The near-peer mathematical mentoring cycle: studying the impact of outreach on high school students' attitudes toward mathematics

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ABSTRACT

College students may be seen as near-peers to high school students and high school students are often able to see themselves in the college students who are but one step ahead. This nearness in maturity and educational level may place college students in a particularly powerful position when it comes to reaching out to high school students to promote higher education in math and science. In this study college students gave dynamic mathematics outreach presentations, MathShows, to minority and low-income high school students in a mid-sized public school district on the U.S. border with Mexico. The study investigated the impacts of this sort of outreach work on high school students' attitudes towards mathematics using a mathematics attitudes survey. Results, obtained from $N = 306$ participants, showed statistically significant improvements in almost all components of mathematical attitudes, with less of an effect on the component of self-confidence in doing mathematics. Differences in impacts by specific student subgroups are all discussed.

KEYWORDS
Mathematics education; outreach; near-peer mentoring; mathematical identity; attitude surveys

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1. Introduction

In this paper, we present a study of the impacts of a mathematics outreach program that used near-peer mentoring to motivate interest in the study of collegiate mathematics among high school mathematics students. The outreach work reported here had the goal of increasing matriculation and retention, especially of minority and low-income high school students, into courses of study in mathematics at the college level while simultaneously promoting the retention of undergraduate students in mathematics careers and matriculation into graduate studies in STEM. There are several reasons for which scholars may choose to pursue engaging in outreach work. For example, promoting interest in the study of advanced mathematics and science may work to upset trends of low achievement in those subjects [1] that are especially evident among minority students, such as Hispanic students and Black students [2]. Furthermore, the limiting factor of low achievement in mathematics and science in advancing students in STEM operates in concert with other key factors that have been identified to impact high school students' interest and choices in STEM, such

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as gender, early high school interest in STEM, exposure to math and science courses, and self-efficacy beliefs [3,4]. This paper focuses on an important factor related to educational and career choices in STEM, namely, attitudes toward mathematics and changes in those attitudes as a result of the mathematics outreach.

2. Review of literature

This study drew upon and contributes to research concerning mathematics learning that happens in high school and college especially during extracurricular activities and informal outreach situations. In particular, the research reported in this paper was informed by the literature concerned with the educational roles of: mathematical identity, Near-peer Mentoring and experiential learning.

2.1. Mathematical identity

As students encounter mathematics through engaging with their peers, their teachers and with others around them in and out of school, they develop a sense of who they are in relation to mathematics. Identity is a complex construct and has been defined by theorists in numerous, often contradicting, ways [5]. This study adopted Anderson's [6] four-dimensional model of mathematical identity as being constructed by students through their *engagement* with mathematics, which affects their *imaginations* of the ways in which mathematics fits into their lives and how they make choices in *alignment* with these imaginations, all of which may be variously supported or weakened by their self-perceived *nature* or natural ability in mathematics. Building on such theories concerning mathematical identity, others have posited specific ways of promoting students' attainment of positive mathematics identities: these include knowing and believing in students, broadening definitions of mathematical success, valuing students' mathematical expressions (whether mathematically correct or incorrect) and understanding that identities are malleable and change over time [7]. The outreach activities investigated in this study were designed to support students' development of positive mathematical identities and the research purpose was focused on measuring and describing changes in critical components of these identities.

2.2. Near-peer mentoring

Students may at times be more willing and able to absorb information that is delivered to them by their near-peers, rather than by traditional figures of authority such as teachers. Multiple studies have shown that peer and near-peer led activities have a strongly positive impact on students [8–13]. Moreover, such near-peer approaches not only affect the intended target audience, but also have a *feedback* effect upon the group doing the presentations. Williams [10] showed the particular benefit upon their near-peers that positive role models can have in enhancing group learning. Miele et al. [14] showed that early exploration of opportunities in science and careers involving near-peer leaders encouraged students to pursue science majors. Additionally, near-peer mentoring has played a central role in helping young students to take interest in and develop skill in scientific inquiry [9,15] and in promoting retention in engineering programs [16]. Mentorship programs in the sciences and mathematics that included activities such as shared lunches and involvement in a team have also been shown to engender in participants a sense of participation in a broader scientific community and even to help community college students to transfer to universities [17].

Furthermore, of particular interest to this study was the finding that near-peer mentorship models have been shown to benefit underrepresented minority students and to have a strongly positive effect on the mentors themselves [13]. This study investigated variables related to students' interest toward mathematics through an intervention that utilized near-peer mentorship for promoting the goal of broadening participation of underrepresented groups in math and science careers. This goal also aligns with current agendas pursued both by funding entities such as the National Science Foundation in the U.S.A. and also by Hispanic Serving Institutions (HSIs) [18].

2.3. Experiential learning

This study embraced the components of experiential learning [19] as important for learning mathematics. Kolb's theory of experiential learning posits that learning happens best when the following four components are present: concrete experience, reflective observation, abstract conceptualization and active experimentation. These processes of experiential learning imply that students play an active role by interacting in multiple ways with concepts and objects. Freeman et al. [20] showed that active learning plays a particular role in increasing students' achievement in STEM. Furthermore, Nordby [21] gives the example of gamification as an experiential learning task that 'invites informal learning into the [mathematics and physics] classroom' (p. 6353) and Weinberg et al. [22] found that an experiential learning program improved middle school students' motivation toward mathematics and science. The outreach activities investigated in this study were designed by using principles of experiential learning: they began with concrete objects and familiar mathematics topics that were accessible to students but then pushed those objects and topics to a new and higher, possibly abstract, conceptualization through visual and tactile experimentation and reflection. This paper reports the effects on high school students of participating in such activities with their college near-peers.

2.4. Theoretical framework

The educational outreach design of this study used the following near-peer mentoring cycle (Figure 1) as a conceptual model to inform the structure and relationships of educational activities and participants. The near-peer mentoring cycle, developed by the authors of this study and founded on the literature concerning mathematical identity [6] and near-peer mentorship referenced above [13], involves three near-peer participant groups in the educational enterprise, all of which both instruct and learn from each other in different ways: university professors engage college students in mathematical investigations and training for doing outreach, college students engage high school students in mathematical investigations and conversations (and examples) about going to college, high school students give college students an audience and constructive feedback concerning their presentations, college students give university professors assistance in research and research data.

