

Article

Role of Parent Language and Ethnicity on Family Science Problem-Solving Processes

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Abstract

The goal of this study was to examine problem-solving processes of elementary-aged children (4th grade U.S., ages 9–10) and their parents as they applied themselves to hands-on science activities together, with the larger goal of studying how parents influence the development of children's science inquiry skills. In this diverse group of families, which was approximately equally balanced in terms of ethnicity (Hispanic and non-Hispanic) and parent and child gender, the influence of parent language, dyad ethnicity, and dyad gender was examined while controlling for family socio-economic status. Four problem-solving processes were examined: writing a hypothesis, recording results, drawing/sketching the process, and writing an explanation of how or why a process worked. The study included 153 families in a metropolitan area in the southwestern U.S. (Phoenix, AZ), approximately balanced in terms of child and parent ethnicity and gender. Gender differences were not observed for any of the problem-solving processes. Differences in some problem-solving processes, especially for writing a hypothesis, were observed based on parent language and dyad ethnicity. Families employed the strategy of drawing/sketching out solutions with a similar level of detail, regardless of parent education, language, ethnicity, and gender. Thus, we propose the use of drawing/sketching in the elementary science classroom as a useful strategy for reaching a diverse audience of learners. Family socio-economic status (as measured by parent education and family income) was strongly associated with parent language and dyad ethnicity. Implications for these findings are discussed.

Keywords: science education; problem-solving; parents; ethnicity; gender; Hispanic; language; bilingualism



Academic Editors: Alberto Robres and Alejandro Quintas-Hijós

Received: 4 September 2025

Revised: 18 November 2025

Accepted: 18 November 2025

Published: 21 November 2025

Citation: Sandrin, S., Broatch, J., & Short-Meyerson, K. (2025). Role of Parent Language and Ethnicity on Family Science Problem-Solving Processes. *Education Sciences*, 15(12), 1573. <https://doi.org/10.3390/educsci15121573>

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1. Introduction

This is a study of elementary (4th grade U.S.) students and their parents, with the goal of learning more about the development of children's science inquiry and reasoning skills. Specifically, the roles of parent language, parent-child dyad ethnicity (Hispanic and non-Hispanic), and parent-child dyad gender in the use of different problem processes were examined. The problem-solving processes investigated in this study included (a) writing a hypothesis, (b) recording results, (c) drawing/sketching processes, and (d) writing explanations of how or why systems worked. While parents play a critical role in how children think and what topics children are exposed to from a young age, most educational studies focus on the formal learning environment, and fewer examine the influence of

parents on student performance and interest in science. The focus of this study is to determine how parental factors influence children's science problem-solving processes and to assess children's strengths so that educators can support children as they develop science inquiry skills in more formal educational settings.

1.1. Theoretical Framework

Parents play an important role in influencing their children's interest, persistence and success in science education. For example, students who reported being supported and encouraged to pursue their science interests by parents and teachers were more likely to persist, had more interest in, and higher self-competence in science than other students. This was true for students from 5th grade (Rice et al., 2013) to high school and early college (Garriott et al., 2014; Stake, 2006). Additionally, parents may support their children by enrolling them in out-of-school science, technology, engineering and math (STEM) activities (Simpkins et al., 2006), or simply by setting up a time and place for their child to study (O'Sullivan et al., 2014). The critical roles that parents play in their children's development of interests and inquiry skills in science are often overlooked. Furthermore, parental influence can lead to differential preparation of students outside of school, which may lead to differences in school performance later on.

1.1.1. Representation of Marginalized Groups in Science

There continue to be gaps in performance by ethnicity and gender in many areas of national science assessments in the United States (USA), the home country for this study. Hispanic students scored significantly lower on the National Assessment of Educational Progress (NAEP) than their non-Hispanic, Caucasian peers at the 4th, 8th and 12th grade levels in physical, life and earth science topics (U.S. Department of Education, 2019). The gaps are smaller with regard to gender, however male students scored higher than female students on physical and overall science in grade 12. Similarly, while Hispanic peoples make up approximately 19.5% of the U.S. population, they only attain between 11% and 14% of all natural and physical science degrees (depending on the field of study). Women attain only about 20–25% of computer science, physics and engineering degrees, but more than half of all life science degrees (National Center for Science and Engineering Statistics, 2021).

Numerous studies have examined the achievement gap between Hispanic and non-Hispanic Caucasian students to identify associated factors. These factors include classroom, family and psychological differences. In the school environment, differential classroom resources and class sizes, or access to career information, or even racial prejudice have been documented as reasons for differential outcomes with Hispanic and non-Hispanic students (Shoffner & Dockery, 2015). These issues can lead to low self-efficacy in Hispanic students (Garriott et al., 2014; Navarro et al., 2007), such that even when science achievement is controlled for in a study, Hispanic students still report less interest in STEM fields as compared to their White and Asian peers (Wang, 2012).

Similarly, the reasons for women's lower representation in computer science, engineering and physical/quantitative sciences has been studied from a number of different perspectives. Girls' preferences for life sciences over more quantitative physical science fields may begin as early as childhood (Bogdan Toma & Meneses Villagra, 2019; Hsieh et al., 2019; Short-Meyerson et al., 2016). Women often report a "chilly climate" due to subtle and sometime unconscious biases in the science community, which can discourage them from pursuing them (Avolio et al., 2020; Cheryan et al., 2017). Additionally, parents often preferentially encourage daughters to enter non-science or science fields that focus on caretaking and helping others through the types of toys that they buy or offer children

from a young age ([Avolio et al., 2020](#); [Francis, 2010](#)) or through discussions while reading children's books ([Shirefley & Leaper, 2022](#); [Tenenbaum & Leaper, 2003](#)).

1.1.2. Parental Support and Representation of Marginalized Groups

A student's science capital can be viewed through the lenses of economic, social, cultural, and symbolic capital. In a study with students age 11–15 in the UK, [Archer et al. \(2015\)](#) found that science capital was a predictor of students' pursuit of advanced science coursework, and that science capital was influenced by a student's cultural capital, ethnicity and gender. Studies with Hispanic and multi-ethnic parents in the USA have demonstrated the importance of parental involvement, a form of science capital, even with parents are not experienced in science in math. It positively impacts their children's math and science interests, self-efficacy, and future goals and expectations ([Ferry et al., 2000](#); [Garriott et al., 2014](#); [Turner et al., 2004](#)), especially maternal support ([Turner et al., 2004](#)). When Hispanic parents offered encouragement, stayed involved, set high academic expectations, and guided their children as mentors to younger siblings, their adolescents were more likely to select science-related fields in college ([Peralta et al., 2013](#); [Thursby Bourke et al., 2024](#)).

