The Effects of Single vs. Mixed Gender Engineering Enrichment Programs on Elementary Students' Perceptions of Engineers

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Abstract

Although there is much debate about the relative effectiveness of single-gender education, previous research comparing aspects of our female-only summer enrichment programs to equivalent mixed-gender programs has shown our female-only programs to be particularly effective in reaching young girls, influencing their perceptions of engineers and attitudes toward engineering as a career. The addition of equivalent male-only programs prompted additional research comparing 1) changes in students' attitudes toward STEM, 2) increases in student learning and content knowledge, 3) classroom climate and students' interactions in the classroom, and 4) students' perceptions of engineers using the Draw an Engineer Test.

Results showed significant increases in students' content knowledge in all programs from the beginning to the end of the programs. And although marked differences were found among the different gender grouped programs in terms of classroom climate and student interactions in the classroom, there were no significant differences between the males and females nor where there any differences between single-gender and mixed gender programs in terms of student content knowledge or attitudes toward engineering. However, significant differences were found in students' self-efficacy and perceptions of engineers from pre- to post.

In-depth analyses of students' perceptions of engineers from the Draw an Engineering Test were conducted to examine the relationship(s) among students' perceptions of engineering, attributes they assigned to the engineers in their drawing and their responses to specific items on the attitudes toward STEM survey. Significant differences were found among the gender-grouped programs in attributes related to the gender of engineers. Girls in the female-only programs were more likely to change the gender of their engineer from male to female in their pre- to post-drawings. Correlations among the gender equity items on the attitudes toward STEM survey and gender attribution of engineers in students' drawing were also examined.

Introduction

The demand for engineers in the United States workforce continues to increase[1] but the number of students studying engineering in college is not increasing enough to meet this demand[2-3]. One of the more significant reasons is the underrepresentation of females in engineering[4-5] despite the fact that gender discrimination in engineering wages has been almost eliminated[6]. To help encourage female students to study engineering, it is important to eliminate misinformation and negative impressions about engineers and engineering[7-9]. Research on engineering recruitment indicates that many young students, particularly females, do not know what engineering is or what engineers do, and many of their parents, teachers, and school counselors do not know enough about engineering to help inform them about careers in engineering[7, 10-12]. Engineers are rarely depicted or glorified in the media as are doctors, lawyers, forensic investigators, rock stars and sports figures. School outreach efforts often fail due to negative stereo-types. Therefore, not enough students explore the various fields of engineering when considering their college choices and future career options and as a result do not prepare academically in middle and high school.

Summer enrichment programs designed to increase academically talented students' interest in the fields of science, technology, engineering and mathematics (STEM)[12] have been developed by the Center for Pre-College Programs at New Jersey Institute of Technology. Programs like these can be instrumental in informing young students about careers in STEM, particularly engineering, and help ensure they receive the academic preparation required to enter college programs in engineering or other highly technical fields[13-14]. One of the programs, Women in Engineering (FEMME) was designed specifically for young girls in an effort to increase the number of women interested in engineering and other technological careers[15-16]. Middle school is an important time for students to begin thinking about future careers, but because boys and girls do not differ much in technical abilities until their high school years but rather in their attitudes toward technological careers like engineering[8, 17] it is especially important for girls. By the latter middle school years, girls start underestimating their own technical abilities and begin to place more importance on being popular than on academic performance[18, 19]. During high school they enroll in fewer mathematics and science courses, and thus lack the background needed to enroll in college STEM programs[17]. Early intervention is needed to address this problem because once students, particularly females, reach college it is too late to prepare[8, 9, 20]. Although there is much debate about the effectiveness of single-gender education[21, 22], all female enrichment programs like FEMME can be particularly effective in reaching young girls, influencing their attitudes before they reach high school[23, 24].

Background

Initially single-gender education was for affluent students, mostly boys, but by the 1970's educators began exploring better educational options for girls in response to the emerging "Gender Gap" between the academic achievement of boys and girls[25]. Considerable research can be found describing the many benefits of single-gender education for girls, suggesting such things as girls' increased confidence, being more likely to ask questions, and maintaining behaviors that tend to disappear due to male dominance in the classroom[26]. Studies of classroom behavior in co-educational classrooms also document teachers' differential treatment of boys and girls, for example, being more tolerant of boys' disruptive behavior and encouraging boys to solve problems on their own while helping girls who experience trouble[22, 27-28], further suggesting the benefits of single gender education.