In this model, participants are involved in a scientific community [17] where diverse kinds of learning are available, for instance: learning of mathematical content, learning of

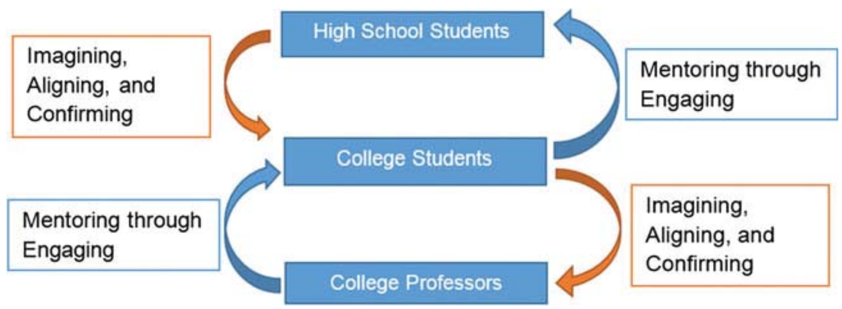

Figure 1. Near-peer mentoring cycle.

college and career readiness tools, learning of research methods and practices, learning of technology, research methods and practices, to name a few. The mathematics outreach work investigated in this project took the learning of mathematics as the central context and it took *experiential learning* [19] as the framework for the design of educational activities. Within the near-peer mentoring cycle model, this paper reports results only on the level of impacts on high school students.

3. Approach to mathematical outreach: MathShows

Finally, this study may also be considered as a formal investigation of the mathematics outreach work developed by the authors over several years. In 2014, the authors became co-directors of a research lab at their institution and began to engage college students in doing mathematics outreach presentations in local high schools, at the invitation of local school districts.

A central component of the mathematics outreach work was what the authors refer to as 'MathShows.' Lichtenstein et al. [23] found that 'a single positive interaction, excitement about a course's teaching and/or context …[can] cause a student to confirm his or her choice to stick with engineering.' In this spirit, the MathShows used in the outreach work were brief presentations designed to last for the duration of one high school class period, usually about 50 minutes or 75 minutes in duration, and involving ideally about 30, but no more than 100, high school students. The MathShows were composed of discrete 'acts', i.e. interactive mathematical demonstrations and investigations that can be completed in at most 15 minutes and often less and that were mostly self-contained in the sense that they did not depend on the other scenes of the show for students to comprehend them. MathShows were designed to be mathematically attainable to the grade/subject-level of the audience. However, the content of the MathShows was designed to be entirely new to the audience, to stand on the horizon of the typical high school curriculum, to be both challenging and exciting to students through experiential learning, and to be specifically and explicitly connected to a branch of higher mathematics seen by college students. Finally, an essential component of each MathShow was testimony by college student performers of their experience in getting into college and studying mathematics. The label 'MathShow' used here may not be a novel term and is definitely not a novel concept; other educators (in particular, Jayadev Athrea, University of Washington, and Sean Lawton, George Mason University, as well as others) have presented mathematics to young students in this way. Toward the end of the paper, we outline the contents of a sample MathShow with suggestions for implementation.

The novelty of the usage of MathShows in this study was in the particular involvement of college students as presenters and developers of MathShows. At the outset of this work, these presentations were conducted by the authors (university professors) with college students functioning as facilitators, distributing materials, etc. However, in subsequent years students were encouraged to take on much greater responsibility for presenting MathShows to high school students, even to the point of at times taking full responsibility for arranging and giving multiple presentations at schools. The apparent impact of this shift was dramatic for both the high school students and for the college students. The high school students seemed to respond with more vigour to the college student presenters than to the college professor, and the college students also took more ownership of the presentations and also persisted in their academic studies. This study reports the authors' attempt to understand this impact through formalizing research questions and collecting associated data that could lead to judgements concerning changes in high school students' perceptions of mathematics as a result of the outreach presentations and concerning college students' perceptions about themselves as presenters of mathematics.

4. Methods

The study presented in this paper used a quantitative survey design as a means of evaluating the effects of the mathematics outreach activities. This section presents details regarding the participants and the instrument selected, as guided by the main research question of the study.

4.1. Research question

The following question guided the selection of methods and tools for investigating the impacts of the outreach described above.

In what ways does a mathematics outreach program utilizing near-peer led MathShows influence high school students' attitudes towards mathematics?

4.2. Participants

This study took place in the Rio Grande Valley of Texas which is one of the fastest growing regions of the United States, and which has a very large Hispanic population (>90%) and also the lowest average income per year in the U.S.A, $27,244. Additionally, according to the U.S. Census Bureau, the proportion of adults aged 25 and over with bachelor's degree or higher in the Rio Grande Valley was below 16%, compared to 28.8% in the United States overall. Hence, it was hoped that one of the broader impacts of this study would be to offer insights into broadening the participation by ethnic minority and low-income students in advanced degrees and careers in mathematics and STEM. Hence, the study utilized the strategic geographic and demographic qualities of the Rio Grande Valley by engaging the participation of college students in a large HSI together with high school students from one mid-sized school district in the Rio Grande Valley. The selected school district served more than 15,000 students, greater than 99% of which were Hispanic students, 81% of which were from low-income homes and 48% of which were English language learners.

Data reported in this study were obtained during one year of the project, from 392 high school geometry students in the district.

4.3. Instrumentation and data collection

For this study the authors used a modified (19-item) version of the Attitudes Towards Mathematics Inventory (ATMI) [24] as a pre- and post-test to capture high school math students' attitudes toward mathematics a few days before and immediately after students had seen a MathShow (outreach presentation) given by the PI and/or other college students. The ATMI is an instrument that contains Likert-scaled items intended to measure four domains of attitudes toward mathematics: Self-Confidence in mathematics, sense of Value for mathematics, Enjoyment in doing mathematics, and Motivation for pursuing mathematics. The instrument used in this study (see Figure A.1 in the Appendix) was adapted from Lim and Chapman's [25] suggested reduced set of ATMI items. Items were randomly ordered in their placement on the survey and approximately half (9) of the 19 items were negatively worded in order to avoid, and identify and omit, acquiescence responses (either all positive or all negative survey responses); very few (<5 out of 392) responses needed to be omitted because of obvious acquiescence. Furthermore, in lieu of reporting a full confirmatory factor analysis of the observed latent factor structure, we report several relevant Cronbach alphas [26]. In this study, the instrument displayed largely acceptable to excellent reliability indices: alphas for the 19-item pre- and post-tests were 0.877 and 0.879, respectively, and alphas for the four latent variable subscales of Self-Confidence, Value, Enjoyment and Motivation, on both pre- (post-) surveys were, 0.732 (0.717), 0.745 (0.777), 0.793 (0.801) and 0.575 (0.663), respectively.

