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The Anna Karenina Principle

Females and STEM

We argue that the Anna Karenina principle is a useful metaphor that captures the reasons behind the gender disparity in the fields of science, technology, engineering, and math (STEM). Inspired by a passage from Leo Tolstoy stating that "all happy families look alike, each unhappy family is unhappy in its own way," the Anna Karenina principle describes the observation that in many complex systems the best way to look at reasons behind some effect is to look at the many necessary conditions that need to be fulfilled, rather than look for a single, direct cause. Playing a gender role in a society is engagement in a complex system and the list of necessary conditions for success in STEM is arguably longer for girls than for boys. In the current article we do not aim to make a comprehensive review of all of them, rather we wished to propose a snapshot of the matter.

STEM became a popular acronym in the early years of the twenty-first century. It originated from the field of education and describes mathematics, science, engineering, and other technology-related subjects [10]. The question of what constitutes a STEM subject or STEM-related work might seem unambiguous, but in fact it's not. Is a social scientist, healthcare professional, or an architect a STEM-related job or not? Deciding on this question markedly changes how one evaluates the current state and growth prospects of STEM jobs [16]. Importantly for the current article, the adopted definition of STEM changes the answer to this question: if we know that somebody is a female, does this change the probability of that person's preference for working in a STEM-related field? If by STEM we understand mostly mechanics, electronics, and engineering then the answer is: it is a rather safe bet that she is not interested. Data suggests that there is about a 76% chance that a randomly picked male will have a higher interest in those fields then a randomly picked female [18]. Putting it differently, 84% of males declare higher interest in those fields than the average female. On the other hand, if we look at physical sciences, natural sciences, mathematics, and computer science then the gamble becomes risky. We drop to a 61% chance of correctly guessing that an unknown person will show higher interest in those fields just because we find out they are a male. When we turn to fields such as biological or medical sciences then the choice becomes a true Casino Royale, with a 50/50 chance of guessing who has higher interests on the sole basis of gender. Furthermore when we look at social sciences and medical services, then the odds turn around. Now there is a 61% chance that a randomly picked female will show higher interest than a randomly picked male.

Photo of Greta Garbo from the 1935 film *Anna Karenina*.

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There is a large heterogeneity of gender related interests in fields we might call "STEM." The more we move from a narrow understanding of STEM as "technology/electronics" to a general "science education," the less our probability estimates should be biased by knowledge of somebody's gender. There are some important conclusions. First, our assessment of probability of a female achieving success in STEM should be partly dependent on the definition of STEM itself. Is a successful female psychologist, a success story in STEM or not? If not, why?

Second, gender differences in interest are not that large, and even in fields such as mechanics or engineering there is a number of highly interested females, who will most likely be working there as a minority (see Figure 1). We will elaborate on this point in a moment.

Third, gender differences in interest do not correspond to a difference in a subjects' complexity or its quantitative analytical requirements, but rather with its expected contents, especially a "people vs things" orientation (9, 18). Large meta-analysis of studies on performance in mathematics supports the conclusion that there are no gender differences in this regard (8), and data from Finland on curiosity in school children shows that most questions about liking complex problems, hunger for knowledge, enjoyment of hands-on exploration, preference for solving problems on your own, or liking strange and puzzling objects are gender neutral (2). Same research shows however, that some curiosity items, such as "do you like taking objects apart" or "understanding how machines work," do show a male-bias.

We cite data on gender-related interests in children from Finland, because it is a relatively gender-equal county. One might suppose that in such countries, there will be a low gender difference in engagement with STEM subjects. Surprisingly it is the opposite. It turns out, that if we look globally, the higher the national gender equality, the higher the STEM graduation gap will be (17). It seems that gender inequality is related to increased life-quality pressures. The higher the life-pressures, the less important are individual preferences and perception of one's personal strengths in career choice. In gender-equal countries girls are slightly less interested in "understanding how machines work" and this influences their subsequent educational and career choices.

Judgment of one's personal strengths also matters. It turns out that while girls perform in school as well or even better than boys in science, they perform even better in reading comprehension and writing (13). Therefore, what matters most as far as perception of one's strengths is concerned is relative comparison rather than absolute performance. Data shows that even when boys overestimate their competence in science subjects and do not show better results than females in those subjects, they see it — relatively to other subjects — as their personal strength (17). Girls, on the other hand, tend to see skills related to human communication, such as reading comprehension and writing, as their personal strengths, even if they perform well in science subjects. Occupational choice depends more on a relative advantage than absolute ability (19), which is an important element of the *expectancy-value theory* (7, 20).

