post changes in attitudes/interests in engineering. One can expect that engineering curricula alone will not bring change in engineering career interests. Parents and teachers' attitudes and beliefs will continue as intervening variables.

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