Unfortunately, parents are also impacted by societal factors that impact their efficacy in assisting their children to succeed in science. In the USA, Hispanic parents are less likely to have graduated high school or college ([U.S. Census Bureau, 2022](#)), and Hispanic families earn approximately 74% of White, Non-Hispanic families. A study by [Silander et al. \(2018\)](#) found that Hispanic parents in the USA feel less confident about their knowledge of science content and in helping their child with science as compared to non-Hispanic Caucasian parents, but their study did not control for family income or parent education. This may lead Hispanic parents to offer less parental science support. [Simpkins et al. \(2015\)](#) determined that Hispanic high school females and males (to a lesser extent) had less science parental support in science and lower science motivational beliefs than male Caucasian peers. Caucasian female students experienced similar support and motivational beliefs as male Hispanic students. Conversely, [Solis and Callanan \(2021\)](#) conducted case studies of Hispanic families of 3- to 5-year-olds as they discussed and conducted a science experiment, and they demonstrated that the overall amount of science interactions of parents with lower levels of schooling were similar to those with higher levels of schooling. They observed that parents with higher-levels of schooling took on more of a teacher-student role in which they guided children toward the "correct" answer. Alternatively, parents with lower-levels of schooling focused on authentically collaborating and learning WITH their children and were more likely to admit if they guessed the answer incorrectly, thereby encouraging problem-based learning in their children. Although the children in our study were older, the range in parent education was also broad and it could be argued that some of the science activities were more complex and so this behavioral difference may have been more pronounced.

Girls often begin to score lower on physical and space science assessments, and to lose interest in these fields, by middle school as social gender stereotypes and patriarchal ideologies are reinforced over time, in the USA ([Baram-Tsabari et al., 2009](#); [U.S. Department of Education, 2019](#)) and globally ([Avolio et al., 2020](#); [Fussy et al., 2023](#); [Mujtaba & Reiss, 2015](#); [UNESCO, 2017](#)). The amount of support and encouragement that a child may receive in science and math from parents, teachers and their communities may also, unfortunately, be related to the child's gender ([Ford et al., 2006](#)), which may in turn lead to differences in children's interests, attitudes, behaviors, and self-efficacy in STEM ([Garriott et al., 2014](#); [Simpkins et al., 2015](#); [UNESCO, 2017](#)). Fortunately, parents also may have positive influences on their child's goals. For example, when mothers helped their adolescent children make personal connections with science topics, their children were more likely to develop

interest and take more courses in science during high school (Hyde et al., 2017). Additionally, parental encouragement and support by providing access to learning experiences in science is even more important than family educational background (Aschbacher et al., 2010; Avolio et al., 2020).

1.1.3. Problem-Based Learning

Our work is grounded in constructivism and problem-based learning (PBL). PBL is based on the constructivist approach to learning, which views the learner as actively engaged in constructing their knowledge through social interaction with others (Vygotsky, 1978). In our study, each child worked with their parent on problems that involved many elements of PBL. One key element of PBL is that students actively engage in real-world authentic problems (Bell, 2010; Hmelo-Silver, 2004). Examples of the problems in our study include choosing the best location to plant a garden, constructing an electric circuit, and determining how heart rate is affected by exercise. They are challenging problems that involve “doing”: making predictions, developing a plan and/or designing an experiment, collecting and analyzing data, and drawing conclusions. Furthermore, PBL is student-centered, in which students have voice and choice (Blumenfeld et al., 1991; Krajcik & Shin, 2014). PBL is designed to be collaborative between participants, as in our study where the parent and child typically both engaged equally, rather than one taking the lead while the other watched.

In a study conducted in Thailand, Chaidam and Poonputta (2022) investigated the use of PBL in 1st grade mathematics. One goal of the study was to examine the efficacy of the PBL model for the students’ learning achievement during a unit on weight and measurement. Participants were 35 1st graders, who first received a multiple choice pre-test. Then there was three weeks of instruction following the PBL approach, which the researchers describe as following five steps: (1) identifying the problem, (2) investigating the inquiry process, (3) exploring the ideas and challenging them through collaborative activities, (4) utilizing the inquiry process to refine products, and (5) developing the summative product that addresses the challenge or problem and sharing it. Results from a post-test indicated significant gains in understanding of weights and measurement. Chaidam and Poonputta also suggest that PBL contributes to the development of students’ analytical thinking, problem solving, decision making and creative thinking skills.

A study in the Southwestern United States (in Arizona and California) incorporated PBL in a family science program for 5th and 6th grade Latinas and their parents (Rillero et al., 2025). The families participated in a 7-week gardening program in which the overall goal was growing a small garden from seeds to harvest. Each week’s session included 90 min of hands-on gardening activities which consisted of choosing the seeds, planning where to plant them, considering environmental factors, caring for the plants, measuring the plants, and more. The curriculum was designed to deepen understanding of concepts such as roots and soils (e.g., using Play-Doh to create a root system with the most surface area). Through surveys at multiple points of the program, the researchers tracked changes in the daughters’ science identity and career aspirations. They found that they both increased throughout the program, and the gains were maintained three months after the program. Rillero et al. (2025) describe how working through each problem included thinking and talking about concepts. Additionally, they state (pp. 7–8) that, “The project-based learning framework in design and implementation stressed (a) discussion before action and then (b) exploration before explanation.” These elements are also important to the problem-solving processes in our current study.

1.1.4. Science Education and Multilingualism

The terms multilingual and bilingual are often used to refer to students who speak more than one language (González-Howard & Suárez, 2021). This manuscript will use the term “bilingual” to refer to participants in our study, with Spanish and English being the two languages. Some of the work discussed in this section also includes students who are multilingual. Both terms assume an asset-oriented perspective.

Advocacy for linguistically and culturally responsive pedagogies, ways of teaching that recognize the cultural and linguistic capital that multilingual students bring to the classroom, has increased globally over the past decade (Archila et al., 2024; Gutierrez et al., 2022; Oliveira et al., 2019; Weidl & Erling, 2025). Despite the fact that multilingual classrooms are becoming more common globally, many pre-service teachers feel unprepared to respond to students in multilingual environments (Rinker & Ekinci, 2025).

Recent literature on multilingualism in science education has been influenced in part by the Next Generation Science Standards (Achieve, 2013) in the USA. Many of the practices set forth in these standards are language intensive, which has prompted science educators and researchers to consider how critically important language is to science learning (Kang et al., 2017). For example, González-Howard and Suárez (2021) have examined how current science standards, such as NGSS, emphasize language-rich practices for sensemaking in science. They are particularly interested in whether/how these practices impact multilingual students. Other studies have embraced the use of students’ linguistic capital. In Colombia, the practice of having students create bilingual (or trilingual) science-content podcasts enhanced their abilities to structure and counter scientific arguments in both (or all) languages (Archila et al., 2024). In a study with middle school mathematics students who were largely bilingual (Spanish-English), the bilingual math teacher explained mathematics vocabulary and symbols and likened math to learning another language, helping the children to conceptualize the material in a new way (Garza Ayala, 2022). Science lessons, with their many vocabulary terms, are similar in this way to mathematics.