This provides an interesting twist to the "leaking pipeline" metaphor. The pipeline can simply be abandoned, when one sees one's strengths in communication, teaching, mentoring, teamwork, and collaborative problem solving, and does not perceive (rightly or not) STEM occupations as highly dependent on those skills. The degree to which mechanics, electronics, and engineering will be seen as areas in which those competencies are an advantage, should relate to the number of females involved, via their assessments of a match in personal strengths.

Now we will return to a slightly more complicated issue that we mentioned previously. Despite current gender differences in interest, there are a large number of females who already are interested in fields such as engineering, computer science, natural sciences, or mathematics and consider engagement in those occupations, but will most likely be working there as a minority. There are possibly several psychological factors that make this more difficult than it could be.

The expectancy-value theory suggests that the amount of effort that you put into problem solving is based on a general prediction about the future: is it worth it? This depends on whether you think you will succeed and whether it will be a worthwhile effort. Subjective task value consists of four aspects: enjoyment one gets from doing a given task, whether a task can be useful to an individual, it's importance for one's identity, and predicted cost, such as time, loss of valued alternatives, stress, etc.

Many success expectancies are socially constructed. Parents declare expectations as to appropriate achievement choices and parents' gender stereotypes may directly impact perceptions of their own kids' abilities, with a preference and more positive evaluation of gender stereotypical behaviors and skills exhibited by children. Those perceptions may, in turn, affect children's beliefs, choices, performance, and self-perceptions of their own abilities in gender-typed domains all throughout adolescence and young adulthood. This can happen through provision