Pen and paper survey data were collected from high school students no more than two weeks prior to each MathShow and again immediately after the show was over. Close timing of data collection with the MathShows was intended to avoid the confounding variable of students' extra time spent in their regular math classes. All findings, including reliability evidence above, presented here come from $N = 306$ respondents who had completed both pre- and post-surveys. A very small number (<1%) of these data contained multiple responses or missing responses. In the former case, a single response was imputed by averaging the multiple Likert-scaled responses given; in the latter case, a response was imputed using the Person-mean substitution method [27]. Most statistical analyses for this study were completed using SPSS and Microsoft Excel.

For the purposes of this study, we define the *impact* of a MathShow in a particular category (Self-Confidence, Value, Enjoyment and Motivation) to be the difference between the post-test score and the pre-test score for that category.

5. Results

This section presents findings concerning the impact of our MathShows on high school students' attitudes toward mathematics. Results of three levels of analysis of the survey data are given: first, evidence of overall changes in attitudes toward mathematics, then evidence of specific changes in attitudes among subgroups in the participant population and finally noteworthy changes in specific survey item responses are presented. The findings given here draw from survey data collected in the 2016–2017 school year from $N = 306$ high school geometry students that had each participated in one of several MathShows given over four schools days and each of which students had completed both the pre- and post-surveys.

5.1. Near-peer led MathShows change high school students' attitudes toward mathematics

As Table 1 indicates, paired *t*-tests of pre- and post- scale scores on several important variables measured by the survey showed that high school students' attitudes had changed in several slight, but statistically significant ways immediately following the near-peer led MathShows. Note that for convenience and brevity, in all tables we will shorten the Self-Confidence category to SC, Value category to VAL, Enjoyment to ENJ and Motivation to MOT. The variable ATMI in the tables refers to the overall average survey score, combining all four attitude subdomains.

As indicated by Table 1, after the MathShows students reported that their sense of the Value of mathematics, their Enjoyment of mathematics and also their Motivation to pursue further studies in mathematics had all slightly increased. These positive changes are also depicted in the bar graphs of Figure 2. Although Figure 2 shows a slight increase in the average Self-Confidence score among these high school students, Table 1

Table 1. Paired samples *t*-tests of MathShow impact.

	t	Sig. (two-tailed)	Mean difference	Std. error of the mean	95% confidence interval of the difference	
					Lower	Upper
ATMI impact	6.222	0.000	0.111	0.018	0.076	0.146
SC impact	1.156	0.249	0.031	0.027	− 0.022	0.083
VAL impact	3.950	0.000	0.108	0.027	0.054	0.163
ENJ impact	6.061	0.000	0.173	0.029	0.117	0.229
MOT impact	4.583	0.000	0.135	0.029	0.077	0.193

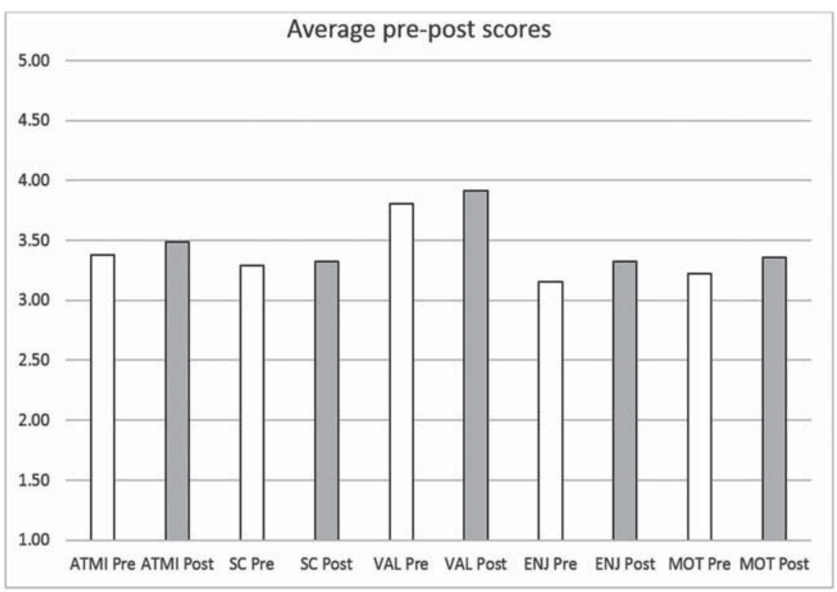

Figure 2. Differences of average pre-post ATMI and subscale scores.

indicates that this change was not statistically significant. There was no evidence that the MathShows impacted the Self-Confidence of the participant group generally, although the Self-Confidence of certain subgroups does exhibit changes, as shown in the next section.

As seen in Table 2 and indicated in Figure 2 below as well, the positive attitude changes were relatively small – all less than half a point on a 5-point Likert scale – but statistically significant. Given that this change in students' attitudes was observed after they had participated in only one brief MathShow involving presenters who were previously unknown to them, it seems likely that an even more sustained intervention, such as multiple MathShows over a longer period of time, might have greater positive impacts in terms of students' attitudes toward mathematics.

5.2. Near-peer led MathShows impact different high school students' attitudes in different ways

To better understand the impacts of the MathShows on high school students, we also investigated the differential changes in attitudes that could be observed in subgroups of students. The MathShows were conducted in 10 different classes at three high schools, which we will refer to as schools A, B and C. Schools A and B were traditional high schools and school C was an alternative school for students who had not been successful in the traditional high school because of conflicting life experiences such as criminal activity, drug use or other difficult family issues. Moreover, out of the 10 classes, 4 were pre-AP classes and 6 were non-pre-AP. In the United States, '*AP*' is an acronym for *Advanced Placement*, and 'pre-AP' denotes students who were enrolled in more advanced courses that prepared them for enrolment in AP high school courses such as calculus and statistics. Table A.1 in the Appendix summarizes the results of the survey for each class.

