The Effects of School-Related and Home-Related Optional Science Experiences on Science Attitudes and Knowledge

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Citation: Liu, A. S., & Schunn, C. D. (2018). The effects of school-related and home-related optional science experiences on science attitudes and knowledge. *Journal of Educational Psychology*

Abstract

Science learning is most often examined within formal education contexts, even though students spend more of their lives outside of the classroom. Students may interact with scientific phenomena during these out-of-school experiences, providing additional opportunities for learning to take place. Prior studies have found that optional science experiences have positive effects on science knowledge and attitudes. However, these studies do not always account for initial differences between students who are able to participate in many optional experiences and those who cannot. Moreover, many studies focus on high-quality science programs, which may not be representative of the average out-of-school experience. Using a longitudinal dataset of 3,700 6th and 8th grade students in urban and suburban schools from two regions in the US, the current study investigates the effects of typically occurring optional science experiences during the school year on the development of science knowledge and attitudes. Using propensity score matching, we matched participating and non-participating students for characteristics that drive self-selection into these experiences, then analyzed separately for effects of school-related versus home-related science learning experiences. Stable patterns across analytic models reveal growth in science attitudes with both school- and home-related science experiences, but a greater relative decline in science knowledge with school-related science experiences. Thus, typically occurring optional science experiences can influence students' attitudes and knowledge, but the effects can vary by the type of experience that students attend.

Keywords: optional science experiences, out-of-school learning, science attitudes, science knowledge

Educational Impact and Implications Statement

The current study finds that, after accounting for initial differences between middle-school students who are more likely to participate in optional science experiences and those who are not, optional science experiences that take place in the school or in the home increased or maintained students' positive attitudes toward science. However, these optional experiences also decrease or prevent growth in students' science knowledge. This suggests that students should be encouraged to participate in optional science experiences to bolster their interest in pursuing science, with special care taken to ensure that their knowledge is being similarly supported.

The Effects of School-Related and Home-Related Optional Science Experiences on Science Attitudes and Knowledge

Science learning is most often examined within formal education contexts. However, students spend most of their waking hours outside of the classroom (National Center for Education Statistics, 2008), where they commonly participate in optional experiences throughout the year that can contribute to their knowledge and interest in science (National Research Council, 2009, 2015; Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003). Examples vary in frequency and depth, with some students participating in after-school science clubs, occasionally doing science experiments with family members, or just watching science and technology-themed television shows at home. Prior studies suggest that participation in at least some of these optional science activities may impact students' interest, perceptions, and abilities in science (Abernathy & Vineyard, 2001; Fredericks & Simpkins, 2012; Huang, Gribbons, Kim, Lee, & Baker, 2000; Quigly, Pongsanon, & Akerson, 2010; Sahin, 2013; Vandell, Reisner, & Pierce, 2007).

Because these experiences are optional and involve the choice to participate, studies on these experiences may suffer from issues of endogeneity; that is, students who choose to participate in optional experiences may be those who are initially more interested or skilled in science. Indeed, studies suggest that optional science experiences mostly include members of more socially-advantaged groups (see Dawson, 2014 for a review), while low socioeconomic status children spend less time in both informal and after-school activities compared to their upper- and middle-class peers (Dearing et al., 2009; Jensen, 2009; Wimer, Simpkins, Dearing, & Bouffard, 2008). While studies have attempted to control for these influences using basic multiple regression techniques (e.g., Lin & Schunn, 2016; Suter, 2016), findings for optional science experiences may still reflect pre-existing differences, rather than the causal impact of the experience itself, if these programs primarily consist of students who are already positioned for future science success.

Furthermore, the individual programs that take part in the few reported experimental studies may be particularly high in quality and unrepresentative of the average optional science learning experience available to students. The programs with greater resources may be more likely to involve themselves in systematic studies, and participating in evaluations on a regular basis may lead to better program quality over time. Evaluations using regional sampling rather than program-based sampling are required to better estimate effects of typical experiences. A recent study by Suter (2016) looked at the relationship between out-of-school activity time and science scores from the Programme for International Student Assessment (PISA), a large dataset of 15-year-olds across 72 countries. In 23 countries, students who spent more time in after-school programs showed higher attitudes but *lower* PISA science scores compared to students with few after-school program hours. In other words, more typically occurring programs may even negatively impact students on some dimensions. Similarly, in a study of a large number of middle schoolers across two regions in the US, Lin and Schunn (2016) found that students who had previously participated in structured science learning experiences had higher interest in science but lower science reasoning ability. However, since both studies analyzed cross-sectional datasets, the causal connections (positive or negative) between program participation and science outcomes remain unclear.

Propensity score matching (PSM) provides a new statistical solution to address issues of causality and representativeness. PSM begins with a regression model of the probability that a participant will be assigned to a treatment – in this case, participating in optional science experiences – based on a set of covariates (e.g., attitudes, demographics, prior behaviors). It then matches participants with similar probabilities of participating in optional experiences to account for initial differences that are most relevant to the likelihood of experiencing the treatment, and compares participants who actually went to experiences against those who did not within the matched sample, allowing for more confident causal inferences. The current study uses PSM with a longitudinal dataset to carefully investigate the effects of optional science experiences during the school year on changes in science attitudes and learning, matching for prior characteristics that may influence self-selection into these experiences.

School-Related vs. Home-Related Optional Experiences

There are many different types of optional experiences in which students can choose to participate during the school year, and many ways to categorize them. In the current study, we classify optional science experiences based on the environment in which they take place: school-related experiences and home-related experiences. The school-related experiences are science learning experiences that are not required school activities but are still directly influenced by actors at the school. These experiences may be closely aligned with the school science curriculum (e.g., participating in an after-school study group or doing an extra-credit project for class), though it may also extend to other topics (e.g., talking to a teacher about science books or being part of a science club). In contrast, the home-related science learning experiences are science learning events that are not connected to the science classroom or actors at the school and are associated instead with the home environment (e.g., looking at science websites or reading science books at home, taking things apart, or collecting items in nature).

