Girls and Women in STEM: A Review of Interventions and Lifespan Developmental Considerations for Increasing Girls' and Women's Participation in STEM

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Executive Summary

Substantial strides in girls' and women's participation in science, technology, engineering, and mathematics (STEM) education and careers have been made over the past thirty years. However, a gender disparity in STEM educational and professional attainment remains. While girls and boys now have nearly equal participation in primary and secondary education, worldwide, the gender gap in completing advanced coursework in STEM subjects, specializing in STEM fields in higher education, continuing into STEM research and professional careers, and leadership within STEM fields remains (UNESCO, 2017). Strengthening girls' and women's participation in STEM has numerous benefits for society and for science. There is currently a global demand for expertise in science, technology, and engineering fields. Reduced participation of women in STEM disciplines limits the pool of qualified, talented, and innovate labor in STEM research and industries. Moreover, women's

The second objective of this report was to present a developmental psychological perspective on the design of STEM interventions. To that end, we reviewed barriers to gender equality in STEM education and professions from a lifespan developmental perspective. Psychological, educational, and social barriers occurring from early education through middle adulthood were presented and discussed so that policymakers, executives, and educators can more precisely target the removal of gender-based obstacles to STEM success. For example, researchers have shown gender differences in spatial reasoning, a cognitive ability that has been linked to STEM achievement and to gender-typed differences in play and object manipulation in early childhood (e.g. block play). Other developmental aspects such as teacher influence in middle childhood, peer influence in adolescence, early professional experiences in emerging adulthood, and work-family balance in middle to late adulthood were outlined and connected to efforts to remove the gender gap in STEM interest, commitment, and advancement.

Lastly, we identified and discussed major limitations and gaps in the literature on interventions for girls and women in STEM. Issues such as appropriate methodology for outcomes research, variety and type of outcomes assessed, target population, and broader social, cultural, and structural barriers to gender equality can impede the interpretation of intervention outcomes or limit the impact of interventions. We hope that by identifying areas of need, we can encourage researchers, policymakers, and educators to address gaps in knowledge and suggest improvements to the design and imp2 0 612 792 reW9ntalTf1 0 0 1 285.t15.42 TmpBT/s

over time was more pronounced for science (Mullis, Martin, & Loveless, 2016). For math achievement, boys are generally more likely to outperform girls in math, however, there is variation in the magnitude of the gender difference across and within nations (Hyde, Mertz, & Schekman, 2009; UNESCO, 2017). In some countries, gender parity has been achieved in science and math learning as measured through TIMSS and PISA -for example, TIMSS 2015 showed that two thirds of countries assessed showed no gender difference in math achievement at the 8^{th} grade level (UNESCO, 2017). The gender differences in the TIMSS and PISA math tend to be small, but in some countries, the gender disparity widens in secondary education (OECD, 2017; Mullis, Martin, & Loveless, 2016).

In some countries such as Bahrain, Jordan, Kuwait, Malaysia, Oman, Saudi Arabia, and Thailand, girls outperformed boys in science math-intensive fields are women and the proportion of women in these fields has actually declined slightly in the past decade (Ceci et al., 2014; UNESCO, 2017).

A second notable pattern is that of the “leaky pipeline:” smaller numbers of women are found at increasingly higher levels of STEM education. Critical junctures of “pipeline leakage”

BAMOT Mentorship Program (Bamberger, 2014)

Interventions to Promote Gender Parity in STEM: Highlighted Cases from around the World

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education and careers. The course was comprised of 7 learning modules: “Study Skills,” “Critical Thinking and Problem Solving,” “Upgrading and Skill Enhancement for Particular Concepts/Processes in Science and Mathematics,” “Student-centered Pedagogical Approaches to Learning Mathematics and Science Concepts,” “Exploring Science, Technology, and Mathematics (STM) in Society,” “Engaging in Real-Life Mathematics and Science Investigations,” and “Understanding and Addressing Attitudes and Beliefs about Self as a Mathematics and Science Learner” (Mbano & Nolan, 2017, p. 64). In addition, students were introduced to STEM women role models who were leaders and employees in the National Statistics Office, public health, and the university technical education program. Students’ examination results after their first year of university and perceptions of the bridge program were collected and analyzed.