Note that during the presentations, each class had at least 20 students, however, not all had completed the pre-survey. Therefore, some had fewer usable surveys. Despite differences in pre-survey response scores, most of the classes exhibited an improvement in most of the categories. However, Class 1 behaved like an outlier with no change or slight decrease in scores for the Self-Confidence, Value and Motivation categories. Table 2 shows results of a homoscedastic independent samples t-test that compares the MathShow impact for Class 1 and all other classes. Equal variances are assumed because Levene's test was insignificant for these two samples. This shows that the impact of the MathShow on students in Class 1 was significantly weaker in terms of the overall ATMI average (with $p = 0.030$) and the Enjoyment category ($p = 0.009$). There are a number of possible explanations for this. Class 1 received the first MathShow presentation of the academic year and it is possible

Table 2. Independent samples t-test for impact for Class 1 ($N = 42$) and other classes ($N = 264$).

					95% Confidence interval of the difference	
	t	Sig. (two-tailed)	Mean difference	Std. error difference	Lower	Upper
ATMI impact	− 2.186	0.030	− 0.112	0.051	− 0.213	− 0.011
SC impact	− 0.532	0.595	− 0.041	0.077	− 0.193	0.111
VAL impact	− 0.469	0.640	− 0.037	0.080	− 0.195	0.120
ENJ impact	− 2.642	0.009	− 0.217	0.082	− 0.379	− 0.055
MOT impact	− 1.917	0.056	− 10.163	0.085	− 0.331	0.004

Table 3. Equal variance independent samples *t*-test for pre-survey and post-survey results for pre-AP ($N = 110$) and non-pre-AP ($N = 196$) students.

					95% confidence interval of the difference	
	t	Sig. (two-tailed)	Mean difference	Std. error difference	Lower	Upper
PreATMI avg	1.162	0.246	0.072	0.062	− 0.050	0.195
PostATMI avg	1.630	0.104	0.099	0.061	− 0.021	0.219
PreSC avg	1.288	0.199	0.100	0.078	− 0.053	0.254
PostSC avg	1.990	0.047	0.149	0.075	0.002	0.296
PreVAL avg	0.418	0.676	0.031	0.075	− 0.116	0.179
PostVAL avg	0.126	0.900	0.010	0.076	− 0.140	0.159
PreENJ avg	0.088	0.930	0.007	0.084	− 0.158	0.172
PostENJ avg	1.267	0.206	0.103	0.081	− 0.057	0.263
PreMOT avg	2.243	0.026	0.170	0.076	0.021	0.319
PostMOT avg	1.831	0.068	0.144	0.079	− 0.011	0.298

that presenters were still getting used to the material and were thus not as effective. Impact upon students in this class may have been further compounded by the fact that this was an early morning session and students were not yet fully awake, although no other morning sessions exhibited this trend.

In Table A.2 of the Appendix, we aggregate the findings by larger subgroups – in particular we compare the pre-AP group of students and the non-pre-AP students. Also, we compare school C, the alternative high school, with standard high schools A and B.

These numbers show students in the alternative school C seemed to display a greater improvement in the Motivation score than schools A and B (+0.31, with std. dev. 0.43, for school C compared to +0.12, with std. dev. 0.52 for schools A and B), despite having a lower average baseline Motivation score (3.13 compared to 3.23 for others, although this difference did not display statistical significance). Levene's test for equality of variances was insignificant with $p = 0.522$, therefore a *t*-test for independent samples with an equal variances assumption was conducted, and it showed $p = 0.057$, or nearly statistically significant. However, the result of a group with an overall lower motivation for mathematics potentially showing a greater improvement as a consequence of MathShows is interesting and warrants further study.

On the other hand, comparing the pre-AP and the non-pre-AP subgroups of students shows that the pre-AP students had somewhat higher baseline scores compared to non-pre-AP and that the gap persisted in the post-survey scores as well. However, as shown in Table 3, the pre-survey Motivation scores and the post-survey Self-Confidence scores are higher in the pre-AP with statistically significant *t*-test *p*-values of 0.026 and 0.047, respectively. The higher Motivation scores for pre-AP students was to be expected since they must have had sufficient motivation to enrol in the more advanced mathematics course.

In order to better understand how initial attitudes to mathematics affected the students' response to the MathShow, we separated the students' responses according to different levels of scores on the pre-survey. In particular, for the overall ATMI score and each of the four categories, we separated the responses into two subgroups: those for which the score was strictly less than the median and those strictly greatly than the median. The definitions of these subgroups are given in Table 4.

A comparison of impact between the high and low subgroups shows that, in general, the MathShows had a greater positive impact on students who had low initial values in any of the categories. This can be seen in Table 4 when comparing the top section of the table

Table 4. Comparison of impact by subgroups defined by high versus low initial responses.

Subgroup	preATMI Low	preSC low	preVAL low	preENJ low	preMOT low
Definition	preATMI $<$ 3.37	preSC $<$ 3.40	preVAL $<$ 3.80	preENJ $<$ 3.20	preMOT $<$ 3.25
N	150	146	134	145	144
ATMI impact	0.19^{***}	0.19^{***}	0.14^{***}	0.19^{***}	0.19^{***}
SC impact	0.10^{*}	0.19^{***}	0.00	$0.08^{\dagger}$	0.07
VAL impact	0.19^{***}	0.13^{**}	0.24^{***}	0.16^{***}	0.17^{***}
ENJ impact	0.26^{***}	0.23^{***}	0.18^{***}	0.34^{***}	0.23^{***}
MOT impact	0.23^{***}	0.20^{**}	0.12^{**}	0.20^{***}	0.33^{***}
Subgroup	preATMI high	preSC high	preVAL high	preENJ high	preMOT high
Definition	preATMI $>$ 3.37	preSC $>$ 3.40	preVAL $>$ 3.80	preENJ $>$ 3.20	preMOT $>$ 3.25
N	148	120	134	126	123
ATMI impact	0.02	0.02	0.08^{**}	−0.01	0.04
SC impact	−0.04	-0.15^{***}	0.04	−0.03	−0.01
VAL impact	0.03	$0.09^{\dagger}$	−0.03	0.02	0.06
ENJ impact	$0.08^{\dagger}$	$0.07^{\dagger}$	0.16^{***}	−0.05	0.14^{***}
MOT impact	0.03	$0.09^{\dagger}$	0.15^{**}	0.04	−0.05
Differences between the 'Low' and 'High' subgroups ('Low'–'High')					
ATMI impact	0.17^{***}	0.17^{***}	0.06	0.20^{***}	0.15^{***}
SC impact	0.14^{*}	0.34^{***}	−0.04	$0.11^{\dagger}$	0.08
VAL impact	0.16^{**}	0.04	0.27^{***}	0.14^{*}	$0.11^{\dagger}$
ENJ impact	0.18^{**}	0.16^{*}	0.02	0.39^{***}	0.09
MOT impact	0.20^{***}	$0.11^{\dagger}$	−0.03	0.16^{*}	0.38^{***}