Oliveira et al. (2019) encourage multilingual students to use their linguistic resources in sense-making. They believe that the two main types of student action in multilingual science teaching are scientific investigation and text production. This includes talking and writing, which are both effective and beneficial. In inquiry-based lessons students often also record their data and other information by drawing and labeling pictures and diagrams. A practical implication is that for assessments, multilingual students should be allowed and encouraged to demonstrate their content knowledge through visuals. Similarly, a study with middle school students in a bilingual classroom in the Northeastern USA demonstrated that engagement in bilingual science lessons enhanced students’ abilities to frame and support scientific argumentation (Licona & Kelly, 2020). In addition to the linguistic resources of multilingual students, Alegría (2014) describes the traditional cultural knowledge (i.e., funds of knowledge) that multicultural students also bring to the classroom. Relatedly, in Yosso’s (2005) framework of community cultural wealth, students bring to their interactions various types of capital, including linguistic capital to the classroom.

When students have limited language skills in the language of instruction, they often struggle to learn science concepts and vocabulary. For example, Lee and Fradd (1995) examined fourth graders’ science knowledge and use of cognitive strategies in the school classroom at public elementary schools in the southeastern USA with students from four ethnolinguistic groups. They reported that students who were language learners were less able to concisely explain science concepts using science vocabulary words. Indeed, a student’s proficiency in science vocabulary predicts science reading comprehension such that even when language learners are similarly proficient in everyday vocabulary

to their peer native speakers, but not yet with science vocabulary, they may be missing some concepts when they are read science text (Ardasheva et al., 2019). Weinburgh et al. (2014) demonstrated that 5th grade students with limited language skills (in the language of instruction) were able to learn significant science vocabulary and concepts during an intensive 3-week summer school program using a 5R strategy (reload, repeat, reposition, replace, reveal). Therefore, students whose families do not speak the language of instruction at home may be less familiar with science vocabulary terms (i.e., those not used in everyday conversation) and may benefit from explicit instruction in science vocabulary.

1.1.5. Multimodality in Science Learning

Partly because of the relevance of language to the current science standards, the topics of translanguaging and multimodality have been recent focuses of research on multilingualism and education, in science as well as other disciplines. Translanguaging, the fluid transitioning between two (or more) languages (Wei, 2018) is important in the classroom because it invites students to use their full repertoire of linguistic and semiotic resources (Pierson & Grapin, 2021) and was demonstrated to be helpful with 5th graders to make meaning of new content and linguistic forms (Poza, 2018). Similarly, the use of multiple modalities (i.e., multimodality), such as spoken and written language and drawing, has been acknowledged as valuable for constructing meaning in science. For example, Pierson and Grapin (2021) examined multimodal modeling in a 6th grade science class through the use of four types of models: physical, embodied, computational, and diagrammatic (e.g., drawing and symbols to highlight relationships, such as arrows to show energy transfer). They found that multimodality promoted higher-order thinking and conceptual understanding, which are valuable skills in science. Moreover, they propose a disciplinary perspective in which there is a connection between translanguaging and multimodal disciplinary practices. This is consistent with the view of González-Howard and Suárez (2021), who define language as both linguistic and multimodal (e.g., including charts, graphs, symbols, models, and gestures).

Drawing, specifically, is an important activity that is employed in many fields of study. In the context of science education, Ainsworth et al. (2011) highlighted five roles that drawing plays in science education including the following; (1) motivating student learning, (2) learning to represent scientific concepts in science using multiple modalities (drawing, talking and writing), (3) development of reasoning and argumentation skills in science, (4) drawing to organize material effectively and draw new inferences, and (5) as a form of communication. For example, among first-grade students in the southeastern USA, students were better able to construct explanations about how a plant functions when drawings were incorporated into the lesson (Wilson & Bradbury, 2016). Further, Krajcik and Sutherland (2010) determined that the practice of going back and forth between text and graphic representations (an intersection of multimodality and translanguaging) helped middle school students to comprehend complex relationships between variables. Additionally, a study with early elementary children in Sweden participating in group work demonstrated how the combined use of text and graphics aids peer discussions about science processes (Caiman & Jakobson, 2024). Finally, the use of a topology-based model for assessing student drawing has shown promise in providing real-time feedback to students to help reduce misconceptions (Smith et al., 2019).

The merging of art (including drawing) and science has become more popular in recent years, and numerous studies have focused on the benefits of art in developing science process skills. For example, Jakobson and Wickman (2015) described how 6- to 7-year-old children in Sweden created artistic leaf imprints as part of a science lesson to make meaning of science content and concepts. In a related study, Caiman and Jakobson (2024) concluded

that both the cognitive and esthetic features of art improved student's communication about science, as well as their skills in making predictions and meticulous observations. Even at the college level, the use of art helps students to develop an intuitive understanding of 3D biological structures (Gurnon et al., 2013). Finally, a study with kindergarten children in Kuwait (Habeb et al., 2024) concluded that the use of art in science instruction helped the students become more creative in their problem-solving strategies.

Although most of the research on translanguaging has been performed in K-12 STEM classrooms, there is a limited body of research on the role of parents and families. Although this paper focuses on science, rather than mathematics, the most relevant study with families and translanguaging in STEM was in mathematical problem solving in a case study of a rising middle elementary aged child with his parents by Gutierrez et al. (2022). Their results illustrated how bilingual parents also use translanguaging, emphasizing the parents' linguistic capital (e.g., the asset of knowing more than one language), and the parents' multimodal practices (e.g., including charts, graphs, symbols, and models). These illustrate a strength-based perspective consistent with Yosso's (2005) framework of community cultural wealth, which emphasizes skills and assets that students bring from their family and culture.

1.1.6. Science Inquiry, Hypothesis Writing and Scientific Reasoning Skill Development

The development of science inquiry skills, including scientific reasoning and writing hypotheses, is important for students during elementary and middle school years (Achieve, 2013). Also, a study with fourth-grade children in Singapore demonstrated that participation in inquiry-based science education enhances students' interests in science (Jocz et al., 2014). Scientific reasoning about how experimental variables are related and influence one another, a skill that is necessary to formulate a hypothesis, is a complex cognitive task. Piaget's cognitive stages of development (Piaget, 1953) predicted that elementary students were unable to tackle the abstract process of writing a hypothesis as a form of scientific reasoning. While elementary students often struggle with writing hypotheses and scientific reasoning in general, more recent studies with students in grades/years three to six in Japan and Germany have demonstrated that Piaget underestimated elementary students' capabilities in this area. However, they acknowledge that some students may be more advanced than others (Grimm et al., 2023; Lecce et al., 2024; Oshima et al., 2004).

The heterogeneity in scientific reasoning ability may be attributed to a number of factors, such as the child's developmental level, cognitive/intellectual ability, motivation, gender, language (different language spoken in class versus at home), ethnicity, and sociocultural background (Koerber et al., 2015; Lecce et al., 2024; Tomlinson et al., 2003). Sandoval et al. (2014) determined that children have more successes in developing science reasoning skills when they can see connections to everyday experiences and community oriented issues. Additionally, students who demonstrate advanced scientific reasoning skills which require making inferences also have exhibited high theory of mind, which describes how people infer the mental state of others including things like beliefs, desires and emotions (Lecce et al., 2024).