Prior factor analysis work supports the separation of school- and home-related optional science learning experiences that occur during the school year, showing that they tend to occur coherently as those place-based groupings but independently of each other (Lin & Schunn, 2016). There are also several important differences between the two types of experiences, which could have notable implications for science outcomes. For example, it may be easier to persuade students to participate in school-related experiences, while participation in home-related experiences may be largely driven by students' individual motivation. School-related experiences may also have access to regular and experienced supervisors who can oversee student attendance and activities, while home-related experiences may have less qualified supervisors or even none at all, when adult support is likely important in guiding student learning (Crowley & Jacobs, 2002). However, school-related experiences may be too similar to what is already taught in formal classrooms and lack the novelty or independent exploration that home-related experiences may provide (Orion & Hofstein, 1994). Many studies have also found significant socioeconomic divides in formal science education, such that minority students often lack access to school resources, experienced teachers, or demanding science programs (Baker, 2016; Oakes, 1990); optional experiences that take place in schools may not be able to escape these limitations and provide little help for students who are already struggling in science. Thus, it is worthwhile to separately consider school- and home-related activities to inform future research, policy, and program development around optional science learning experiences.

The Impact of Optional Science Experiences on Science Attitudes and Knowledge

Just as there are many ways to categorize optional science experiences, there are many different outcomes that can be investigated. The current study examines the impact of optional experiences on three different types of science attitudes and two forms of content and skill learning. Students who take part in optional experiences have shown positive attitudes toward science, preference for participating in science activities compared to non-science alternatives, and greater interest in pursuing science careers (e.g., Abernathy & Vineyard, 2001; Gibson & Chase, 2002; Knox, Moynihan, & Markowitz, 2003; Kong, Dabney, & Tai, 2014; Markowitz, 2004; Sahin, 2013), with a particularly consistent positive relationship for home-related experiences (e.g., Dabney et al., 2012; Henriksen, Jensen, & Sjaastad, 2015; Maltese & Tai, 2011; Paris, Yambor, & Packard, 1998; Simpkins, Davis-Kean, & Eccles, 2006; Uitto, Jutti, Lavonen, & Meisalo, 2006). We aim to confirm that these findings on science attitude remain when accounting for self-selection biases and when looking across typically occurring, rather than only well-designed, experiences.

In contrast to science attitudes, prior findings on science learning are more varied. While some studies have shown improvements in later science achievement after participation in specific optional science programs (Markowitz, 2004; Quigly et al., 2010), several recent studies of more typically occurring optional science programs have found negative effects of optional science experiences on science skills and knowledge (Lin & Schunn, 2016; Suter, 2016). This is particularly worrying, making it especially important to ensure that these results hold when accounting for issues of causality and representativeness through more careful methodologies such as PSM. Optional science experiences may influence science knowledge by improving the specific content knowledge that is the focus of the optional learning experience, but this may not overlap with the focal content being taught in class during that school year. Alternatively, optional science experiences may influence science knowledge by supporting practices that improve learning (e.g., students may go to science websites to research a question brought up in class or ask a teacher or mentor for help). We focus primarily on the latter (though we include measures for both specific content knowledge and more general science skills), as it is impossible to measure the diverse science content knowledge that students could be learning at home or in programs given the range of offerings across a region.

The Current Study

We investigate the effects of optional science experiences that occur during the school year on the development of science attitudes and abilities, after matching for characteristics that may influence self-selection into these experiences. We also explore whether this relationship varies for school-related vs. home-related science learning experiences.

We investigated these questions within the context of the Science Learning Activation Lab, a research and design effort to improve learning in various topics. The goal of the Activation Lab is to determine the dispositions, practices, and knowledge that characterize an "activated learner", with the assumption that these characteristics predict and enable student success. An "activated science learner" is described as someone who is fascinated by science, sees the value in science (for both the student and society), believes they can do science, and can apply scientific practices to understand novel situations (Dorph, Cannady, & Schunn, 2016). In addition to having longitudinal data on these dispositional measures, Activation Lab datasets also include data about optional science experiences (both throughout the student's prior life and within the current year), family and home support for science learning, various demographics, and students' science knowledge, making them particularly rich datasets for matching participants who may or may not attend optional science experiences. Focusing on the largest dataset, ALES14 (Activated Learning Enables Success 2014), we use the pre-test dispositional and knowledge measures and these other covariates – factors that are likely to influence students' decisions to attend optional science learning experiences – to calculate a propensity score representing the probability that a student would have attended each of the two types of optional science learning experiences (school- and home-related experiences). We then match students with similar propensity scores (i.e., those who are approximately equal in expectation) between the two comparison groups – students who actually participated in many optional science experiences and those who attended few or no experiences – to ensure that the two comparison groups were not significantly different at pre-test. This allows us to determine whether students who participated in many experiences show changes in interest or learning compared to students who participated in few or no experiences, after accounting for other initial differences that could have influenced their interest or learning outcomes.

Method

Participants

The study uses the ALES 2014 dataset, which has approximately 3,700 6th and 8th grade middle-school students who serve as an initial source of data for the analyses reported in this study. It is useful to begin with a large dataset because the propensity matching process can exclude many participants, either because participants are missing some data for computing the propensity score or because they do not have a matched propensity participant. The students came from six public schools within one school district in Pittsburgh, Pennsylvania and five public schools within three school districts in the Bay Area of California, purposely selected to obtain urban schools and a broad sample of ethnicities. District officials provided permission for schools to participate, and 43 teachers (13 from Pittsburgh, 30 from California) were recruited at professional development events with a very high response rate.

6th grade data account for 47% of the sample, and the mean ages were 11.4 years (*SD* = 0.6) for 6th graders and 13.3 years (*SD* = 0.6) for 8th graders. Some students were absent on some days or unable to complete some measures, so sample size varies across analyses, especially for analyses integrating many measures; sample sizes for each analysis will be specified in the

Results section. Based on student self-reports, 37% of students were White, 26% were Black or African-American, 8% were Asian, 5% were Indian or Middle Eastern, 6% were Native American or Pacific Islander, 16% were Hispanic, Latino, or Mexican, and 14% did not report their race or ethnicity. In terms of self-reported sex, the sample was 39% female, 38% male, 4% other, and 19% not reported. The study was approved by the University of Pittsburgh and University of California-Berkeley Institutional Review Boards.