Note: Superscripts denote two-tailed *t*-test significance levels. In the top two parts of the table this is a paired samples test comparing pre-survey and post-survey results within each subgroup. The bottom part of the table gives an independent samples comparison between the 'Low' and 'High' subgroups.
† $p < 0.1$, * $p < .05$, ** $p < .01$, *** $p < .001$.

with the middle section. In fact, in some cases, students with already high scores in the pre-survey reported lower scores in the post-survey. This is particularly evident in the preSC high group, where Self-Confidence decreased markedly after the MathShows. This decrease was statistically significant with $p < 0.001$. This could be attributed to the possibility that some students exhibited high self-confidence in mathematics because they thought they already knew a great deal of mathematics, however the MathShows then showed them that in fact there is much more to mathematics than what they already knew. On the whole, most decreases in attitudes were rather small, and statistically insignificant, whereas the positive effect on students with low initial perceptions were more profound, and were statistically significant.

The bottom section of Table 4 shows the difference in impact between the 'High' and 'Low' subgroups. This data is also presented graphically in Figure A.2. Superscripts denote different degrees of statistical significance of these differences. Details of these *t*-tests can be found in Tables A.3–A.7 in the Appendix. Overall, we see that most of the differences in the impact are statistically significant. In particular, between the preATMI low group and the preATMI high subgroup, the difference in impact is statistically significant across the board – for the overall score and each of the individual categories. For the preSC low and preSC high subgroups, the difference in impact is statistically significant for the overall ATMI score, the Self-Confidence category, and the Enjoyment category. For the preVAL low and preVAL high subgroups, the difference is only statistically significant for the value category. In the preENJ low and preENJ high subgroups, the difference in impact is statistically significant for all categories except Self-Confidence, where the *t*-test gave a *p*-value of 0.057. Finally for the PreMOT low and PreMOT high subgroups, the difference is statistically significant for the overall ATMI score and the Motivation score.

Table 5. Paired *t*-tests of pre-post survey item responses from all respondents, $N = 306$.

	t	Sig. (two-tailed)	Mean difference, post–pre	Std. érr.	95% conf. int Lower	95% conf. int Upper
Q4	5.765	0.000	0.333	0.058	0.220	0.447
Q3	5.197	0.000	0.248	0.048	0.154	0.342
Q18	4.846	0.000	0.248	0.051	0.148	0.349
Q19	4.549	0.000	0.229	0.050	0.130	0.328
Q12	4.489	0.000	0.209	0.047	0.117	0.301
Q5	3.595	0.000	0.160	0.045	0.072	0.248
Q17	3.165	0.002	0.154	0.049	0.058	0.249
Q15	2.095	0.037	0.105	0.050	0.006	0.203
Q16	1.911	0.057	0.118	0.062	− 0.004	0.239
Q8	1.807	0.072	0.092	0.051	− 0.008	0.191
Q1	− 1.598	0.111	− 0.085	0.053	− 0.190	0.020
Q7	1.108	0.269	0.059	0.053	− 0.046	0.163
Q9	1.096	0.274	0.059	0.054	− 0.047	0.164
Q10	0.923	0.357	0.046	0.050	− 0.052	0.143
Q2	0.870	0.385	0.039	0.045	− 0.049	0.128
Q11	0.683	0.495	0.039	0.057	− 0.074	0.152
Q6	0.622	0.534	0.033	0.053	− 0.071	0.136
Q14	0.441	0.659	0.023	0.052	− 0.079	0.125
Q13	− 0.133	0.894	− 0.007	0.049	− 0.103	0.090

5.3. Near-peer led MathShows evoke stronger changes in some attitudes than in other attitudes

As a final step to better understanding how the near-peer led MathShows impacted students, we also looked across all participants at changes in agreement with specific attitude statements about mathematics. Hence, we close the presentation of results by giving evidence concerning changes in specific feelings about mathematics captured by the instrument. Table 5 presents paired *t*-test results of pre- and post-item-level responses across all items of the instrument, sorted according to significance level, and including all students.

In the first eight rows of Table 2 changes in levels of agreement with the items are statistically significant at least at the 0.05 level. Among these items four of them (Q4, Q12, Q5 and Q15) concern the attitude of Enjoyment of mathematics expressed in agreement with such statements as 'Math is a very interesting subject' (Q4) and 'I am happier in a math class than in any other class' (Q12). Two of the items, Q18 and Q19, assess Motivation for pursuing mathematics expressed in the respective statements 'I am willing to take more than the required amount of math' and 'I am confident that I could learn advanced math.' Finally, one item each concerns the attitudes of Value for mathematics and Self-Confidence in doing mathematics, as expressed respectively by the statements 'College math lessons would be very helpful no matter what I decide to study in the future' and "I am always calm and relaxed in a math class.' All of these item-level changes in attitudes were statistically significant in the positive direction: that is, after the MathShow students reported more positive attitudes than they had prior to the show. By contrast, the attitude statement having the least significant change was the Self-Confidence item Q13: 'Studying math makes me feel nervous' (a negatively oriented statement, hence reverse coded for the analysis). Furthermore, the strength of the statistical significance of changes in the eight items referenced above is reflective of (and partially responsible for) the associated significance of changes in pre–post scale scores of the four associated latent variables depicted by Table 1; items concerned with the variable of Enjoyment boasted the greatest positive changes while most changes in agreement with self-confidence items were not statistically significant.