In contrast, recent literature summarizing research on single-gender education caution that much of the research is not rigorous, not scientifically based, and tends to focus on private and Catholic schools where subjects are basically self-selected[25] and provide no strong conclusions supporting or dismissing the overall benefits[29]. Researchers recommend that there should be a clear rationale with specific goals for single-gender education[30-32]. Summer enrichment programs like FEMME, designed with the goal to increase the number of women interested in engineering and other technological careers in an atmosphere free from male dominance are consistent with this recommendation and prior evaluations of the FEMME program have been positive[16].

Success of the FEMME Program

Although initial evaluations of the FEMME program were mostly of a formative nature, the results were positive. Follow-up studies of program participants who had completed high school found that almost 70% reported they were either currently enrolled in a technology based degree program or had chosen a career path in STEM[32-33]. More rigorous evaluations of the FEMME program[34-36] used the Middle School Attitude toward STEM survey [MASTEM][12] that measures: Interest in engineering, Stereotypic impressions of engineers, Negative opinions about STEM, Positive opinions about STEM, Self Efficacy for Problem Solving and Technical Skills, and Gender Equity. Girls participating in FEMME programs have been found to have significantly more positive attitudes toward STEM, particularly engineering, and significantly more knowledge of engineering careers compared to other students (both male and female) from similar backgrounds [35, 37]. Many young girls who attend a FEMME program return for multiple summers and results of pre-post attitude evaluations using the MASTEM have shown the girls' more strongly agreed with the notion that "girls are just as good as boys in the areas of mathematics and science" and disagreed more strongly that "boys are better at engineering than girls" after attending one of the FEMME programs.

Single Gender Programs for Boys

More recent single-gender research focused on boys has found the climate in all-male classrooms to be much different than the climate in all-female classrooms[26, 38]. Increased use of technology, more opportunities for physical activity and the presence of male role models is beneficial for boys' learning[39-40]. But is the single-gender atmosphere or the altering of the classroom structure to teach the same curriculum responsible for the benefits?

Offering mixed gender programs and all-female programs meant that approximately 70% of the students accepted into our summer enrichment programs were female. This and a marked increase in applications from 4th and 5th grade boys prompted the addition of two all-male programs during the summer of 2012. The programs were identical to the fourth and fifth grade FEMME programs and the 4th and 5th grade mixed-gender programs. Each of the programs accepted 23 to 25 students; across all six programs there were 141 students.

Evaluation

A semi-qualitative and objective evaluation was planned to examine differences in classroom climate, changes in students' attitudes toward STEM, increases in content knowledge and changes in students' perceptions of what engineers actually do. Students completed: 1) the MASTEM (referenced above)[12], 2) separate grade-appropriate content knowledge tests of engineering, mathematics, computer technology and communications each developed specifically for these programs, and 3) the Draw an Engineer Test; each was administered at the beginning and the end of their program. At the end of the programs the teachers were interviewed to collect qualitative information about differences in classroom climate and student behavior among the three types of classes.

The mathematics, science and engineering classes for both post 4th grade single-gender programs (male and female) were taught by the same teacher as were both the post 5th grade single-gender programs. Although the mixed gender programs were taught by a different teacher, the curriculum (lessons, activities, field trips, etc.) was exactly the same. Field trips were attended by all groups within the same grade level together and were chaperoned by all teachers. Other classes, such as computer lab and communications were taught by different teachers within each subject, i.e. in computer labs all students in all programs were taught by the same teacher. No changes in teaching were made to accommodate either gender. All of the teachers had taught either the all-female or mixed gender programs previously and were familiar with the curriculum.

The Draw an Engineer Test

The Draw an Engineer Test (DAET)[41], adapted from the Draw a Scientist Test[42], was developed as a tool to more fully evaluate young students perceptions of who engineers are and what they actually do[43-44]. Students are asked to draw a picture of an engineer at work and provide a short sentence to describe what the engineer in the picture is doing. A checklist has been developed to quantify the appearance (gender, color, etc.) and location of the engineers in the picture, as well as to summarize other objects and/or people in the picture and inferences of action[45]. Previous research has found that purely quantitative measures derived from surveys such as the MASTEM are not always sufficient to capture cognitive changes in students' perceptions about engineers and a more qualitative measure such as the DAET can be more informative[36, 46].