Materials

The measures used in the current study were created and extensively validated by the Science Learning Activation Lab, and most of the measures have been used in many prior publications (Bathgate, Crowell, Cannady, Dorph, & Schunn, 2015; Dorph et al., 2016; Lin & Schunn, 2016; Sha, Schunn, & Bathgate, 2015; Sha, Schunn, Bathgate, & Ben-Eliyahu, 2016). The measure development and refinement process involved iterative evaluation and improvements in validity and reliability using qualitative data, quantitative data, and expert review. Item-Response Theory analyses were conducted to ensure that Likert ratings could be meaningfully analyzed using scale means (i.e., approximately equal separation across Likert rating options) and that responses to items or item accuracy did not differ based on sex, race, or ethnicity. Detailed reports for each measure can be found at http://activationlab.org/tools, except for the Recent Optional Science Experiences survey, which is a relatively new addition to the tool set and therefore described in greater depth here. In total, the study uses two 'treatment' variables (School-Related and Home-Related Experiences from the Recent Optional Science Experiences survey), three attitude outcome measures (post Fascination, post Values, post Competency Beliefs), two science learning outcome measures (post Scientific Content Knowledge, post Scientific Sensemaking), and 13 covariates to create a propensity matching score for each participant (pre Scientific Content Knowledge, pre Scientific Sensemaking, pre Fascination, pre Values, pre Competency Beliefs, Prior Science Experiences, Home Resources, Family Support, class, grade, location, sex, minority status). Four additional covariates (parental job type, parental job level, parental education, and student Choice Preferences) were also used to test a second propensity score model (the "Parental Match" sample, described in more detail in the Propensity Score Matching section). Measures collected at the first time point were used as pre-tests and for creating propensity matching scores, and the subset of measures collected at the second time point were then used in pre-post ways to measure change resulting from optional science learning experiences.

Recent optional science experiences. This survey, collected at the second time point, consisted of 11 items (see Table 1) about the optional science experiences in which students had participated since the beginning of the school year. Five school-related items ($\alpha = .72$) asked about experiences that took place in a structured school environment, typically involving teachers or peers (e.g., "I did my homework or projects for science class with other students"). Six home-related items ($\alpha = .76$) asked about experiences that would typically take place in or near the home and were explicitly outside of class (e.g., "Outside of class, I watched TV programs about science topics"). Students indicated the extent of their participation in each activity using a 4-point Likert scale (Never, Once, A Few Times, Many Times). The school-related and home-related scores were averaged separately to create a school-related and home-related score for each participant. Participants with an average score of 2.5 or higher (the scale mid-point) were categorized as High-Participation students, and participants with an average score of less than 2.5 were categorized as Low-Participation students.

(Insert Table 1 here)

A Principal Components Factor Analysis with a Promax rotation was conducted on the 11 items to verify that items were accurately categorized as "school-related" and "home-related." The exploratory factor analysis resulted in a two-factor solution (see Table 2), showing that all except one item loaded more highly onto their expected factor than the other factor. The exception ("Outside of class, I collected rocks, butterflies, bugs, or other things in nature") loaded on both factors, so was kept in the "Home-Related" category because it was the better theoretical fit.

(Insert Table 2 here)

Fascination in science. The survey administered pre and post measured students' curiosity toward science (e.g., "I wonder about how nature works: every day/once a week/once a month/never"), their positive affect toward science (e.g., "In general, I find science: very interesting/interesting/boring/very boring"), and their desire to master science (e.g., "I want to read everything I can find about science: YES!/yes/no/NO!"), three aspects of a strong intrinsic attachment to science. Eight items ($\alpha = .86$) were answered using a 4-item Likert scale, with responses depending on the question, as shown in the examples above. A mean Fascination score was calculated for each participant at each time point.

Values in science. The survey administered pre and post measured the extrinsic importance that students place on being able to do science. Eight items ($\alpha = .83$) involved questions about how often they expect science to be useful to their personal goals (e.g., "Thinking like a scientist will help me do well in: all my classes/most of my classes/a few classes/none of my classes") and how useful they think science is to society (e.g., "Science makes the world a better place to live: YES!/yes/no/NO!"). Items were answered using a 4-item

Likert scale, with responses depending on the item, and a mean Values score was calculated for each participant at each time point.

Competency beliefs in science. The survey administered pre and post asked about students' beliefs in their scientific skills and abilities in general (e.g., "I think I am very good at coming up with questions about science: YES!/yes/no/NO!"), during structured activities in or after class (e.g., "If I did my own project in an after school science club, it would be: excellent/good/ok/poor"), and during informal activities (e.g., "If I went to a science museum, I could figure out what is being shown in: all areas/most areas/a few areas/none of it"). Students responded to eight items ($\alpha = .84$) using a 4-point Likert scale, with responses depending on the question. A mean Competency Beliefs score was calculated for each participant at each time point.

Scientific content knowledge. Content knowledge tests administered pre and post assessed how much the students learned from their classroom over the studied 4-month period. Each classroom was given an individual assessment that aligned with their curriculum, since different grades and different schools within a grade level had very different curricula (e.g., physical sciences vs. biological science); even within a school district with a shared official curriculum, different teachers could cover very different amounts of content in a fixed amount of time because of depth vs. breadth choices or numbers of science hours available per week. The tests assessed the central conceptual content, focusing on big ideas rather than basic facts. Each test form consisted of 18 multiple choice questions that were drawn from research assessment banks, such as TIMSS (Mullis, Martin, Gonzalez, & Chrostowski, 2004), AAAS (Laugksch & Spargo, 1996), and MOSART (Sadler et al., 2009) (e.g., "What is the primary energy source that drives all weather events, including precipitation, hurricanes, and tornadoes? (a) the Sun, (b) the

Moon, (c) Earth's gravity, or (d) Earth's rotation"). Items were individually sampled from the test banks for each class to match the content that was to be covered in that class, building from a topics survey completed by the teacher at the beginning of the semester. The teachers also re-verified that the sampled questions involved specific content that was covered in the curriculum. In total, there were five different tests for the 6^{th} grade classrooms and four different tests for the 8^{th} grade classrooms. We standardized test scores at each time point by subtracting the relevant test form mean and dividing by the relevant test form standard deviation, so that the scores would be comparable across classrooms and grades.

Scientific sensemaking. The multiple-choice assessment administered pre and post measured students' ability to use scientific methods (e.g., asking questions that can be answered through scientific methods, finding mechanistic explanations for phenomena, engaging in argumentation, interpreting data, and designing experiments) to understand applied situations (see Vincent-Ruz & Schunn, 2017 for measure details). The applied situations were chosen to be compelling and approachable across a wide range of demographics to ensure that individual differences in background knowledge or interest were not primary performance drivers (Bathgate et al., 2015), and Item Response Theory analyses verified that no item-level performance differences were found based on sex, race, or ethnicity. The particular applied situations used in the current study were understanding dolphin behavior (13 items in the fall questionnaire) or monkey behavior (12 items in the spring questionnaire) with the goal of improving animal conservation efforts. The proportion of correct responses were recorded for each participant at each time point.