Compared to other women students at the university, students who attended the bridge programs had higher pass rates (81% and 100% for bridge students and 62% and 75% for other women students in Chancellor College and The Polytechnic, respectively). Students who completed the bridge program strongly associated the program with STEM education motivation and teaching of reasoning and study skills.

Overall, the bridging programs appeared to have positive long-term impacts on participants’ math and science performance, as measured by STEM subject exams and self-reported academic skills and confidence. Due to the interactive nature of the bridge programs, data on students’ STEM professional and social networks, friendships, and sense of belonging in STEM fields would have provided valuable information. It is possible that the shared experience and mentorship of the bridge program led to increased social belonging and social support, which enhanced confidence and academic achievement. Future research on bridge programs should seek to examine these potential effects. The intervention is also notable for targeting groups of young women and girls who were disadvantaged due to lower socioeconomic standing. It appears that the bridge programs effectively addressed gaps in knowledge and provided supportive communities wherein the young women and girls could thrive.

A limitation of this research is the lack of a randomized control group. While it is to the study’s credit that the researchers constructed a retroactive control group using data from other women at the university, it is unclear if the comparison group was matched to the intervention groups based on major, socioeconomic status, and other individual factors. A second major limitation was that the sample size for both studies was very low. It is unclear how well the outcomes reported in this study would generalize to larger groups or at different universities. Future studies should examine whether similar bridging programs are a scalable intervention for larger groups.

Case #2. The Nigeria Federal Science & Technical Education at Post-Basic Levels (STE272(lab(c)-1(i)7(e)7(n)-6(c)7(e)7( )-20(&)7(T)7(e)7(c)7(h)-6(n)-6(i)-1(c)(a)71 12 Tf1 092 reW*nBT G[( )]TJE

outreach and recruitment of student participants from different regions of New Zealand. The

engineering careers and understanding of concepts. However, it appeared that girls perceived that they gained skills and knowledge of how to purposefully create objects and devices to solve problems.

While this intervention is laudable for its comprehensiveness, use of preintervention data in formulating learning modules, and involvement of many stakeholders (e.g. national, state, local, university, school, family, professional engineering levels), the assessment of outcomes had limitations. Little and León de la Barra's (2009) published report did not include detailed descriptions of the data collected and analyses performed. It would be valuable to understand whether the intervention impacted girls' performance in school STEM courses. A more rigorous experimental design would be the comparison of the intervention group to a control group. For example, although the researchers did not find significant changes from preintervention to postintervention, it is possible that *without* exposure to the multifaceted initiative, girls would have otherwise held more negative attitudes towards engineering or had less interest in pursuing engineering. Potential buffering effects of the intervention against a loss of interest in engineering cannot be identified with the present research design.

Case #3. Makerspace Hands-On STEM Projects for Primary School Girls in Australia (Sheffield, Koul, Blackley, & Maynad, 2017).

The aim of the Makerspace in STEM (MIS) program was to provide an opportunity for girls to gain experience from female mentors and teachers through playful, hands-on, collaborative projects centered around STEM topics (Sheffield, Koul, Blackley, & Maynard, 2017). By engaging in creative projects in an informal setting, MIS may help spark young girls' interest in STEM education. The present study sought to understand how girls engaged with a Makerspace project and how well they integrated the project with STEM schoolwork and skills.

71 Year 5 and Year 6 girls from an all-girls' Catholic school in Australia participated in the research. High-performing Year 6 students from the school were not represented in the sample due to being on a field trip during the Makerspace event. The Makerspace day took place at the school during regular school hours. Each student was given a bag that contained materials that students could use for their project, which was to create a circuit that could light a bulb in a flower. Female pre-service teachers served as Makerspace mentors for the girls and assisted with projects during the day. Data was collected using a questionnaire, pre-service teachers' observations, and observations of students through video recordings.