When we apply Vygotsky's principle of the zone of proximal development and the use of scaffolding (Vygotsky, 1978; Wood et al., 1976) to the development of scientific reasoning skill level, we allow for even more heterogeneity in abilities depending on the amount of scaffolding a child receives. Indeed, parent education has been determined to influence elementary student science reasoning skills regardless of measured intelligence of the child (Koerber et al., 2015), presumably due to scaffolding of these skills outside of the formal educational environment. When children were asked to demonstrate this skill in elementary classrooms, the use of scaffolding to support variable testing and hypothesis

writing showed significant improvement in students' ability levels (Grimm et al., 2023; Robisch et al., 2014). Robisch et al. (2014) argued that scaffolding helped to reduce the cognitive load of hypothesis-based reasoning with conditionals and to redirect misguided reasoning of students as they worked on a physical science activity. Conversely, Oshima et al. (2004) concluded that students still experienced challenges with writing hypotheses even after extensive group collaborations with other students, indicating that peer to peer collaborations may not provide adequate scaffolding for elementary aged children.

1.2. Present Study

The present study, grounded in constructivism and problem-based learning and informed by the studies referenced above, examines the influence of parents on the development of their fourth-grade (ages 9–10) children's science inquiry skills. More specifically, it examines how parent education, language, ethnicity and child or parent gender further influences use of specific problem-solving processes in the context of the southwestern USA (Phoenix, AZ). Our participants comprised three dyad ethnicity groups, including 62 dyads with both a Hispanic child and parent, 15 dyads with a Hispanic child and a non-Hispanic parent, and 70 dyads with both a non-Hispanic child and parent. They were also approximately equally balanced across dyad groups by gender (mother-daughter, mother-son, father-daughter, father-son). Finally, these families included a cross-section of families with regard to parent education level, income level (which is statistically related to education level) and heterogeneity of language (varying degrees of bilingualism).

In order to assess science inquiry skills, the study included four common problem-solving processes: (a) writing a hypothesis, (b) recording results, (c) drawing/sketching the process, and (d) writing an explanation about the results of the activity (conclusions). Of these processes, writing a hypothesis requires the most science reasoning skills, as it requires practitioners to compare two variables. Robisch et al. (2014) reported the importance of scaffolding in the development of science reasoning skills, while Koerber et al. (2015) demonstrated that parent education was a significant factor in the heterogeneity of children's skills in this area. Furthermore, we aim to examine how educational environments may capitalize on the strengths of bilingual students and families by incorporating multimodal processes such as the use of drawing and figures. Studies on multimodality and translanguaging have demonstrated the importance of incorporating drawing and sketches to more fully engage students and improve their conceptual understanding of science topics (González-Howard & Suárez, 2021; Krajcik & Sutherland, 2010; Pierson & Grapin, 2021).

In short, our research questions about engagement in the science problem-solving processes include:

1. How is engagement in science problem-solving processes influenced by parent language?
2. How is engagement in science problem-solving processes influenced by dyad ethnicity?
3. Can the variables of parent language and ethnicity be isolated from socioeconomic status (income and parent education)?
4. How is engagement in science problem-solving processes influenced by dyad gender?

2. Materials and Methods

2.1. Participants and Recruitment

A total of 153 fourth-grade students and their parents (including some stepparents) participated in this study in a large metropolitan area in the Southwestern USA (Phoenix, AZ). Considerable effort was taken to balance the sample with regard to parent and child ethnicity and gender, using targeted recruiting fliers, so as to include an approximately equal number of Hispanic and non-Hispanic families (Table 1, also from the study by Short-

[Meyerson et al., 2024](#)) in different combinations by gender (mother-son, mother-daughter, father-son, father-daughter). The families were recruited from public schools and libraries, community centers, the local Boys & Girls Club and YMCA and other similar locations by posting and distributing fliers with the researcher's email and phone number. Thus, our sample included students predominantly from public and charter schools, however we did not exclude students from private or home-school systems. We did not recruit from a science center or similar location that might bias our sample (i.e., they may be more interested in science than a typical family). For their participation, families were offered a \$50 gift card from a selection of options.

Table 1. Dyad ethnicity and gender distribution.

	H-H	NonH-NonH	NonH-H	Unspecified	Totals
Father-son	13	16	5	1	35
Father-daughter	12	16	4	0	32
Mother-son	14	21	3	4	42
Mother-daughter	23	17	3	1	44
Totals	62	70	15	6	153

The parent-child dyad groups referenced in the table by ethnicity include the following; H-H = Hispanic parent with Hispanic child, NonH-H = NonHispanic parent with Hispanic child, and NonH-NonH = NonHispanic parent with NonHispanic child.

The families were recruited from a variety of neighborhoods across the metropolitan area, including some lower-income and some higher-income regions. It is important to note that recruitment did include some targeted advertising to balance our sample with regard to dyad gender and ethnicity, however family income and education level was not included in the call. As a result, the sample reflects the general socioeconomic trends prevalent in this region with regard to ethnicity. Although fliers were distributed in both Spanish and English, it is also possible and even likely that English speaking families were more comfortable responding to a request from researchers at an institute of higher education (at which English is the dominant language).

Demographic information was collected from the parents as part of an extensive questionnaire that they filled out at the end of each session. The demographic categories in the questionnaire were the same as those employed by the U.S. Census and National Science Foundation ([National Center for Science and Engineering Statistics, 2021](#); [U.S. Census Bureau, 2024](#)), which distinguishes between race and ethnicity. Hispanic ethnicity is a binary category (yes or no), with the option to select all applicable sub-groups. In the NonHispanic group, 85% of the parents identified as Caucasian or mixed race (Caucasian, African American, Native American and/or Asian). Of the Hispanic parents, more than 90% self-identified as Mexican, Mexican American or Chicano, while one each of the other parents identified as Guatemalan, Spanish, El Salvadoran or Dominican. The children's average age was 9.89 years ($SD = 0.55$ and was not significantly different for groups by child ethnicity or gender. Parents ranged in age significantly, but there were not significant differences by parent gender. Hispanic parents $\bar{x} = 36.96$ years, $SD = 6.02$) were younger than non-Hispanic parents ($\bar{x} = 40.29$ years, $SD = 6.96$). With regard to annual income, parents self-reported family income in \$10,000 increments up to \$110,000/year. Hispanic families self-reported an approximate mean income of \$28,000, while non-Hispanic families reported an approximate mean income of \$60,000. Finally, parent education level was also determined using categories from 0 (Little to no high school), which combined with the original category of 1 for "less than high school" and "some high school") to 4 (College Degree—Bachelor's and Beyond, which combined the categories of "College Degree" and "Graduate Degree" for analysis purposes. Mothers and fathers had similar levels of

education with an average level of some college. Non-Hispanic parents reported having some college or a college degree on average ($\bar{x} = 3.51$, $SD = 1.22$) while Hispanic parents reported having a GED or high school degree on average ($\bar{x} = 2.24$, $SD = 1.37$) based on the following education categories on the demographic survey (Table 2).

Table 2. Parent Education Level by Dyad Ethnicity.