6. Discussion

This study has attempted to measure and describe changes in high school students' attitudes toward mathematics as a result of participating in a mathematics outreach program in which they became engaged in dynamic, interactive MathShows led by college mathematics students. Using an established measure of attitudes towards mathematics [24,25], we have shown that, in general, a single experience of MathShows had a positive impact on students' attitudes toward mathematics in terms of their sense of Enjoyment in mathematics, their sense of the Value that mathematical study has in their lives and in terms of their Motivation to pursue higher mathematics. Furthermore, we have shown that the students who had initially claimed more negative attitudes toward mathematics were also the students that generally showed the greatest gains in terms of average attitude scores. That is, in general all students benefitted from MathShows in terms of improved attitudes toward mathematics but the greatest benefit was to those whose baseline attitude scores were the lowest. This finding is made especially clear by the third section of Table 4.

Of particular interest was the finding that, in light of the largely positive outcomes, MathShows had a relatively limited effect on students' sense of Self-Confidence in doing mathematics. While some subgroups of students, such as those who initially had indicated low Self-confidence on the pre-test showed gains, levels of Self-confidence remained largely unchanged for most students or even diminished slightly, as in the case of those students who had initially claimed to be quite confident in doing math. Taken together with nearly uniform positive changes in other attitudinal variables, there is reason to wonder whether Self-Confidence may be a more a stable, and less malleable, component of attitudes toward mathematics. Similarly, it may be that the feelings of insecurity and anxiety toward mathematics are more deeply seated than the positive feelings of Enjoyment, Motivation and Value. However, balancing these comments is the observation that the more advanced students (pre-AP), not necessarily those who had initially claimed greater Self-confidence, were in fact the group having greater levels of Self-confidence after the MathShows. It may be that those students who, beyond *claiming* good Self-confidence, but actually *possessing* more proficiency in mathematics were, in retrospect, made more aware of their mathematical Self-confidence after the MathShows.

At the very least, this study has shown that near-peer led MathShows can promote the Enjoyment of mathematics among high school students. This fact is seen in the relatively large pre-post change in the ENJ variable across all students (Table 1) and in the large number of significant item-level pre–post changes for survey items pertaining to Enjoyment (Table 5). It is also seen in Table 4 in the way that the two respective groups of those with lower mathematics attitudes (across all variables) and those with higher mathematics attitudes (across nearly all variables) both saw an increase in their Enjoyment of mathematics. Significantly, students who had initially claimed to Value mathematics more highly also had a significant improvement in their Enjoyment and Motivation in mathematics, and those students who had initially claimed a higher degree of Motivation for doing mathematics also claimed greater Enjoyment of mathematics after the MathShows.

It is important to note that since the post-surveys were taken by students immediately after a MathShow presentation, these results reflect only a short-term impact. A follow-up study will focus on longer-term effects of such one-time interventions and will also explore how perceptions of mathematics change in time for students who have been exposed to MathShows compared to students who have not had such an exposure.

7. On presenting MathShows: some suggestions

For readers who might be interested in implementing mathematics outreach similar to what we have described in these pages, we insert here a brief sketch of one possible MathShow, with some hints of things that we have learned to be important for successfully carrying out this sort of program. Most of our MathShows have taken place in the classrooms (libraries, lecture halls, cafeterias, etc.) of local high schools. Consequently, the show is designed to last the duration of one typical class period, between 45 and 55 minutes, or up to 75 minutes for extended periods. Because of the variation in presentation lengths that naturally occurs to accommodate diverse school schedules, it is convenient for the show to be composed of discrete 'acts' that stand alone, some of which can spontaneously be included or excluded in any particular presentation as needed. (It may help to think of each 'act' as a 'one-act play.') For many reasons, such as ease of manipulating the sequence of acts and also maintaining student engagement in the show, each act is intentionally limited to no more than 15 minutes in length, and preferably a bit shorter. Also, as much as possible presenters should vary between each act, with non-presenters taking on supporting roles, such as materials management and crowd control, when not 'on stage.' An example MathShow could have the following sequence of acts:

(1) Introduction of acting troupe, with brief personal statements from college student actors (names, majors, hometowns, etc.). The act could alternatively be placed at the end of the MathShow. 10 minutes.
(2) Act one: modular arithmetic, showing the surprising result that $1 + 1$ is not always 2, but might equal zero (mod 2) for instance. 10 minutes.
(3) Act two: spherical geometry, leading to the surprising result that some triangles can have up to three right angles. 15 minutes.
(4) Act three: infinite sums, leading to the surprising result that an infinite, non-increasing sum (of fractions of candy bars, for instance) may yield a finite number. 10 minutes.

The list above gives a sample of topics that we have used, and only the specific mathematical topic that is central to the act, however it is up to the actors to interpret the act, giving each segment its unique 'personality', with associated manipulative instructional materials and such. For instance, one of our college students would routinely narrate an *end-of-the-world* story (Act three above) in which he alone possessed the last remaining candy bar but was willing to halve it with his infinitely many friends (high school audience members).

Ideally, a MathShow should be advanced enough to challenge most high school students (or middle or even elementary students, by design), yet accessible enough to be appreciated (grasped) by the audience. This requires the careful selection and sequencing of advanced topics that can be operationalized for young students in often concrete ways using concrete objects and other props. If the show is too difficult for the audience, then it seems possible that the young students may in fact be discouraged from studying mathematics, resulting possibly in decreased self-confidence toward mathematics. Indeed, inappropriate rigour may partially explain our observation that some more self-confident students saw a decrease in confidence after the show. Other MathShows created and enacted by our college student actors have treated such topics as imaginary numbers, logic gates and coding (through video games and instructions for making sandwiches), and even differential equations. During each season of MathShows given, we have usually requested our participating public school districts to schedule a particular show for a specific level of student. For instance, the exemplary MathShow given above is suitable for second or third year high school students, who have typically learned some algebraic and geometric concepts, but would be suitable for advanced younger students or even older students as well.