Survey responses showed that nearly all participants enjoyed the project and would be willing to complete future Makerspace projects at school. More than 80% of the sample reported that they enjoyed science and planned to continue taking science in Years 11 and 12. Pre-service teachers observed that students were most likely to practice trial-and-error problem-solving and that students seemed to enjoy the project. Observations indicated that

take care to randomly assign participants to a condition, in order to control for cohort effects and individual differences of students. The mentees in the study were all high-achieving girls. It is difficult to generalize findings to a more varied sample of mentees, who may bring different needs to the mentoring relationship.

The many-to-many group mentoring structure examined in this study appears to be an effective way to increase high-achieving girls' commitment to STEM education and careers. Importantly, it developed wider STEM networks for mentees, which may have additional payoffs past secondary education.

Case #2. Perceptions of the Athena SWAN Charter at the University of Oxford in the UK (Ovseiko, Chapple, Edmunds, & Ziebland, 2017).

The Athena SWAN Charter for Women in Science merges two initiatives (Athena Project and Scientific Women's Academic Network) in the UK for increasing gender equality in the academic sciences. Institutions can achieve awards based on the degree to which they propose and implement institutional changes that are aligned with the ten Athena SWAN principles for gender equality in the Athena SWAN Charter. For example, principles include a commitment to reducing the gender difference in pay, addressing the leaky pipeline problem in girls' and women's continuation in STEM education and careers, and addressing transgender discrimination. The three tiers of awards include:

¶ Bronze: assessment of the state of gender equality at the institution, devising an action plan to address gender equality issues that spans 4-years, and creating an organizational structure that can allow for the implementation of the action plan.

¶ Silver: institution that has previously attained the Bronze award demonstrated that the action plan was implemented and resulted in positive effects.

¶ Gold: institution demonstrates sustained and substantial achievements in enhancing gender equality, responding to challenges, promoting best practices for gender equality, and evidence-backed commitment to all Athena SWAN principles.

Crucially, as of 2011, National Institute for Health Research funding is contingent on an institution receiving at least a Silver Award. The present study sought to obtain information about the perceptions of Athena SWAN by employees at the University of Oxford, a member institution (Ovseiko, Chapple, Edmunds, & Ziebland, 2017).

The study was a qualitative analysis of participant responses from previously conducted assessments of organizational culture by the institution. Researchers examined data from 59 respondents who had mentioned Athena SWAN in their comments in a previous survey. Researchers also reviewed the responses of a separate group of 37 women at the institution who were senior scientists in the Medical Sciences Division and Mathematical, Physical and Life Sciences Division. This sample of women provided narrative interviews that were approximately an hour in duration, each.

Analysis of respondents' and interviewees' comments regarding the Athena SWAN initiative yielded common themes. Respondents and interviewees were generally enthusiastic about the encouragement to apply for grants, professional support through mentorship, career development opportunities, and seminars about women in science that emerged out of Athena SWAN initiatives. Employees also noted cultural shifts regarding time use, caretaking, and parental leave, with Athena SWAN leading to positive changes in flexible scheduling,

attitudes to science, perceptions of scientists, and participation in extracurricular activities with a science focus. A modified version of the questionnaire was used for the posttest (parental attitudes and participation in extracurricular activities items were removed). Lastly, researchers conducted two classroom observations and discussion groups six months after the intervention. In these sessions, students discussed their enjoyment of the intervention activities, what they learned about STEM careers,

There were additional limitations to the study that could have affected the interpretation of the results. Participants self-selected into the intervention and control groups. Due to the fact that the intervention and control groups were not randomized, girls' family backgrounds, science and math achievement, and STEM interests were not controlled in this study. There may also have been interaction between the intervention and control groups, In summary, type of schooling did not substantially impact enrollment in advanced math and science courses (Feniger, 2010). Interesting, the most striking effect was for advanced computer science courses, where attending a single-sex school was associated with increased enrollment among girls. However, the author pointed out that this difference could be due to the way that computer science and other advanced math coursework tend to be "packaged" together in secular coeducational schools but not at religious same-sex schools. This informal tracking pathway into math and science coursework may deter some girls, as opposed to the more "a la carte" advanced science offerings available in religious schools. A further limitation of this study is that it is not a true intervention with a manipulated independent variable. Therefore, the results describe associations between schooling type and enrollment into coursework, but cannot determine whether schooling type causes differences in advanced math and science course enrollment.