	H-H	NonH-H	NonH-NonH
Little to No High School	19	1	1
High school degree/GED	11	0	3
Some College	17	7	26
College Degree—Bachelor’s and Beyond	11	6	39
Not Reported	4	1	1

The parent–child dyad groups referenced in the table by ethnicity include the following; H-H = Hispanic parent with Hispanic child, NonH-H = NonHispanic parent with Hispanic child, and NonH-NonH = NonHispanic parent with NonHispanic child.

Parents responded to a number of questions regarding parent and family language in order to gauge family heterogeneity of language (degree of bilingualism). Although a few other languages were represented in our study, English and Spanish included a vast majority of the families in this study with all families reporting at least one of these languages as their primary language. Families were asked to rank on a scale from 1 to 5 (with 1 representing one language exclusively and 5 representing the other language exclusively) which language they spoke more often at home, that they read in, that they wrote in, and that they spoke with friends. Although many of the families were bilingual, it is important to note that science instruction in the schools in this area is always in English, regardless of the child’s first language.

2.2. Materials

Four instruments were employed during the parent–child sessions; hands-on science activities with response sheets (Table 3), a written parent questionnaire (which included demographic questions), a science content assessment, and a structured child interview (all three available as Supplementary Materials). This paper will focus on the results from the hands-on science activities and some of the demographic data from the parent questionnaires. The information collected by other instruments is the focus of other papers (Messinger et al., 2016; Sandrin et al., 2020; Short-Meyerson et al., 2024). As previously mentioned, families had the option of selecting each item in Spanish or English, and they were instructed to fill them out in whichever language they preferred (or a mixture of both).

The hands-on science activities were all based on broader questions, many of which were also adapted from past questions used in the National Assessment of Educational Progress (U.S. Department of Education, 2019). Three hands-on activities involved physical science (e.g., constructing an electric circuit) and three involved life science (e.g., determining what happens to heart rate with exercise). As they worked on the hands-on activities, the parent–child dyads were asked to discuss how they would like to address the activities and to make notes on the response sheets provided (Table 3), including responding to the questions or prompts for each activity. The written responses to these activities are the focus of this study.

The parent questionnaire and the child interview inquired about their interests in different science topics. The parent questionnaire also asked many demographic questions including parent education and occupation, family income, parent and child ages, and languages spoken at home. The science content assessment included 13 multiple-choice questions (six life science, six physical science and one space science) published in the

NAEP 4th grade science assessment (U.S. Department of Education, 2019) and results from analysis of this data have been reported previously (Sandrin et al., 2020). Although qualitative data were collected through parent questionnaires and child interviews, the present analysis focuses on quantitative scoring of written responses. Some analysis of the parent and children’s responses from these other instruments are summarized in a previous presentation (Messinger et al., 2016).

Table 3. Hands-on science activity descriptions and prompts.

Life Science Activities	Physical Science Activities
New plants Materials: Lego© brick house, flower and cactus to plant, light to represent sunlight, stickers for water Instructions: You would like to grow some new plants in your yard. Put a flower at the location where you think the flower will grow the best, and a cactus where it will grow best. The stickers on the yard/house show where you will have easy access to water (such as a drip line or hose). Remember that in Arizona, the Sun is strongest on the South side of a house. <u>Why</u> did you choose the locations that you did? Draw a picture of the house, showing the location of the house, the “Sun” and water, and your plants below.	Separating Mixtures Materials: sand, iron filings, gravel, bar magnet, sand sifter Instructions: The large container has a mixture of sand, gravel and iron filings. Also, you have samples of each material separately in little sample jars. Using the tools/items available to you, how can you separate the materials (sand, gravel and iron filings)? First, write your best idea. OK, now try it! Did it work? If not, think of a different idea and try it.
Taste test Materials: salt water, lime juice, cotton swabs, tasting dishes Instructions: What part(s) of your tongue tastes “salty” and “tangy?” Please note your predictions by drawing arrows to the areas of the tongue below. Now use the cotton swabs to put drops of salt water and lime juice, separately, on different parts of your tongue. Do you taste these flavors on only certain parts of the tongue? Tell us where you can taste each flavor by labeling the tongue below. Can you <u>explain</u> your observations?	Electric Circuit Materials: light bulb, wires, battery pack Instructions: Try to put an electric circuit together so that the light bulb lights up. You can use the following materials: • Wires (2 at most) • Light bulb • Battery pack Sketch the circuit you have just created. Please label the parts and draw arrows to show the flow of the electric current. <u>Explain</u> how it works.
Heart rate Materials: timer/stop watch, heart monitor Instructions: First, pick who will monitor heart rate and who will exercise. Take the resting heart rate of the exerciser. If you do not have a heart monitor, count the pulse in the wrist for 30 s, and multiply this number by 2. Record it below. Resting heart rate: _____ beats/minute What do you think happens to your heart rate when you exercise? Why do you predict that? Now, try jogging in place or doing jumping jacks for 1 min. Then take the heart rate again. Heart rate after exercise: _____ beats/min What happened? <u>Why</u>?	Sink/float Materials: plastic animal, marble, cork, paper clip, coin, container of water Instructions: Which of the objects do you expect to sink or float in water? First, make a prediction for each object and describe <u>why</u> you think it will sink or float. Then try it and note your observations.

2.3. Procedures

Each child–parent dyad participated in a 1 to 1.5 h session with multiple components. Sessions took place in study rooms at local libraries on weekends and evenings, in public school conference rooms after school hours, on a local college campus on weekends, and at public recreation centers on weekends. All materials for participants were available in English and/or Spanish. Additionally, a bilingual (English/Spanish) research assistant hosted each session. Upon arrival, the parent and child were asked to separately complete a multiple-choice science content assessment. Then after a brief snack/water break they were asked to play a short picture game (e.g., “Spot It”) with each other to encourage

casual communication. After a round of the game, the dyad was instructed to work on six hands-on science activities together. The activities were presented in a pre-determined randomized order, and included props and instructions. The dyad was instructed to record their responses to the questions and prompts for each activity on a response sheet. Finally, the child was interviewed while the parent filled out a parent questionnaire. A detailed protocol for each session is located in Supplementary Materials.

The hands-on science activities and child interviews were audio and video recorded. All other results from the session (content assessment, science activity response sheets and parent questionnaire) were filled out by the parent and/or child. Each activity was scored using a rubric on a scale of 1–5 with 5 being the most complete. Each activity employed three of the four following science problem-solving processes:

- A. Written hypothesis or written plan for the science problem,
- B. Results recorded and written record of whether or not the problem was solved successfully,
- C. Draw or sketch a picture, and
- D. Discussion about how or why the activity worked out

The written responses from each activity were recorded by the dyads, and these responses were scored for each process listed above. Appendix A contains rubrics for scoring the problem-solving processes, typically with regard to completeness and attention to detail. Appendix B includes examples of high-scoring and low-scoring responses from families for each problem-solving process. Processes B (recording of results) and D (discussion of how/why strategy worked) were scored for every activity. Conversely, the activity worksheets only asked the dyads to document process A (writing a hypothesis or prediction) for four of the six activities, and to make a sketch or drawing (process C) for two of the six activities. Some activities did not lend themselves well to drawing a picture, such as sink and float which would involve too many drawings (one for each item tested) or taste test (since the tongue image was given). Similarly, other activities did not lend themselves as well to stating a hypothesis (new plants and electric circuits), as the drawings were essentially their hypothesis in drawing form. The worksheet responses were scored by two individuals—the trainer (the first author) and a trained, advanced undergraduate psychology student. They each scored approximately 20% of the worksheets and then discussed discrepancies. The student completed the rest of the scoring. Inter-rater reliability agreement scores of >80% were established for each process or each activity (Table 4).