The remaining five measures were measured only at the first time point and were used to predict participation in recent optional science experiences.

Prior science experiences. The survey involved 16 items ($\alpha = .83$) asking about students' prior experiences with school-related science experiences (e.g., "Have you ever participated in a school family science night") and home-related science experiences outside of school (e.g., "Have you ever done science experiments even when not at school"). Unlike the Recent Optional Science Experiences survey, which asks only about optional science experiences from the current year, the Prior Science Experiences survey asks about science experiences throughout the student's life. Students reported the extent to which they had participated in any of these experiences during their life using a 3-point Likert scale (More than once, Once, Never). A mean Prior Experiences score was calculated for each participant and used to predict participation in recent optional science experiences.

Home resources for science learning. The seven-item survey ($\alpha = .73$) measured students' access to resources that can support science learning and can be taken as an indicator of socio-economic status. These included technological items (e.g., access to calculators, computers, internet, or E-readers), books (e.g., dictionaries or science books), and locations devoted to studying (e.g., a study or homework area). Students were asked how often they were provided access to these items using a 4-point Likert scale (Always, Most of the time, Rarely, Never). A mean Home Resources score was calculated for each participant.

Family support for learning. The five-item survey ($\alpha = .78$) measured the level of support for learning that students received from their family. Students rated their agreement using a 4-point Likert scale (YES!, yes, no, NO!) to statements about family members' beliefs about learning (e.g., "My learning in school is important to someone in my family"), family members' levels of knowledge (e.g., "When I work on homework at home, I have someone who can help me with it if I need help"), and family members' level of involvement (e.g., "Someone in my family makes sure I finish my homework every day"). A mean Family Support score was calculated for each participant.

Choice preferences in science. The survey measured the extent to which students want to engage in science or scientific activities, separate from their actual participation in these experiences. Similar to the Recent Optional Science Experiences survey, ten items ($\alpha = .84$) investigated choice preferences for school-related activities that typically involve teachers or peers (e.g., "I would like to talk to a science teacher about good science books or websites") and for home-related experiences that occur outside of school (e.g., "I would like to attend a science camp next summer"). Students indicated their level of agreement to each item using a 4-point Likert scale ("YES!, yes, no, NO!"). A mean Choice Preferences score was calculated for each participant.

Demographics. The survey asked participants about their sex, race/ethnicity, job of each parent, and education of each parent. From the race and ethnicity data, a binary Underrepresented Minority variable was calculated (coded as 0 for White and Asian students, 1 for Black, African-American, Indian, Middle-Eastern, Native American, Pacific Islander, Hispanic, Latino, and Mexican). The parental job data were transformed into highest job type (the most STEM-relevant job held across both parents, measured as Non-STEM, Health, and STEM) and highest job level (the highest job level attained across both parents, measured as No Job, Middle Level, and Professional Level). Parental education was ordinally coded as the highest educational level attained across both parents (from "Did not graduate high school" to "More school after college"). Additionally, each student's classroom, location, and grade were also collected.

Procedure

Surveys were administered to students at the beginning of the fall and at the beginning of the spring. At both times, students completed the paper and pencil surveys across two days. On Day 1, students took the Scientific Sensemaking, Fascination, Values, Competency Beliefs, and Choice Preferences surveys (pre-test only). On Day 2, students took the Scientific Content Knowledge assessment. At pretest only, on Day 2, students completed the Prior Experiences, Home Resources, and Family Support surveys, as well as demographics questionnaires (purposely placed last to avoid any priming effects that could change attitudinal or ability measures). At posttest only, also on Day 2, students took the Recent Optional Science Experiences survey.

Propensity Score Matching

Propensity scores were obtained using logistic regression models to estimate the likelihood of participating in many vs. few recent school-related and home-related optional science experiences. The covariates used to create the propensity score were theoretically motivated. Based on prior research (Lin & Schunn, 2016; Sha et al., 2016), we expected that three types of factors could influence recent experience participation: school-level factors, family-level factors, and student-level factors. At the school level, we included the student's class, current grade, and location to account for possible teacher or peer influences. At the family level, we accounted for the number of optional science experiences in which the student had participated in previously throughout their lifetime. We also included measures of family support and home resources for learning to account for the encouragement students receive from their families to participate in these optional science experiences. At the student level, we consider students' motivation towards and prior achievement in science (measured by their pre-test values in Fascination, Values, Competency Beliefs, Content Knowledge, and Scientific Sensemaking), as well as their sex and underrepresented minority status. To minimize loss of demographics information, which was collected last on the second day, demographics information was also collected a year later as part of a larger longitudinal study. When demographics information conflicted between the current and later year, the later time point's information was used. This led to the following propensity score model, where *RE* is a variable indicating the probability that a student would report going to at least some or many recent optional science experiences (coded as 1) or few or no recent experiences (coded as 0):

$$\text{Prob}(RE) = \beta_0 + \beta_1(\text{Class}) + \beta_2(\text{Grade}) + \beta_3(\text{Location}) + \beta_4(\text{Prior Experiences}) + \beta_5(\text{Family Learning Support}) + \beta_6(\text{Home Resources}) + \beta_7(\text{Pre Science Fascination}) + \beta_8(\text{Pre Science Values}) + \beta_9(\text{Pre Science Competency Beliefs}) + \beta_{10}(\text{Pre Science Content Knowledge}) + \beta_{11}(\text{Pre Scientific Sensemaking Ability}) + \beta_{12}(\text{Sex}) + \beta_{13}(\text{Underrepresented Minority Status}).$$

Participants with missing data for any of the model variables were removed using list-wise deletion from the sample. Groups were then matched using nearest neighbor matching without replacement and a caliper of 0.2; that is, we matched students who attended some or many recent experiences ("High-Participation" students) with the students who attended few or no experiences ("Low-Participation" students) who had the closest propensity scores to each other, with a maximum allowed distance of 0.2 between two matched propensity scores. This ensured that all participants in the High-Participation had at least one participant in the Low-Participation group similar to them and that the two groups were approximately equal in averages and distributions, so any differences found could be attributed to participation in optional science experiences rather than initial differences between the groups. The model was run twice to separately predict the probability for school-related recent experiences and the probability for home-related recent experiences.