There are different ways that we have found to be productive in mentoring college students to perform MathShows. When involving college students in doing mathematics outreach we have found it useful to keep the near-peer mentoring cycle (Figure 1) in mind and, rather than teaching or telling them how to do it, to mentor our students into participation with us by first modelling effective MathShows for them. With new students it helps to demonstrate a few MathShows and to let them begin participating by supporting the show before getting 'on stage.' Professors and experienced student actors are suitable mentors to newer students. Additionally, in designing new acts for MathShows, we have found it useful to direct our college students to first reflect on the most interesting mathematical things that they have seen in their collegiate years, the most striking, most novel, most personally awe-inspiring topics and problems, and to then work in teams to develop these into MathShow acts. This process is strongly supported by an iterative sequence of designing the act, presenting to peers, giving/receiving feedback and then redesigning the act, all of which, we have found, have a very positive impact on college students' own academic pursuits.

8. Conclusion

We close by making a few additional comments about the potentially positive impacts of involving college students in conducting mathematics outreach, such as MathShows, in public schools and of the possible avenues for research that such work opens. As we have just discussed, this study gave evidence of the extent to which younger math students' attitudes toward mathematics are affected in positive ways by interacting with those who are just ahead of them in the educational pipeline in the context of near-peer led MathShows. However, we can also make an anecdotal observation about the implied benefits upon the college student presenters of the MathShows themselves. Among four college mathematics students that had become involved two years earlier as undergraduates in our outreach work, most of them claimed not to have given serious thought about pursuing graduate studies until they began to help with the mathematics outreach work. However, since that time, all four of them have completed Master's degrees in mathematics and some of them want to earn PhDs. It appeared that helping to present mathematics to younger students had an effect on the career trajectory of these college students. A comment of one of them illustrates this quite well when, during one outreach presentation, he remarked to the high school audience that 'As high school students you don't get to do this kind of math. But *we mathematicians* at the university do this kind of stuff.' This comment seemed to indicate a change in the college students' mathematical identity: rather than aligning with and identifying himself as a 'student', he had become in his own eyes a 'mathematician'. It would be worthwhile for researchers to investigate with more rigour the relative impacts on the mathematical identities of the near-peer groups involved in mathematical outreach such as MathShows, observing and describing such things as the changes that occur in college students when they are positioned as mathematical experts and entrusted with inspiring youth to pursue math.

Finally, mathematical outreach and research work done in this way may also be conceived of as community engaged scholarship [28,29], which is an emerging field of combined inquiry and learning. Outreach activities such as those described in this paper can often be done as a service to the participating public school districts and their students, and come at minimal, if any, monetary cost to the districts. A large number of students can be served: for instance, in the one year of this study 10 MathShows were given to more than 400 high school students, with the goal of supporting high school students in studying mathematics and pursuing college degrees. Furthermore, this outreach work involves many college students in community engagement activities which can support them in pursuit of their own degrees and encouragement to persist in careers and/or advanced studies in mathematics. Community engaged scholars can find many unanswered questions and topics to pursue in the course of community outreach. This study of changes in attitudes toward mathematics resulting from near-peer led MathShows is but one of them.

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Appendix

ENTER YOUR STUDY ID NUMBER HERE: ______________________________ DO NOT WRITE YOUR NAME ANYWHERE ON THIS SURVEY

INSTRUCTIONS: Please read every sentence carefully and then circle the one answer that matches how you feel about it.

1	I am never confused in my math class.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
2	A strong math background could help me in my professional life.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
3	College math lessons would be very helpful no matter what I decide to study in future.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
4	Math is not a very interesting subject.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
5	I really like math.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
6	It makes me nervous to even think about having to do a math problem.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
7	I don't like to solve new problems in math.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
8	Math is one of the least important subjects for people to study.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
9	I feel a sense of insecurity when attempting math.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
10	Math is a worthless and unnecessary subject.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
11	The challenge of math does not appeal to me.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
12	I am happier in a math class than in any other class.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
13	Studying math makes me feel nervous.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
14	I plan to take as little math as I can during my education.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
15	I have usually enjoyed studying math in school.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
16	Math is not important in everyday life.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
17	I am always calm and relaxed in a math class.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
18	I am willing to take more than the required amount of math.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
19	I am confident that I could learn advanced math.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Figure A1. Short attitudes towards mathematics inventory (ATMI) used in this study.

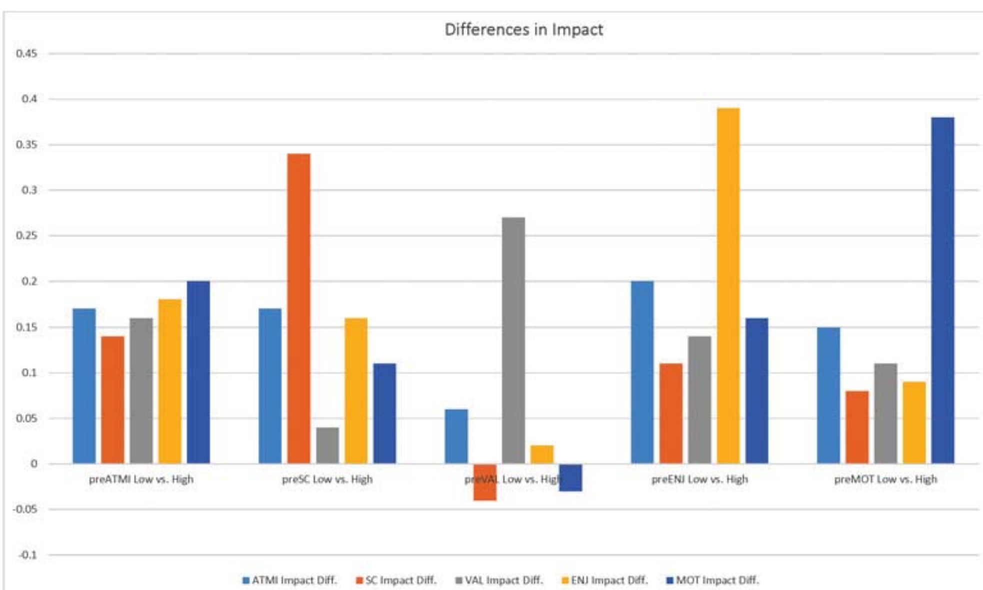

Figure A2. Differences in impact across ATMI variables between groups with high initial scores and low initial scores for each variable.

Table A1. Survey responses for different groups of students.