Results

Differences in Classroom Climate

The teacher who taught the single-gender post 4th grade classes described the girls in the FEMME program as cooperative and communicative with much less physical activity than the boys in the all-male group. The boys were much more active and less cooperative than the girls, requiring more discipline and suggestions to stay on task. The teacher who taught the single-gender post 5th grade classes described the girls in the FEMME program as much more task-oriented and less competitive than the boys in the all-male group. The girls' solutions to problems were not necessarily better than the boys', nor did they appear to complete tasks more quickly than the boys. The teacher described the girls as "serious and more focused". The girls were less competitive and more willing to share and help each other than the boys. Both of these teachers had taught the mixed gender and FEMME programs in previous years and agreed that the classroom atmosphere in each of the single gender programs was very different than in the mixed gender groups.

In the mixed-gender programs (approximately 42% female; 58% male) the girls focused more on the task rather than interacting with the other girls and boys, whereas in all-female groups, even though the girls remained focused, they interacted more with other members of the group. The girls appeared to distance themselves during group activities in mixed gender groups. Comparing notes about identical classroom lessons or activities with the teachers who taught the mixed gender programs suggested less personal interaction during group work in mixed gender groups and a lower level of class participation from girls in the mixed-gender programs.

Attitudes toward STEM and Content Learning

Three-factor repeated measures analysis of variance techniques were used to test for changes in students attitudes toward STEM and increases in students' content knowledge as measured by the MASTEM[12] and program specific content knowledge tests which included mathematics, engineering, computers and communication. Two between subject factors, gender and type of class (single-gender vs. mixed gender) and one within subject factor (time from beginning to the end of the program) were used to test for differential effects due to gender or type of class. All students in each of the six programs showed significant and substantial increases in all areas of content knowledge from the beginning to the end of their respective programs. Within the single-gender and the mixed-gender programs there were no significant differences between the content knowledge scores for the males and females, nor where there any differences between scores among the single-gender and mixed gender programs. All students, male and female performed equally well in all programs. Details of the results are reported elsewhere[47].

No significant changes were found in students' attitudes toward STEM in terms of Interest in engineering: (stereotypic and nonstereotypic), Negative opinions of STEM, Positive opinions of STEM, or Gender equity[47]. Although this was disappointing it was not surprising; the students' attitudes toward STEM were already very positive before beginning the programs as is typical of students who attend enrichment programs[36, 46]. However, significant differences were found in Self Efficacy. For both the male and female students in the single-gender programs the mean Self-Efficacy scores increased significantly from the beginning to the end of the program, while the mean Self-Efficacy scores decreased for students in the mixed-gender programs[47].

Increased self-efficacy is important for continued learning and persistence when learning becomes more complex or students have difficulty. A classroom environment that supports collaboration and positive interactions among students is also important. Unfortunately, insignificant changes in objective measures of students' learning and attitudes toward STEM are often found with high-achieving students such as those who attend enrichment programs[35-36, 46] and in a case like this suggest there may be no academic benefit to single-single programs. More qualitative measures of changes in students' cognitions and/or perceptions that more adequately capture these types of latent measures are necessary.

Preceptions of Engineers through Drawings

Previous research using the Draw an Engineer Test has found the DAET to be a useful semi-qualitative tool in more fully exploring young students' perceptions of engineers, what they believe engineers actually do, and how their perceptions may have changed as a result of educational interventions[36, 46]. Students' drawings of Engineers at Work are summarized using the DAET checklist[45]. The checklist begins with an examination of the engineer to check the species (i.e. Human?), actual presence, gender, skin color, and other attributes, like glasses, lab coats, crazy hair or other clothes. Then the location of the engineer (inside, outside, in space, underwater) is coded and there is a list of inferred actions that can be indicated, like fixing vs. designing, teaching, experimenting vs. building, or even NO action can be indicated. The types of other objects in the drawing are also coded, for instance, the presence of other people, animals, symbols that would indicate math or chemistry, airplanes, computers, car, trains, signs of thinking, etc. The wearing of a hard hat and a face shield has been added to the attributes, "signs of communicating with others" has been added to the list of actions and more specific details about the species and gender of the engineer are also being explored to more fully understand students' perceptions and how they change.