After list-wise deletion and matching on school-related experiences, there were 309 High-Participation students and 309 Low-Participation students. For matching on home-related experiences, there were 514 High-Participation students and 514 Low-Participation students. Table 3 shows descriptives for every covariate before and after matching, with significance differences based on independent-samples t-tests, as well as the average propensity scores before and after matching. As shown, the two groups differed greatly before matching (as expected, if there was self-selection into groups) and were much more equal after matching, suggesting that the propensity score method almost entirely eliminated the initial differences between the comparison groups.

(Insert Table 3 here)

We also ran a second, more conservative propensity score model ("Parental Match") that added parents' job type, job level, and parents' education level to approximate the student's family means, as well as student's Choice Preferences to account for their desire to participate in science activities:

$$\text{Prob}(RE) = \beta_0 + \beta_1(\text{Class}) + \beta_2(\text{Grade}) + \beta_3(\text{Location}) + \beta_4(\text{Prior Experiences}) + \beta_5(\text{Family Learning Support}) + \beta_6(\text{Home Resources}) + \beta_7(\text{Pre Science Fascination}) + \beta_8(\text{Pre Science Values}) + \beta_9(\text{Pre Science Competency Beliefs}) + \beta_{10}(\text{Pre Science Content Knowledge}) + \beta_{11}(\text{Pre Scientific Sensemaking Ability}) + \beta_{12}(\text{Sex}) + \beta_{13}(\text{Underrepresented Minority Status}) + \beta_{14}(\text{Highest Parent Job Type}) + \beta_{15}(\text{Highest Parent Job Level}) + \beta_{16}(\text{Highest Parent Education Level}) + \beta_{17}(\text{Pre Science Choice Preferences}).$$

While these covariates may add additional information about participants' propensity toward participating in optional recent experiences, they were also the covariates with the most missing data and significantly reduced the sample size for analyses (82 High-Participation students and 82 Low-Participation students for school-related experiences, 128 High-Participation and 128 Low-Participation students for home-related experiences). Thus, the Parental Match model was run separately from the main matching model listed above.

Results

Effects of Recent School-Related Experiences

Match sample regressions. Five sets of regressions were conducted on the matched school-related sample to predict the outcomes of mean Fascination, mean Values, mean Competency Beliefs, mean Scientific Content Knowledge, and mean Scientific Sensemaking at spring. All of these regressions included the focal high vs. low Recent School-Related Science Experiences as a predictor. The inclusion of other covariates varied across regression sets, which are described in detail below.

Figure 1a and 1b show mean outcome values and effect sizes (Cohen's *d*) of Fascination, Values, Competency Beliefs, Scientific Content Knowledge, and Scientific Sensemaking for High-Participation and Low-Participation students using the matched participant set. Averages and standard deviations are shown in Table 4. Power analyses reveal that the sample was able to detect a minimum effect size (Cohen's *d*) of .23 at 80% power.

Recent school-related experiences were a positive predictor of Fascination ($F(1, 587) = 22.8$, $p < .001$, $R^2 = .04$), Values ($F(1, 592) = 2.75$, $p < .001$, $R^2 = .03$), and Competency Beliefs ($F(1, 1, 594) = 23.7$, $p < .001$, $R^2 = .04$), showing that students who attended more recent school-related experiences were more likely to become interested in science, see the importance of science, and feel confident in their science abilities than students who attended few of these experiences. However, they also negatively predicted Scientific Content Knowledge ($F(1, 555) = 7.15$, $p = .008$, $R^2 = .013$) and Scientific Sensemaking ($F(1, 595) = 13.3$, $p < .001$, $R^2 = .022$), suggesting that more time spent in school-related experiences was associated with relatively less science content and skill learning.

(Insert Table 4 here)

Alternative model regressions. In addition to the Match model described above, we ran similar regressions on four alternative samples to determine the extent to which propensity matching affected results and the robustness of the results. The first was the unmatched sample with all 17 covariates included (the "Full OLS" with 95 High-Participation and 349 Low-Participation students after list-wise deletion), which did not account for any initial differences between the High-Participation and Low-Participation groups. The second was the Match sample, as reported in the Propensity Score Matching section, with the propensity model covariates included in the regression ("Match plus covariates" with 309 High-Participation students and 309 Low-Participation students). The third was the "Parental Match" sample (82 High-Participation and 82 Low-Participation students) in which the propensity scores were calculated with an additional four covariates with high amounts of missing data (highest parent job type, highest parent job level, highest parent education, and pre-test choice preferences). The fourth was the Parental Match sample with the propensity model covariates included in the regression ("Parental Match plus covariates" with 82 High-Participation students and 82 Low-Participation students). Power analyses show that the samples were able to detect minimum effect sizes (Cohen's *d*) that were small at 80% power across analyses: 0.32 (Full OLS), 0.23 (Match, Match plus covariates), and 0.44 (Parental Match, Parental Match plus covariates).

Table 5 shows the estimated effects of optional science learning experiences for the Full OLS, Match, Match plus covariates, Parental Match, and Parental Match plus covariates on the five outcome variables. As with the Match results, there was a consistent positive relationship between School-Related recent experiences, Fascination, and Values, and a negative relationship with Content Knowledge and Scientific Sensemaking (though estimates did not always reach significance in the Parental Match samples, possibly due to the high amount of missing data). Competency Beliefs appear to be less robust, as the estimates between recent experiences and Competency Beliefs decreased considerably when the Parental Match algorithm was used.

(Insert Table 5 here)

Pre-post analyses. We also conducted follow-up analyses on the Match sample to determine how science knowledge and attitudes changed over the 4-month period from fall to spring (summarized in Table 6 and 7). Repeated-measures ANOVAs were run on each outcome measure, using Time (fall, spring) as a within-subjects measure and Participation (High-Participation, Low-Participation) as a between-subjects measure. All three attitude outcomes showed significant Time X Participation interactions (Fascination: $F(1, 587) = 19.5$, $p < .001$, $\eta^2_p = .03$; Values: $F(1, 592) = 23.4$, $p < .001$, $\eta^2_p = .04$; Competency Beliefs: $F(1, 594) = 25.2$, $p < .001$, $\eta^2_p = .04$). Low-Participation students showed a significant drop over time in Fascination, $F(1, 295) = 40.2$, $p < .001$, $\eta^2_p = .12$, Values, $F(1, 299) = 7.95$, $p = .005$, $\eta^2_p = .03$, and Competency Beliefs, $F(1, 302) = 6.96$, $p = .009$, $\eta^2_p = .02$. Higher participation in school-related optional experiences helped students to maintain their initial levels of Fascination and even increased their Values, $F(1, 293) = 15.5$, $p < .001$, $\eta^2_p = .05$, and Competency Beliefs, $F(1, 292) = 20.1$, $p < .001$, $\eta^2_p = .06$.