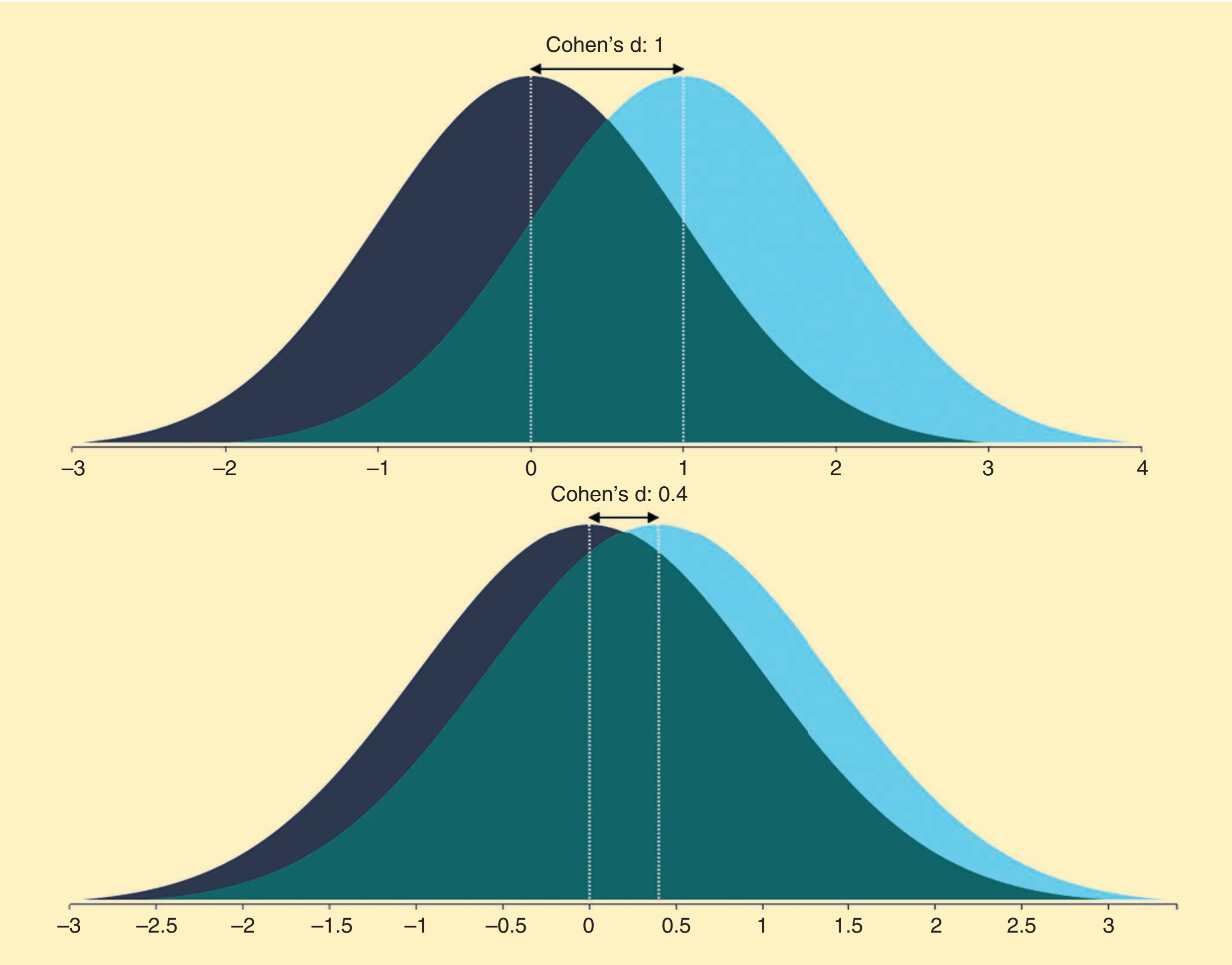

FIGURE 1. Approximate gender differences in interest in mechanics, electronics and engineering (top) and physical sciences, natural sciences, mathematics, and computer science (bottom). Based on data from Su and Rounds [18], visualization of effect sizes from work by Kristoffer Magnusson.

of opportunities and encouragement of behaviors and choices consistent with stereotypes. Research has found that parents generally endorse the cultural stereotype that high achievement in math is more "natural" for boys than for girls [6]. Chhin and colleagues [3] report that parental expectations have a long-term impact on the constraints of their children's occupational choices. Children as young as 6 years old show beliefs that high-level intellectual "brilliance" is more typical of boys than girls, whereas being "nice" the opposite [1]. Helen Watt's research among Australian adolescents [21] confirms the importance of higher intrinsic values and self-perceptions of mathematical talent and success expectancies in subsequent selection of higher math courses. Girls rated those aspects significantly lower than boys did, despite comparable levels of actual prior mathematical achievement, while there were no general differences on math utility value. Girls' perceptions of math as difficult impacted on their level of participation in more advanced math courses.

There are also social expectations regarding what is a good life. Role congruity theory postulates that an individual will be positively evaluated when their characteristics match with their group's stereotype or typical social roles, while an incongruity may lead to less positive evaluations [4, 5]. Double blind is a term that describes a situation when a person struggles to meet two contradictory demands, in which fulfilling one means a failure in the other, as those are mutually exclusive. Women in various traditionally male professional roles may experience a gender specific double blind. Two types of bias may occur here, descriptive: a stereotype of women as having less of a given "masculine" ability or potential; and prescriptive: related to women who violate the rules for how men and women "should" behave. The prescriptive nature of gender stereotypes may result in negative reactions to females exhibiting "masculine" traits such as authority or agency. The sheer awareness of the risk of being subject to various social and economic reprisals as a result of not fulfilling a gender stereotype or norm is known as fear of backlash [11], [15]. This may be seen as one of the forces that keeps women out of so-called "masculine" domains, where they are bound to face the gender double blind. Rudman and Fairchild [14] demonstrated in their experiments that when negative reactions to stereotype violation were likely, both genders decided to show greater gender conformity, even if they were aware of the fact this maintains stereotypes in their perceivers.

In conclusion, if our goal is such that the assessment of the probability of a person's success in STEM should not be contingent on knowing her or his gender, then we need to deal with multiple issues. Some of them relate to how we define the STEM field itself, others relate to personal interests, relative judgments of individual talent, and success expectancies. Those success expectancies and value judgments are socially constructed forecasts — predictions about possible enjoyment, usefulness, importance for identity, and cost. The issue is that there is a general lack of ability in terms of such forecasting. People greatly underestimate the degree of change that they might experience in the upcoming decade of their lives. Quoidbach *et al.* [12] call it the "end of history" illusion. They have found that both young and older people believe that they might have changed a lot in the past, but that they will not change much in the future. We all seem to assume that we are "now" the person we "will be" for the rest of our lives, but this is an illusion. The future in complex, nonlinear systems, with multiple complicated interactions, is uncertain with the possibility of small causes having large effects.

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