First, the physical characteristics of the engineer were examined for signs of gender including long hair, the wearing of a dress, facial hair, name badges, etc and verbiage in the sentence describing what the engineer is doing was checked for the use of He, She, it, my or "the engineer". Often the engineer students draw is a stick figure with no gender or a mechanic/worker with only legs protruding out from under a rocket or car. When a stick figure, androgynous person or partly hidden person is described as "it", "my engineer" or "the engineer" in the sentence then the gender of the engineer is coded as unknown. All students' beginning and ending drawings were examined and the engineer was coded as Male, Female or Unknown.

The physical characteristics of the engineer including gender were examined in relation to students' gender and type of program, all-male, all female, or mixed-gender. None of the male students in either the single-gender or mixed gender programs drew female engineers at the beginning or the end of the program. While approximately 25-30% of the girls in the mixed-and single-gender programs drew female engineers at both the beginning and end of their programs, only girls in the single-gender female program changed their image of an engineer from a male or a person of unknown gender to a female. This seems to contradict the fact that there was no change in the girls' average response to the gender equity items on the MASTEM. And although the girls' average responses to the gender equity items were slightly higher than for the boys, there were no significant differences between the boys and girls or among the different types of programs. For example, girls' did not disagree more strongly with the statement "Boys are better at being engineers than girls" at the end of the program than they did at the beginning, nor did they respond much differently than the boys overall. This prompted an in-depth examination of individual changes on the gender specific items of the MASTEM and specific gender related changes in students' drawings to examine the correlation between the two measures as they produced different conclusions about students' gender attributions of engineers.

In addition, differences in other aspects of students' drawings from pre- to post- were examined to help identify important changes in students' perceptions of engineers and engineering and to determine if correlations exist between their perceptions depicted in their drawings and responses to the MASTEM. Although there were 141 students enrolled across the six programs (three gender groupings across two grades), only 134 completed both the pre- and post- measures.

Physical characteristics of engineers

Approximately 30% of all the students drew their engineer as a stick figure pre- and post-. Although there was no significant change from pre- to post- within each of the three gender groups, it was interesting to note that only 18% of the girls in the single-gender FEMME program drew stick figures while 40% of the students in single-gender male groups and the mixed group drew stick figures pre and post. The girls in the FEMME group were also more likely to give their engineers a skin color (mostly peach) than students in either of the other two groups and almost 35% of them drew a female engineer in their pre-drawing. None of the boys in the single-gender male group or the mixed group drew a female engineer and less than 15% of the girls in the mixed gender group drew a female engineer. Although this is not surprising, it is important. Some of the girls in the 5th grade FEMME group were in the 4th grade FEMME group the previous summer and probably already perceived engineers as female, and it is possible that the girls in the 4th grade FEMME group held the notion that engineers could be female just because they were in an all-girl engineering program. Looking at how their perceptions of an engineers' gender changed would be an interesting measure of the impact of the program(s). Possible changes in gender of the engineer from pre- to post- are:

<u>No change</u>: Male\Male, Female\Female and unknown\unknown.

<u>Change from</u>: Male to Female or unknown, Female to Male or unknown, and unknown to Male or Female.

Almost 80% of the boys in the single-gender male group and 50% in the mixed-gender group drew male engineers in their pre-drawings, the remaining drew engineers of unknown gender; none drew female engineers. There was very little change in their post-drawings. In the single gender male group, most drew male engineers again, less than 10% changed from male to unknown gender and another 10% changed from unknown gender to male. There was less change in the mixed gender group. The only gender differences between the drawings of the engineers by the boys in the mixed group and the boys in the single-gender group was that the boys in the mixed group drew more engineers of unknown gender. None of the boys in either group drew female engineers, pre- or post.

In the single-gender female group, the girls who drew female engineers in their pre-drawing (35%) also drew female engineers in their post-drawing. More than 60% of the girls who drew male engineers or engineers of unknown gender in their pre-drawings drew female engineers in their post-drawings such that almost 75% of the girls drew female engineers in their post-drawings. In contrast, of the approximately 30% of the girls in the mixed-gender group who drew female engineers in their pre-drawings, half of them drew male engineers or engineers of unknown gender in their post-drawings. And, only about 20% of the girls in the mixed gender group that drew male engineers or engineers of unknown gender in their pre-drawings changed the gender of their engineer to female such that only about 40% of the girls in the mixed-gender group drew female engineers in their post-drawings.