For the knowledge measures, there was a significant interaction for Scientific Sensemaking, $F(1, 595) = 14.0$, $p < .001$, $\eta^2_p = .02$, and a marginally significant Time X Participation interaction for Content Knowledge, $F(1, 555) = 3.21$, $p = .07$, $\eta^2_p = .01$. The High-Participation students showed no change in Scientific Sensemaking, while the Low-Participation students improved over time, $F(1, 302) = 13.0$, $p < .001$, $\eta^2_p = .04$. Though the interaction did not reach significance, Content Knowledge showed a different pattern, in which High-Participation students significantly decreased in Content Knowledge from fall to spring, $F(1, 274) = 4.75$, $p = .03$, $\eta^2_p = .02$, while there was no change for Low-Participation students.

(Insert Table 6 and 7 here)

Effects of Recent Home-Related Experiences

Match sample regressions. As with the school-related experiences, five regressions were conducted to predict Fascination, Values, Competency Beliefs, Scientific Content Knowledge, and Scientific Sensemaking at spring, this time using high vs. low Recent Home-Related Science Experiences as a predictor. Average values and effect sizes (Cohen's *d*) of High-Participation and Low-Participation students are shown in Figure 1c and 1d, and Table 8 shows means and standard deviations. Power analyses show that the sample was able to detect a minimum effect size (Cohen's *d*) of .17 at 80% power.

Similar to school-related experiences, home-related experiences also significantly predicted higher Fascination ($F(1, 995) = 53.2$, $p < .001$, $R^2 = .05$), Values ($F(1, 998) = 35.8$, $p < .001$, $R^2 = .04$), and Competency Beliefs ($F(1, 1000) = 30.2$, $p < .001$, $R^2 = .03$) in science. There was no influence of home-related experiences on Content Knowledge ($F(1, 934) = 0.19$, $p =$

0.66, $R^2 < .001$), but a slight negative association with Scientific Sensemaking ($F(1, 1001) = 6.25$, $p = .013$, $R^2 = 0.006$).

(Insert Table 8 here)

Alternative model regressions. We again ran similar Home-Related regressions on the full unmatched sample with all 17 covariates included (the "Full OLS" with 196 High-Participation students and 243 Low-Participation students after list-wise deletion), the matched sample with the propensity model covariates included (the "Match plus covariates" with 514 High-Participation students and 514 Low-Participation students), the matched sample with highest parent job type, highest parent job level, highest parent education, and pre-test choice preferences added (the "Parental Match" sample with 128 High-Participation students and 128 Low-Participation students), and the Parental Match sample with propensity model covariates included in the regression (the "Parental Match plus covariates" with 128 High-Participation students and 128 Low-Participation students), shown in Table 5. Power analyses show that the samples were able to detect minimum effect sizes (Cohen's *d*) that were small at 80% power across analyses: 0.27 (Full OLS), 0.17 (Match, Match plus covariates), and 0.35 (Parental Match, Parental Match plus covariates). The alternative models still showed strong, positive relationships between Home-Related experiences and Fascination, Values, and Competency Beliefs, and no relationship with Content Knowledge. However, unlike the Match sample regressions, they showed no significant relationship with Scientific Sensemaking, suggesting that home-related experiences may have a relatively weak negative influence on science learning.

Pre-post analyses. We again conducted follow-up repeated-measures ANOVAs to look at change on each outcome measure over the 4-month period for the Match sample, using Time (fall, spring) as a within-subjects measure and Participation (High-Participation, Low-

Participation) as a between-subjects measure (summarized in Table 6 and 7). There was a significant Time X Participation interaction for Fascination, $F(1, 995) = 4.37$, $p < .001$, $\eta^2_p = .03$), Values, $F(1, 998) = 32.8$, $p < .001$, $\eta^2_p = .03$, and Competency Beliefs, $F(1, 1000) = 22.9$, $p < .001$, $\eta^2_p = .02$. As with the school-related experiences, Low-Participation students decreased in Fascination, $F(1, 496) = 85.2$, $p < .001$, $\eta^2_p = .15$, Values, $F(1, 506) = 32.1$, $p < .001$, $\eta^2_p = .06$, and Competency Beliefs, $F(1, 499) = 7.12$, $p = .008$, $\eta^2_p = .01$. Meanwhile, students with high participation in home-related experiences maintained their level of Fascination and significantly increased in Values, $F(1, 492) = 6.40$, $p = .01$, $\eta^2_p = .01$, and Competency Beliefs, $F(1, 501) = 16.9$, $p < .001$, $\eta^2_p = .03$. For knowledge, there was only a significant Time X Experience interaction for Scientific Sensemaking, $F(1, 1001) = 8.46$, $p = .004$, $\eta^2_p = .01$, where Low-Participation students increased over time, $F(1, 504) = 3.90$, $p = .049$, $\eta^2_p = .01$, while High-Participation students decreased, $F(1, 497) = 4.56$, $p = .03$, $\eta^2_p = .01$. Thus, home-related recent experiences also protect and improve students' attitudes toward science, but may still have a detrimental (though weaker) effect on more general science skills.

General Discussion

In the current study, we investigated whether school-related and home-related optional science experiences are associated with science knowledge and attitudes, using propensity score matching to address issues of causality and representativeness. After matching students on their likelihood to participate in optional experiences, we found that students who attended many school- and home-related optional experiences held more positive attitudes toward science compared to those who attended few optional experiences. Recent optional experiences helped students to maintain their initial levels of fascination, while also increasing the external value they place on science and their perceived competency in science.

In contrast, more optional experiences were negatively associated with science learning, as measured by science content knowledge and more general skills of applying the scientific method. More specifically, school-related experiences showed a negative relationship with both Content Knowledge and Scientific Sensemaking, while home-related experiences only showed a weaker negative relationship with Scientific Sensemaking. Both school- and home-related experiences appeared to prevent knowledge growths that were seen in students who attended few recent experiences, and home-related experiences may have decreased Scientific Sensemaking as well. It is possible that knowledge measures on the specific content taught by a given program would show improvements, but the current results suggest that the average optional experience does not teach effective practices that generalize to improvements in school learning.