Table 4. Inter-rater reliability scores for scoring each activity and science problem-solving process.

Activity	Problem-Solving Process	Inter-Rater Reliability
Separating Mixtures	A	0.87
	B	0.93
	D	0.80
Electric Circuit	B	0.97
	C	0.80
	D	0.90
Sink/Float	A	0.97
	B	0.87
	D	0.80
New plants	B	0.83
	C	0.87
	D	0.87
Taste test	A	0.80
	B	0.80
	D	0.93
Heart rate	A	0.80
	B	0.87
	D	0.80

2.4. Heterogeneity of Language Index

A single “heterogeneity of language” index was derived to capture the balance and consistency of bilingual practices from three parent-reported items that captured the extent to which Spanish and/or English was utilized at home by the parent across three modes of communication; speaking, reading, and writing. First, the mean of these three items was computed, yielding a continuum from 1 (all Spanish) to 5 (all English). Second, to capture consistency across speaking, reading, and writing contexts, the observed range of responses was scaled to a 0–1 so that perfect agreement corresponded to maximum language consistency (1) and maximal dispersion to no language consistency (0). Finally, the index was rescaled to $[-1, 1]$, where -1 denotes exclusively English only (speaking, reading, writing) and 1 exclusively Spanish, and intermediate values indicate both the balance and consistency of bilingual practices.

2.5. Analysis

The current paper reports only the quantitative analysis of the written activity pages that the parents and children worked on together. Because the purpose of this paper was to statistically examine group-level differences in problem-solving processes rather than conduct a mixed-method triangulation, a quantitative design was deemed most appropriate. This quantitative study utilized a two-step analytical approach to examine how the factors of language heterogeneity, dyad ethnicity, and dyad gender influence engagement in science problem-solving processes. First, each factor of interest was analyzed with an analysis of variance (ANOVA) individually to isolate and interpret its unique effect on the dyad’s engagement in the science problem-solving processes (e.g., A: writing a hypothesis, B: recording results, C: drawing/sketching, D: writing explanations), and followed up by a Tukey adjusted test of multiple comparisons where appropriate. Next, an analysis of covariance (ANCOVA) was employed to examine the influence of the three factors, while statistically controlling for socioeconomic status as measured by parental education and household income. This approach enabled both targeted analysis of individual factors and a broader understanding of each factor affects science engagement within the context of social and economic background. Additionally, significant differences between two demographic groups (Hispanic and NonHispanic) presented in the Participant section were calculated using a non-pooled two sample t-test. The data analysis for this paper was conducted using SAS/STAT software (<https://support.sas.com/en/software/sas-stat-support.html> (accessed on 17 November 2025), SAS Institute Inc., Cary, NC, USA), and visuals were created in R (R Core Team, 2024) using the package ggplot2 (Wickham, 2016).

3. Results

3.1. Heterogeneity of Language

The vast majority of parents (91 parents) had a heterogeneity of language index of -1 , meaning fully English across all three language modalities (speaking, reading, writing) as shown in Figure 1. A smaller peak appears at $+1$ (13 parents), reflecting those who reported exclusively Spanish use across all three modalities. The remaining 41 parents (8 missing) are spread across intermediate values (e.g., approximately -0.5 , 0 , and $+0.5$), indicating varying degrees of heterogeneity of language and cross-modality (speaking, reading, writing) consistency. This visualization confirms that most parents gravitate toward a single-language profile, but 28% of parents in the study exhibit bilingual language practices.

The isolated role of the heterogeneity of parent language in the science problem-solving processes is displayed in Figure 2. This figure reveals a statistically significant ($p = 0.001$) downward trend in Process A scores (writing a hypothesis), with the dyads with Spanish-language dominant parents exhibiting lower Process A scores than dyads

with English-language dominant parents. Processes B, C, and D show no significant differences in scores across the language index. Processes B and D (recording results and writing explanations, respectively) had a slight downward trend, while Process C (drawing/sketching) had a slight upward trend. Thus, while the scores for Processes B, C, D were not statistically significant, the trend was different for Process C than for any of the other processes. The upward trend for Process C indicates that dyads with parents who spoke predominantly Spanish may have similar or slightly higher scores than dyads with parents who spoke predominantly English.

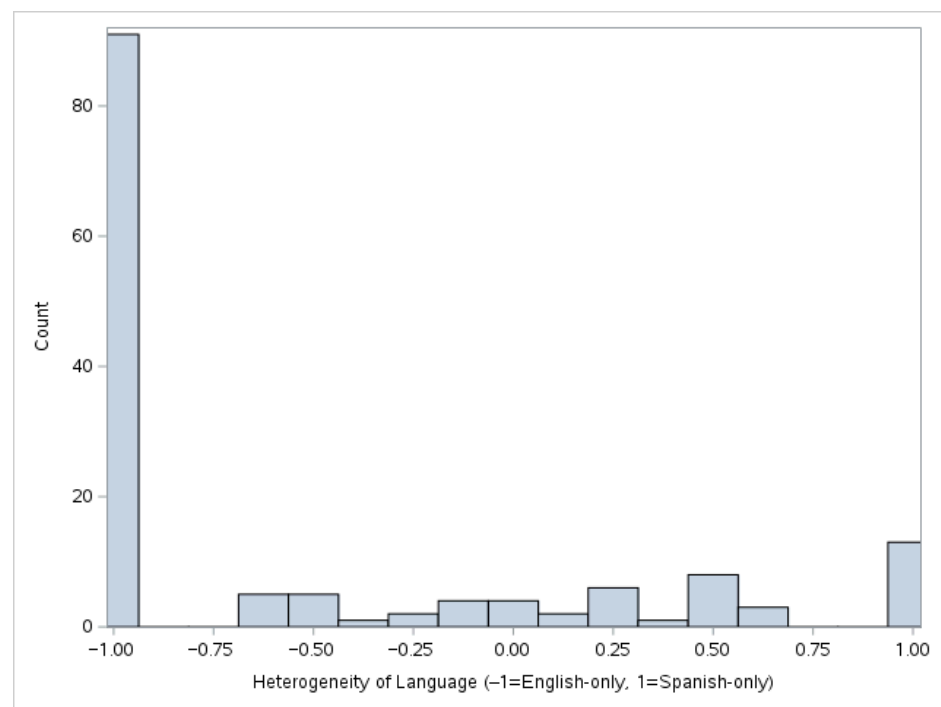


Figure 1. Distribution of the “heterogeneity of language” score (−1 = English-only, 0 = English/Spanish equally spoken, 1 = Spanish-only).