South and Central Asia

Case #1: Digital Learning and Gamification in Secondary School Science Classrooms in Pakistan (Khan, Ahmad, & Malik, 2017).

Lessons in Pakistan are typically taught using lecture-based instruction. Khan, Ahmad, and Malik (2017) investigated the impact that game-based learning (GBL) and digital game-based learning (DGBL) has on students' engagement in secondary school science classrooms. In particular, researchers were interested in whether these pedagogies improved student engagement, especially for girls, compared to conventional lecture instruction. Gamification of learning incorporates components (e.g. progression, feedback, rewards, achievements/milestones) that are characteristic of game design into classroom instruction.

The participants in this intervention study were comprised of 72 8th grade students of a low-cost private school in Pakistan. The experimenters used a quasi-experimental design with two control groups and two experimental groups. The control groups remained in lecture-based classrooms and the treatment groups received the game interventions. The design of the treatment groups was based on the Games Based Learning Instructional Design approach wherein researchers determined a suitable content focus (chemistry) based on a previously administered student survey, aligned the gameplay with the Pakistan National Curriculum of Science's learning goals for chemistry, and designed the visual ˛ s f ƶ ʐ ! u wned the treatment groups performed significantly better than boys in the treatment group. In summary, DGBL had a positive impact on student engagement, with especially positive effects on interest and science learning for girls in the treatment group (Khan, Amad, & Malik, 2017).

Limitations of this intervention include the inability to generalize the results to more diverse science math subjects and to different classrooms and student age groups. Information on whether the intervention impacted students' grades in science and whether interest and engagement of students led to eventual decisions to major in STEM fields and pursue STEM careers was not collected. Therefore, it is difficult to generalize beyond the immediate impact of gamification techniques on students. However, the present study presented a compelling reason to incorporate game-based activities in science instruction and to further investigate gamification as a method of increasing girls' interest and learning in STEM fields. Future interventions along this line should also take into account students' access to computers and technology and incorporate game-based learning into computer programming and technology courses.

Case #2: Cooperative Learning in Elementary School Science Classrooms in Pakistan (Saad & Saad, 2017)

In this study, researchers examined the impact of cooperative learning pedagogy in science classes in an all-girls' elementary school in Pakistan. Cooperative learning involves creating teams or groups of students who are given a shared activity and instructed to work interdependently toward a shared goal. Previous research and theorizing on pedagogical methods for increasing girls' interest in STEM fields has suggested that incorporating cooperative learning techniques may be effective (Saad & Saad, 2017). The present study compared academic achievement after exposure to cooperative learning compared to exposure to the more traditional lecture-based teaching model that is typically used in schools in Pakistan.

Researchers recruited 128 grade-VII students at an all-girls' government school. The researchers used a pretest posttest control group design wherein students were divided into either a treatment (cooperative learning) or a control (lecture) group and science tests were used to assess academic performance before and after the intervention. The science tests were content-based multiple choice, true and false, matching, fill-in-the-blank, and open-response items. Students in both groups experienced 13 weeks of science instruction over approximately three months. The cooperative learning instruction was implemented by a

Western Hemisphere

(student-selected value written on a slip of paper within the keychain) intervention, in order to be exposed to reminders of the intervention for the duration of the study. Participants in the control condition had a choice of either the Waterloo key chain or the blank, but customizable paper slip key chain.