The results regarding science attitudes fit well with prior literature, which has often found a positive relationship between out-of-school programs and students' engagement with science (e.g., Abernathy & Vineyard, 2001; Dabney et al., 2012; Gibson & Chase, 2002; Henriksen et al., 2015; Knox et al., 2003; Kong et al., 2014; Maltese & Tai, 2011; Markowitz, 2004; Paris et al., 1998; Sahin, 2013; Simpkins et al., 2006; Uitto et al., 2006). The findings also provide a more detailed look at how optional experiences can support interest over time by preventing loss of interest in science that other students appear to experience, and by boosting overall interest. This supports previous findings showing a drop in science motivation at this age range (e.g., Adams, Doig, & Rosier, 1991; Goodrum, Hackling, & Rennie, 2001) as students begin transitioning from middle-school to high-school and science classes become more rigorous and focused on specific content (Aikenhead, Calabrese, & Chinn, 2006; Schwab, 1962, 1965; Speering & Rennie, 1996). Optional science experiences may be more likely to focus on science as inquiry and promote the exploration of students' individual interests, maintaining their interest in science.

While our findings on science learning support Suter's (2016) and Lin and Schunn's (2016) negative associations between optional experiences and science abilities, they are inconsistent with many prior studies that show positive achievement outcomes after out-of-school programs. This suggests that the current study's use of a large, regional dataset, and the use of PSM to manage issues of self-selection within this larger sample, may be accounting for biases in prior results. In addition, the current study provides evidence that all types of optional experiences are not uniform, as the negative influences on knowledge were more robust for school-related experiences than home-related experiences, indicating the importance of considering different types of optional experiences and their implications.

Optional Science Experiences' Negative Impact on Science Knowledge

Optional science experiences can clearly be valuable for students, particularly for supporting their science interests. However, given the accumulating evidence that gains in students' attitudes may not be equally matched by changes in knowledge, it is important to ask when and why optional science experiences hurt science knowledge, and why the effect appears stronger for school-related experiences compared to home-related experiences. While the current ALES14 dataset was rich with information on student characteristics, it was limited in the information collected about each students' individual optional experiences, making it difficult to answer either question. Here, we consider possible factors that could affect the relationship between optional science experiences and student knowledge, that future studies can investigate in more detail, while also taking the issues of self-selection and representativeness addressed by the current study into account.

One likely factor is program quality. Other studies have found that quality can significantly affect whether an optional experience is beneficial. For example, Gerber, Cavallo, and Marek (2001) found that students who participated in high-quality, enriched informal learning environments had higher scientific reasoning abilities than students who participated in impoverished informal learning environments. It is possible that the school-related experiences in the current dataset were lower in quality than the home-related experiences or other out-of-school programs from prior studies, leading to the negative associations found between experiences and knowledge.

Assuming that program quality plays a large role in the relationship between optional science experiences and achievement, this opens the question of what differentiates high and low quality experiences. Studies have suggested that high-quality programs provide positive social influences for students (especially at-risk students) by providing a safe environment to explore their science understanding and a sense of belonging to a group (American Youth Policy Forum, 2006). Low quality experiences may still provide interesting experiential learning opportunities that promote science interest (as evidenced by our attitude results), but students may lack guidance in connecting activities back to their scientific understanding. Much of this learning guidance is provided by program supervisors, who can vary significantly in their level of experience. Many out-of-school programs are primarily staffed by teachers who lack a STEM degree, and who report feeling unqualified to teach science (Knapp, 2007); they may be ill-equipped to guide students and correct any existing misconceptions about science, or may even unintentionally promote them. While school-related experiences may be more likely to have qualified science instructors available to supervise activities, this may not always be the case, especially for activities that are more student-driven (e.g., being part of a study group with other students).

Separate from program quality, other mechanisms may also differentiate school- and home-related activities and their impacts on student knowledge. For example, structured school-related experiences may provide less freedom and fewer opportunities for students to explore their own science interests or to learn unusual topics that are not typically covered in the classroom. Other structural similarities besides topic similarity between classrooms and school-related optional experiences may also influence science knowledge. For example, if science teachers are more likely to supervise school-based optional experiences than home-related experiences and a teacher manages optional experiences similarly to their classroom, then students who struggle in class may also struggle during the optional experience. Further, if a student has strained relationships with teachers or peers in their classes, then participating in school-related experiences such as science clubs or study groups could be detrimental for them. Future studies should collect information about individual program quality, such as social relationships, topics covered, and supervision available, in addition to the student information needed to account for potential endogeneity.

It may also be worthwhile to consider whether meaningful sub-categories of school-related activities exist that differentially impact science attitudes and knowledge. For example, some experiences may be more peer-driven (e.g., being part of an out-of-class study group, doing group projects), while others may be more instructor-driven (e.g., being part of a science club, talking to a teacher about books or websites). Looking more in-depth at individual programs, as well as other categorizations of programs, may offer further information about the qualities that make for a positive optional experience for students.

In conclusion, optional science experiences are consistently beneficial for science attitudes, but school-related science experiences (and to a lesser extent, home-related experiences) show negative associations with science learning when issues of self-selection are taken into account. The current study shows the importance of using more advanced statistical methods to provide a better picture of optional experience outcomes, as well as considering the different types of experiences in which students participate. While optional science experiences can be an effective way to engage students in more science, not all experiences are equal for learning outcomes. More work should be done investigating the factors that differentiate effective optional experiences from ineffective ones to ensure that students are gaining both the motivation and ability to succeed in science.

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Table 1

School and Home-related Items on the Recent Optional Science Experiences Questionnaire

School-Related	Home-Related
I talked to a science teacher about good science books or websites.	Outside of class, I collected rocks, butterflies, bugs, or other things in nature.
I was part of a group that got together outside of class time to study for science class.	Outside of class, I watched TV programs about science topics.
I did my homework or projects for science class with other students.	Outside of class, I read books about science or science fiction.
I did an extra-credit project for science class.	Outside of class, I took things apart to see how they work.
I was part of a science club after school or on the weekends.	Outside of class, I went to science websites to look up information.
	Outside of class, I did science experiments at home.