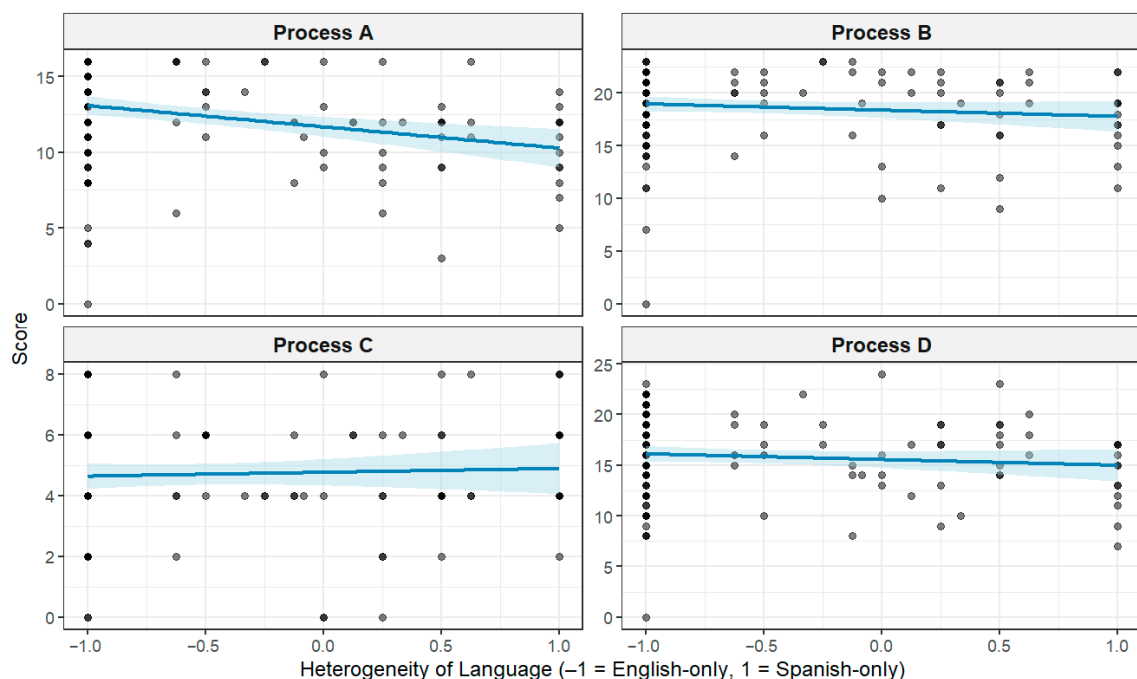


Figure 2. Isolated effect of language on the four problem-solving processes A–D as labeled.

The effect of language was also evaluated while controlling for the socioeconomic factors of family income and parental education. In addition to the SES covariates, differences in the marginal effect of language on process scores across the varying levels of education were explored. In all processes, the main effect of language heterogeneity was not significant after controlling for parental education and income, and familial income was nonsignificant in all models. However, the significance of the marginal effect of language across different levels of parental education varied across the different types of problem-solving processes.

There is emerging evidence that suggests there is a difference in the effect of language on the problem-solving processes across different educational levels. Figure 3 displays the simple effects analyses indicating that the relationship between language heterogeneity and problem-solving score varied across levels of parental education controlling for familial income. In particular, the effect of language for educational level 1 (“Little to No High school”) appears to differ from the overall trend line and other educational levels. For this group, the process scores tend to increase, rather than decrease, as the heterogeneity of language increases (i.e., from English only to bilingual to Spanish only).

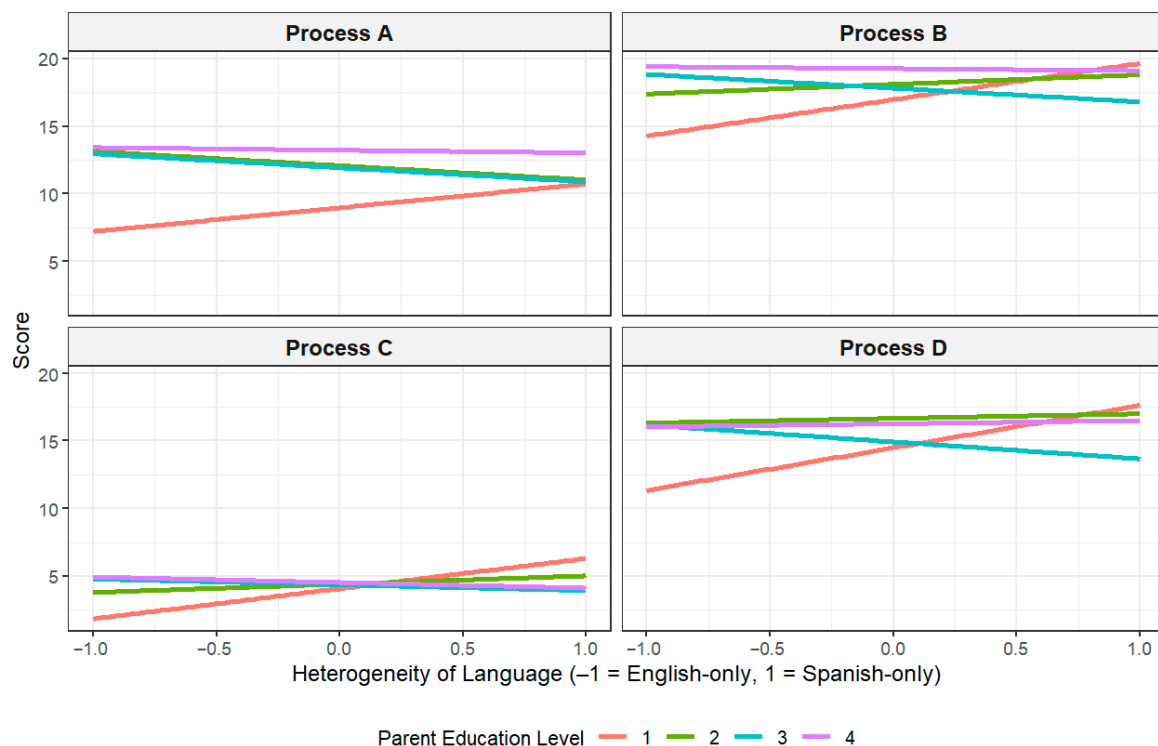


Figure 3. Simple effect analysis of the relationship between heterogeneity of language and problem-solving scores for the four levels of parent education: 1 (little to no high school), 2 (some high school), 3 (high school graduate or equivalent), and 4 (college degree—Bachelor's and beyond).

3.2. Dyad Ethnicity

The role of dyad ethnicity was also examined for each problem-solving process. As shown in Table 5 there is an overall mean difference in the Process A scores among dyad ethnicity groups ($p = 0.0007$). More specifically, there is a significant difference between the NonH-NonH and H-H dyads ($p = 0.0004$). While there is no difference between ethnicity groups for Process C, for Processes B and D the differences approached significance.

Table 5. Process Scores by Dyad Ethnicity for the three (Parent—Child) Ethnicity Dyad Groups.