Changes in gender attribution of the engineers where coded in several different ways to capture change from male to female, unknown to female, unknown to male, etc., and correlated with changes in students responses to the gender equity items on the MASTEM: "Boys are better at being engineers than girls" and "Girls can do math and science just as well as boys". No significant relationships or patterns were found across all three groups or within any of the groups. Regardless of the gender attribution of the engineers in their pre-drawings most students, male and female, agreed that girls can do math and science just as well as boys, and disagreed that boys better at being engineers than girls, so that while there was significant change in many of the girls drawings there was little or no change in their responses to the MASTEM.

What engineers do?

Drawings along with the one sentence attribution are examined to determined what the engineer is actually doing and coded as; 1) making\fixing\working with hands, 2) operating\driving machines or vehicles, 3) building, 4) designing\inventing\creating, 5) studying\reading\questioning, 6) using a computer, 7) experimenting\testing\creating knowledge, or 8) no action inferred. See Table I for a pre- post- summary of the percentage of drawings coded in each category. A desirable change would be for significantly more drawings to be coded as "designing, inventing, creating or experimenting, testing, creating knowledge". A chi Square test found the increases from 5% to 30% and 3% to 11% respectively to be significant (To reduce the number of cells with percentages less than 5% using a computer was combined with operating machines) (X_7^2, $p<.01$). After completing their summer programs, more students depicted engineers in their drawings that were "designing, inventing, creating or experimenting, testing, creating knowledge" and fewer were "building, making, or fixing". This change was consistent across all three of the gender groups. A common misconception about engineers is that they spend a lot of time using a computer and it was encouraging to see that even though the percentage of drawing with engineers using computers was low in students' pre-drawings, it was even lower in their post drawings.

TABLE I
PRE- POST- SUMMARY OF WHAT ENGINEERS ARE DOING

	Pre	Post
Making\fixing\working with hands	48%	31%
Operating\driving machines or vehicles	5%	4%
Building	22%	14%
Studying\reading\questioning	9%	8%
Using a computer	4%	1%
Designing\inventing\creating	5%	30%
Experimenting\testing\creating knowledge	3%	11%
No action inferred	4%	1%

The other objects, such as tools, robots, symbols, sign, etc and/or people in the drawings are also included to help determine students' perceptions of what engineers do. Table II is a pre- post- summary of the objects and other people found in students' drawings across all three gender groups. Drawings were coded to indicate only one inference of action so that the percentages in Table I add up to 100%, but up to 8 other objects or people were coded in students' drawing so the percentage in Table II will add up to more than 100%.

T-tests for proportions were used to test for significant changes in the percentage of objects depicted in the pre- and post- drawings. The percentage of drawings with computers also decreased significantly. Many more drawings had computers in them but did not necessarily have the engineer drawn such that the engineer had his/her on the keyboard indicating use as in Table I, but just the presence of computers decreased also.

The presence of rockets and space vehicles increased because the 5th grade programs focus on aeronautical engineering. The importance of this significant increase comes from the fact that more than 50% of the students that drew a rocket in their post drawing indicated the engineer was testing the rocket rather than fixing it. Interestingly, these students were in the single-gender groups and not the mixed gender group.

In the post drawings, engineers were more often depicted as studying or looking at what appeared to be blueprints, graphs or other drawings, often with signs of thinking that included scratching their heads or a "bubble" indicating what they were thinking or saying…for example "I sure hope my new rockets flies". More than 50% of these drawings were by girls in the single-gender FEMME group. The percentage of boys in the single-gender group who drew their engineer with signs of thinking increased from 7 % to 20%, the percentage of boys in the mixed-gender group who drew their engineer with signs of thinking increased from 4 % to 22%, the percentage of girls in the mixed-gender group who drew their engineer with signs of thinking increased from 5 % to 10%, and the percentage of girls in the single-gender FEMME group who drew their engineer with signs of thinking increased from 14 % to 38%. The girls in the single gender FEMME group also drew female engineers experimenting with chemicals more often than the girls in the mixed-gender group or any of the boys.