Class	1	2	3	4	5	6	7	8	9	10
School	A	A	A	A	A	A	B	B	C	C
Pre-AP	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Class period	1	2	3	1	2	3	1	2	1	2
i	42	47	46	29	40	40	30	5	16	11
PreATMI avg	3.30	3.35	3.43	3.57	3.37	3.40	3.29	3.27	3.24	3.44
PostATMI avg	3.31	3.42	3.52	3.68	3.52	3.53	3.51	3.28	3.43	3.57
PostATMI–PreATMI	0.01	0.08	0.09	0.11	0.15	0.13	0.22	0.01	0.19	0.12
PreSC avg	3.10	3.35	3.29	3.68	3.33	3.27	3.15	3.32	3.14	3.29
PostSC avg	3.10	3.37	3.33	3.68	3.36	3.31	3.33	3.16	3.13	3.24
PostSC–PreSC	0.00	0.02	0.05	0.01	0.02	0.04	0.17	− 0.16	− 0.01	− 0.05
PreVAL avg	3.79	3.74	3.96	3.76	3.83	3.82	3.69	3.84	3.69	4.05
PostVAL avg	3.86	3.78	3.95	3.86	4.03	3.94	4.02	3.44	3.88	4.18
PostVAL–PreVAL	0.08	0.05	− 0.01	0.10	0.20	0.13	0.33	− 0.40	0.19	0.13
PreENJ avg	3.12	3.17	3.16	3.39	3.18	3.17	2.97	2.92	3.03	3.16
PostENJ avg	3.10	3.29	3.38	3.61	3.40	3.35	3.24	3.12	3.30	3.36
PostENJ–PreENJ	− 0.01	0.11	0.22	0.22	0.22	0.18	0.27	0.20	0.28	0.20
PreMOT avg	3.15	3.09	3.29	3.42	3.09	3.35	3.37	2.95	3.06	3.23
PostMOT avg	3.14	3.22	3.40	3.53	3.25	3.54	3.46	3.45	3.42	3.48
PostENJ–PreENJ	− 0.01	0.13	0.10	0.10	0.16	0.19	0.09	0.50	0.36	0.25

Table A2. Aggregate results by subgroup.

	School C	Schools A and B	Pre-AP	Non-Pre-AP
N	27	279	110	196
PreATMI avg	3.32	3.38	3.42	3.36
PostATMI avg	3.49	3.49	3.55	3.47
PostATMI–PreATMI	0.17	0.11	0.13	0.11
PreSC avg	3.20	3.29	3.35	3.25
PostSC avg	3.17	3.33	3.42	3.26
PostSC–PreSC	− 0.03	0.04	0.06	0.01
PreVAL avg	3.84	3.80	3.83	3.79
PostVAL avg	4.00	3.91	3.92	3.91
PostVAL–PreVAL	0.16	0.10	0.09	0.12
PreENJ avg	3.08	3.15	3.16	3.14
PostENJ avg	3.33	3.32	3.39	3.28
PostENJ–PreENJ	0.24	0.17	0.23	0.14
PreMOT avg	3.13	3.23	3.33	3.16
PostMOT avg	3.44	3.35	3.45	3.30
PostENJ–PreENJ	0.31	0.12	0.12	0.15

Table A3. Equal variances two samples *t*-test for difference in impact between preATMI low ($N = 150$) and preATMI high ($N = 148$) subgroups.

Q11

					95% confidence interval of the difference	
	t	Sig. (two-tailed)	Mean difference	Std. error difference	Lower	Upper
ATMI impact	4.869	0.000	0.170	0.035	0.101	0.239
SC impact	2.598	0.010	0.139	0.054	0.034	0.245
VAL impact	2.935	0.004	0.158	0.054	0.052	0.264
ENJ impact	3.202	0.002	0.184	0.058	0.071	0.298
MOT impact	3.523	0.000	0.205	0.058	0.090	0.319

Table A4. Equal variances two samples *t*-test for difference in impact between preSC low ($N = 147$) and preSC high ($N = 119$) subgroups.

	t	Sig. (two-tailed)	Mean difference	Std. error difference	95% confidence interval of the difference	
					Lower	Upper
ATMI impact	4.456	0.000	0.167	0.037	0.093	0.241
SC impact	6.368	0.000	0.346	0.054	0.239	0.453
VAL impact	0.665	0.507	0.039	0.059	− 0.077	0.156
ENJ impact	2.583	0.010	0.160	0.062	0.038	0.282
MOT impact	1.756	0.080	0.111	0.063	− 0.013	0.235

Table A5. Equal variances two samples *t*-test for difference in impact between preVAL low ($N = 133$) and preVAL high ($N = 134$) subgroups.

	t	Sig. (two-tailed)	Mean difference	Std. error difference	95% confidence interval of the difference	
					Lower	Upper
ATMI impact	1.607	0.109	0.060	0.038	− 0.014	0.134
SC impact	− 0.650	0.516	− 0.037	0.057	− 0.150	0.076
VAL impact	4.808	0.000	0.272	0.057	0.161	0.383
ENJ impact	0.239	0.811	0.015	0.062	− 0.107	0.136
MOT impact	− 0.413	0.680	− 0.025	0.061	− 0.145	0.095

Table A6. Equal variances two samples *t*-test for difference in impact between preENJ low ($N = 145$) and preENJ high ($N = 126$) subgroups.

	t	Sig. (two-tailed)	Mean difference	Std. error difference	95% confidence interval of the difference	
					Lower	Upper
ATMI impact	0.027	0.000	0.202	0.036	0.130	0.273
SC impact	0.353	0.057	0.109	0.057	− 0.003	0.221
VAL impact	0.022	0.017	0.140	0.058	0.026	0.254
ENJ impact	0.528	0.000	0.388	0.056	0.277	0.498
MOT impact	0.712	0.011	0.162	0.063	0.038	0.286

Table A7. Equal variances two samples *t*-test for difference in impact between preMOT low ($N = 144$) and preMOT high ($N = 123$) subgroups.

	t	Sig. (two-tailed)	Mean difference	Std. error difference	95% confidence interval of the difference	
					Lower	Upper
ATMI impact	4.104	0.000	0.154	0.038	0.080	0.228
SC impact	1.325	0.186	0.078	0.059	− 0.038	0.193
VAL impact	1.765	0.079	0.106	0.060	− 0.012	0.224
ENJ impact	1.558	0.120	0.098	0.063	− 0.026	0.222
MOT impact	6.265	0.000	0.380	0.061	0.261	0.500