Following the manipulation, participants filled out a postintervention survey that contained the same questions about attitudes towards engineering, self-efficacy, and future success in engineering as in the preintervention survey. For the next 12 days following the intervention, students completed brief, 5-minute surveys that assessed students' perceptions of daily stressors, self-esteem, sources of stressors, confidence in being able to manage academic stress. Lastly, in the second semester of school, four months after the intervention, Cohort 1 completed a survey assessing the same attitudes towards engineering, gender identification, friendships, and implicit attitudes about women in engineering that we(n)21( )-20(i)7(n)21(e)-13((w)-27(o)21(n should recruit participants from a greater range of STEM majors. It is also unclear how the two interventions, social-belonging and affirmation-training could be combined or which to recommend for educators to implement. The study found positive effects of both interventions but also some distinct effects of one interven mathematics and language. Beyond this, students can choose to take additional subject tests in sciences and social sciences. The Science Test is further divided into optional subject areas, Biology, Chemistry, and Physics. In the present study, researchers investigated whether gender gaps in interest and achievement in STEM fields were associated with type of high school attended (single vs mixed-sex) (Gándara & Silva, 2016). Officials from the Pontificia Universidad Católica de Chile accessed admissions data for 141,090 students (46.5% male and 53.5% female) from 2010 that was. Of the students, 59,019 took the PSU Science Test. Admissions data included students' demographic information, school type, socioeconomic status, academic records, and PSU scores for subject tests.

Researchers found that girls in the sample had a significantly higher GPA than males, but boys and girls were equally likely to have taken a Science Test. School type was not associated with girls' decision to take a Science Test, overall. However, girls who attended single-sex schools were more likely to take the Physics and Chemistry tests, while girls who attended mixed-sex schools were more likely to take the Biology test. There were no gender differences in taking the Chemistry test, but girls were significantly more likely overall to take the Biology test compared to boys, whereas boys were significantly more likely to take the Physics test than girls. In terms of test performance, students who attended single-sex schooling, regardless of gender, had higher scores on all Science Test subjects compared to their counterparts in mixed-sex schooling. For the Biology and Physics tests, the gender gap in achievement favoring boys was larger for students who were in single technology (e.g. online learning or homework assignments) and using face-to-face classroom time for students to apply their knowledge, usually in active projects and group collaboration. The present study summarized outcomes from a teacher's all-girls' chemistry class following a change in instructional method (flipping the classroom) (Sookoo-Singh & Boisselle, 2018).

Students were 27 Year 10 girls aged 14-15. The instructor administered a pretest survey assessing motivation. The intervention took place over a 6-week time frame. Within that time, students completed online-learning and instruction in chemistry outside of the classroom and engaged in hands-on activities that applied this learning during class time. Students also provided journal responses that contained reflections on their learning of the subject. A posttest survey assessing motivation and a unit test on student learning were administered after the intervention.

There was an increase in students' motivation from pretest to posttest (Sookoo-Singh & Boisselle, 2018). However, when comparing the unit test score to students' grades in the previous semester, there was no effect of the flipped classroom intervention. Student journal responses indicated positive reception of the pedagogical method, with some exceptions. Students who did not have a positive view of the flipped classroom also experienced difficulties with using the instructional technology (Sookoo-Singh & Boisselle, 2018).

One major limitation of this research is the lack of an equivalent control and an equivalent pretest academic performance measure. Based on the results, it is difficult to definitely conclude that the flipped classroom enhanced motivation. A control group that experienced conventional instruction of the same chemistry concepts should be compared to the intervention group. A separate limitation is student access to technology that would enable participation in a flipped classroom. Widespread use of this instructional method would necessitate improvements to internet access and relevant infrastructure and access to home

Middle adulthood		

providing opportunities for girls who are interested in STEM fields to meet other similarly-aged girls with the same interests can be impactful experiences.

Conclusions

The present report reviewed examples of STEM interventions intended to bolster girls' and women's interest in, positive attitudes towards, and achievement in STEM. Due the academic interests of our course, we focused on interventions that targeted girls and women during the crucial developmental periods that overlap with secondary and tertiary schooling, spanning from approximately 10-22 years of age. This aligns with research emphasizing the importance of these developmental periods for committing to STEM educational tracks, selecting university majors, and pursuing careers in STEM (UNESCO, 2017). The present report also focused on summarizing published or publicly available outcomes research on STEM intervention programs for girls and women *outside* of the United States. To that end, we collected information on STEM programs and initiatives of varying scope and aims from shows that educational, psychological, and social interventions can be effective tools, that there is global variation and malleability in gender differences in math and science achievement, and that STEM achievement gaps have

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