Table 2

Obliquely Rotated Component Loadings for the Recent Optional Science Experiences Questionnaire

Component	1	2
I was part of a science club after school or on the weekends.	.79	-.21
I talked to a science teacher about good science books or websites.	.79	-.02
I was part of a group that got together outside of class time to study for science class.	.56	.09
I did an extra-credit project for science class.	.42	.18
Outside of class, I collected rocks, butterflies, bugs, or other things in nature.	.37	.29
I did my homework or projects for science class with other students.	.23	.20
Outside of class, I read books about science or science fiction.	-.06	.70
Outside of class, I did science experiments at home.	.00	.66
Outside of class, I watched TV programs about science topics.	-.11	.62
Outside of class, I took things apart to see how they work.	.14	.46
Outside of class, I went to science websites to look up information.	.29	.41
Eigenvalues	4.04	1.28
Percentage of total variance	37%	12%

Table 3

Mean Differences Between Covariates Before and After Matching

Covariate	**% Missing**	**Before Matching (School-Related)**	**After Matching (School-Related)**	**Before Matching (Home-Related)**	**After Matching (Home-Related)**
Propensity Score	--	.18	.02	.30	.03
Grade	0%	0.07*	-0.04	-0.14***	-0.04
Location	0%	0.00	-0.04	-0.05*	-0.01
Prior Experiences	26%	0.03	0.01	0.19***	0.03
Family Support	19%	0.04	0.00	0.13***	-0.01
Home Resources	19%	-0.03	-0.03	0.09**	0.00
Pre Fascination	26%	0.14***	0.03	0.31***	0.05†
Pre Values	26%	0.06†	0.01	0.23***	0.01
Pre Competency Beliefs	25%	0.08*	0.00	0.27***	0.04
Pre Content Knowledge	22%	-0.31***	-0.08	0.10*	0.01
Pre Scientific Sensemaking	27%	-0.14***	-0.02	-0.03**	0.00
Sex	22%	-0.15***	-0.01	-0.13***	-0.02
Minority	23%	0.14***	-0.00	0.03	-0.02
Parent Job Type	39%	-0.01	-0.12	0.11	-0.05
Parent Job Level	63%	-0.04	-0.20	0.01	-0.11
Parent Education	37%	0.00	-0.11	0.20†	0.08
Pre Choice Preferences	31%	0.16*	0.00	0.35***	0.05

Note. *** $p < .001$, ** $p < .01$, * $p < .05$, † $p < .1$

Table 4

Averages and Standard Deviations for the School-Related Matched Data.

	High-Participation	Low-Participation
Pre Fascination	2.78 (0.61)	2.75 (0.52)
Post Fascination	2.79 (0.61)	2.56 (0.56)
Pre Values	2.72 (0.58)	2.71 (0.46)
Post Values	2.83 (0.56)	2.64 (0.48)
Pre Competency Beliefs	2.91 (0.56)	2.91 (0.50)
Post Competency Beliefs	3.04 (0.53)	2.84 (0.50)
Pre Content Knowledge	-0.10 (0.96)	-0.02 (0.97)
Post Content Knowledge	-0.22 (0.97)	0.00 (0.97)
Pre Scientific Sensemaking	.51 (.26)	.53 (.25)
Post Scientific Sensemaking	.50 (.26)	.57 (.24)

Note. Attitudes are on a 1-4 scale, science content knowledge are z-scores, and scientific sensemaking scores are on a 0-1 scale.

Table 5

Alternative Model Regression Results of the Effects of School-Related and Home-Related Experiences on *Each Outcome Variable*

	Fascination	Values	Competency Beliefs	Content Knowledge	Scientific Sensemaking
School-Related Experiences Effect					
Full OLS (*N*=444)	.12**	.14***	.08*	-.09*	-.09**
Match (*N*=618)	.19***	.18***	.20***	-.11**	-.15***
plus covariates	.17***	.18***	.18***	-.10**	-.14***
Parental Match (*N*=164)	.13	.15†	.05	-.13	-.14†
plus covariates	.14*	.14†	.03	-.17*	-.10†
Home-Related Experiences Effect					
Full OLS (*N*=439)	.22***	.17***	.14***	.01	-.05
Match (*N*=1,028)	.23***	.19***	.17***	-.01	-.08*
plus covariates	.20***	.18***	.15***	-.01	-.07***
Parental Match (*N*=256)	.25***	.22***	.17**	.06	-.02
plus covariates	.23***	.19***	.13**	-.01	-.04

Note. *** $p < .001$, ** $p < .01$, * $p < .05$, † $p < .1$

Table 6

Summary of the Pre-Post Effects of High Participation in Optional Experiences

	Fascination	**Values**	**Competency Beliefs**	**Content Knowledge**	**Scientific Sensemaking**
School-Related	No change	Increases	Increases	Decreases	No change
Home-Related	No change	Increases	Increases	No change	Decreases

Table 7

Summary of the Pre-Post Effects of Low Participation in Optional Experiences

	Fascination	**Values**	**Competency Beliefs**	**Content Knowledge**	**Scientific Sensemaking**
School-Related	Decreases	Decreases	Decreases	No change	Increases
Home-Related	Decreases	Decreases	Decreases	No change	Increases

Table 8

Averages and Standard Deviations for the Home-Related Matched Data.

	High-Participation	Low-Participation
Pre Fascination	2.73 (0.56)	2.68 (0.50)
Post Fascination	2.72 (0.55)	2.47 (0.51)
Pre Values	2.70 (0.52)	2.69 (0.45)
Post Values	2.75 (0.50)	2.57 (0.46)
Pre Competency Beliefs	2.91 (0.53)	2.87 (0.48)
Post Competency Beliefs	3.00 (0.48)	2.83 (0.51)
Pre Content Knowledge	0.14 (1.01)	0.13 (0.98)
Post Content Knowledge	0.13 (1.03)	0.16 (0.95)
Pre Scientific Sensemaking	.61 (.25)	.61 (.23)
Post Scientific Sensemaking	.59 (.26)	.63 (.24)

Note. Attitudes are on a 1-4 scale, science content knowledge are z-scores, and scientific sensemaking scores are on a 0-1 scale.

Figure Captions

Figure 1. Average post outcome values for Matched (a) School-Related attitude measures, (b) School-Related knowledge measures, (c) Home-Related attitude measures, and (d) Home-Related knowledge measures. Dotted lines signify mean pre values, and effect sizes are shown above each comparison.