TABLE II
PRE- POST- SUMMARY OF DRAWINGS OF ENGINEERS AT WORK

	Pre	Post
Robots	9%	5%
Computers	13%	6%*
Building tools (wrench, hammer, etc)	45%	42%
Measuring tools (rulers, etc)	<1%	1%
Writing Objects (paper, pen, pencil)	3%	2%
Animals\Plants\Fish	2%	3%
Passenger Vehicles (cars, small trucks)	25%	25%
Construction Vehicles	6%	5%
Flying Vehicles	12%	13%
Rockets\Space Vehicles	4%	15%*
Trains	3%	0%
Fictional Machines	2%	<1%
Other Machines	7%	11%
Books	1%	1%
Furniture	27%	24%
Math Symbols	3%	4%
Chemistry (flasks, test tubes, etc)	4%	7%
Blueprints (Drawings, Graphs)	9%	17% *
Danger (fire, explosions)	1%	1%
Civil Structures (bridges, buildings)	14%	11%
Technology (TV, radio, phone)	1%	1%
Medicine (syringes, needles, etc)	1%	1%
Other People	9%	9%
Signs of Thinking	8%	23% *

* Significant change, $p<.05$

Disscussion

Results of the current investigation are mixed but still allow for some important conclusions. While all of the students who attended the summer programs in the Center for Pre-College Programs at New Jersey Institute of Technology had positive attitudes towards STEM and showed significant academic gains, their attitudes toward STEM did not increase significantly during the program. Although students' perceptions of engineers and what students think engineers actually do depicted in their drawings of engineers at work showed significant change, few significant differences were found between the boys and girls and among the three different gender grouped programs except for the female only girls' perception that engineers are female.

There was no significant change from pre- to post- in the girls' responses to the gender equity items on the MASTEM[12] even though more than half of the girls in the single-gender program changed the gender of the engineer in their pre-drawing from male or unknown gender to female in their post-drawing. No correlations could be found between changes in students' responses to these items and changes in the gender of the engineer in their drawings for boys or girls in any of the gender groups. Most girls and even boys disagreed that boys were better at being engineers than girls on the pre-survey even though none of the boys and very few girls drew female engineers. Possibly, students knew the "right" response was to disagree, whether or not they actually believed it, and their drawings showed their true underlying beliefs more clearly and thus showed a changed from pre- to post- that the survey did not.

Across all three gender groups a significant proportion of students' drawings changed from engineers building, fixing and operating machinery (pre) to engineers testing, designing, inventing or experimenting (post), indicating that all students developed a more accurate perception of what engineers actually do while participating in their summer program. Examination of the other objects and people in the students drawing indicated additional significant changes. Students' post drawings showed fewer engineers alone with a computer or driving a train, which are common misconceptions about engineers. Students' post drawings also showed more signs of thinking, looking at blueprints or graphs and more people testing rockets. Although the percentage of drawings with other people did not change from pre- to post-, the nature of the drawings with more than one person changed. Most pre-drawings showed another person either with no real indication of what the person was doing or the person was driving a vehicle, while the other people in the post drawings appeared to be interacting with the engineer more often and none were operating vehicles.

Increased self-efficacy and an increase in girls' perceptions that women can be engineers strongly suggest that there are benefits to female only programs for girls. Certainly an increase in self-efficacy and a more accurate perception of what engineers do can be considered beneficial for the boys in the male only program. Clearly the increased academic gains for student in the mixed gender programs, as with the single-gender programs, are positive effects, students in the mixed gender group did not experience the benefits of increased self-efficacy and the girls' did not complete this program with a strong belief that engineers can be female.

Insignificant changes in students' attitudes toward STEM, like those found in the current study using the MASTEM have been found before with high-achieving students, such as those who attend enrichment programs[35-36, 46]. The fact that no significant correlations were found between characteristics of students' drawing and their responses to the MASTEM suggest that more qualitative measures like the Draw an Engineer Test are better measures of changes in students' perceptions as a result of enrichment programs than more objective types of measures like the MASTEM which are typically used to evaluate new programs or changes in curriculum.

Evaluation of the programs offered by the Center for Pre-College Programs at New Jersey Institute of Technology is an on-going and continuous process. The assessments described in the current paper are being replicated and results with be reported when the analyses have been completed.

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