	H-H	NonH-H	NonH-NonH	<i>p</i> -Value
Process A	11.39 (3.26)	12.13 (4.6)	13.47 (2.44)	0.0007 *
Process B	17.85 (4.17)	18.73 (2.43)	19.27 (3.07)	0.0735
Process C	4.48 (2.04)	5.2 (2.11)	4.83 (2.06)	0.4022
Process D	15.03 (4)	16.8 (2.57)	16.4 (3.91)	0.0791
Number of dyads	<i>n</i> = 62	<i>n</i> = 15	<i>n</i> = 70	

* Data presented as mean (standard deviation). The parent–child dyad groups referenced in the table by ethnicity include the following; H-H = Hispanic parent with Hispanic child, NonH-H = NonHispanic parent with Hispanic child, and NonH-NonH = NonHispanic parent with NonHispanic child.

The effect of dyad ethnicity was also evaluated while controlling for the socioeconomic factors of family income and parental education. However, parental education and dyad ethnicity are highly correlated, distorting the true relationship. In this case, because parental education varies systematically across ethnic groups it mimics the effect of dyad ethnicity as seen in Table 6.

Table 6. Process Scores for Parent Educational Levels.

	Little to No HS	HS Diploma/GED	Some College	BS/BA or Graduate	<i>p</i> -Value
Process A	9.18 (3.42)	11.93 (2.79)	12.71 (3.13)	13.43 (2.79)	<0.0001 *
Process B	17.27 (5.1)	17.86 (3.18)	18.57 (3.36)	19.17 (3.51)	0.0825
Process C	4.73 (2.27)	4.57 (1.65)	4.71 (2.07)	4.79 (2.12)	0.9850
Process D	14.36 (4.83)	16.5 (4)	15.73 (3.35)	16.34 (4.05)	0.2168
Number of parents per category	<i>n</i> = 22	<i>n</i> = 14	<i>n</i> = 51	<i>n</i> = 58	

* Data presented as mean (standard deviation). The parent–child dyad groups referenced in the table by ethnicity include the following.

Similarly to the dyad ethnicity results, there is an overall mean difference in the Process A scores, among educational levels ($p < 0.0001$). More specifically, the Process A scores of the students whose parent’s educational level was “Little to No High School” were significantly lower than all other educational levels ($p = 0.0432$). Again, while the scores for Processes B, C, D were not statistically significant, the trend was different for Process C than for any of the other processes. Therefore, the differences seen in ethnicity cannot be isolated from educational levels.

3.3. Gender

There were not any significant differences in process scores by dyad gender. This was true for gender overall without considering other factors or covariates, and when evaluated separately for parent gender and child gender.

4. Discussion

This unique study of parents in informal educational settings examines how they influence the development of important science inquiry skills in their children through problem-based learning. As stated by Bell (2010) and Hmelo-Silver (2004), problem-based learning allows students to engage with authentic problems to further their understanding. Examples of authentic problems in this study included choosing the best location to plant a garden, constructing an electric circuit, and determining how heart rate is affected by exercise. Further, this study focused on the influences of parent ethnicity, language and gender on four specific science inquiry skills; writing a hypothesis, recording results, drawing/sketching and writing explanations. It examined whether the factors of family income and parent education can be isolated from ethnicity and parent language in the context of the southwestern USA. In Phoenix, and the southwestern USA overall, the

largest ethnic minority community is Hispanic (with Mexico the predominant country of origin). Parents in this community tend to be of lower income and have less education than their nonHispanic Caucasian neighbors. For this study, we chose to recruit representative groups of families, rather than attempting to balance the sample by socioeconomic status. If families had been recruited only from higher income communities, the sample would then be skewed in a different manner and would not be an accurate representation of the community itself. As a result, it was not possible to distinguish ethnicity and parent language from family income and parent education. Thus, these results are presented as such with complete transparency.

While parents may positively influence their children's involvement with science in many ways (Ferry et al., 2000; Garriott et al., 2014; Hyde et al., 2017; Peralta et al., 2013; Thursby Bourke et al., 2024; Turner et al., 2004), they are also less likely to offer assistance with questions on science homework when they feel less competent with science topics (Silander et al., 2018). The impact of gaps in parents' content knowledge and confidence may explain why children with parents who have a STEM career are more likely to major in a STEM field in college (Moakler & Kim, 2014; Trudel et al., 2016).

Students with the support of science communities of practice in their schools and extended families are also more likely to pursue science studies (Aschbacher et al., 2010) as explained by the concept of "science capital" (Archer et al., 2015). Children from families who have some experience with STEM professions, or more formal experience with STEM education, are more likely to demonstrate high "science capital." As we saw in this study, if parents are less confident and thus provide less hands-on assistance with and discussion about science studies, children may have less opportunities to practice the more cognitively demanding skill of science reasoning that is necessary for writing/developing a hypothesis.

Parent language, family ethnicity and socioeconomic status were found to influence the dyad's scores for the process of writing a hypothesis (Process A). Similar trends were observed for the tasks of writing an explanation and describing the results/conclusions (Processes B and D), but these were not statistically significant indicating that any trends were small. Writing a hypothesis is a complex science reasoning skill, and one that may utilize more complicated language skills as compared to the other two written process tasks. The children in this study were enrolled in schools in which science instruction took place in English only. They do not benefit from the practice of translanguaging in school, such that they can develop science vocabulary in more than one language, as we see from other studies where translanguaging was encouraged in the science or mathematics classroom (Archila et al., 2024; Garza Ayala, 2022; Licona & Kelly, 2020). Thus, in parent-child dyads in which the parents only spoke Spanish, the children were translating their prior science knowledge from English (language of instruction) to Spanish in order to converse with their parents. Further, when students are learning science in a language that is not their parents' first language, they may not know specific science vocabulary terms that can limit comprehension, and thus science reasoning, about a topic that they are learning (Ardasheva et al., 2019; Weinburgh et al., 2014). Tomlinson et al. (2003) also identified these factors of language (when the school language differs from the family/parent language) as significant in hypothesis-based reasoning.

With regard to family ethnicity and socioeconomic impacts on science process scores, we found that these are also important factors, but that they are highly interdependent. These factors, along with language, influence the "science capital" of a family (Archer et al., 2015), and have been shown to be factors in children's development of science reasoning skills (Koerber et al., 2015). Further, for families who have recently immigrated to the USA from another country, the educational system may be unfamiliar including the differing roles of teachers and expectations for specific forms of parental involvement (Liu et al., 2024).

Another unique and unexpected finding from this study was that at the lowest parent education level, the influence of language heterogeneity was different such that parents who spoke more Spanish tended to have higher scores on writing a hypothesis as compared to predominantly English-speaking families. Thus, parent language may not be as important as parent education level below a specific threshold as also noted by [Solis and Callanan \(2021\)](#). [Koerber et al. \(2015\)](#) also reported that parent education was a significant factor in elementary-aged children's development of science reasoning skills, including writing hypotheses.

Families had similar scores for drawing and sketching (Process C) regardless of parent language, dyad ethnicity, family socioeconomic status or gender. Indeed, bilingual families may have had slightly higher scores on Process C (although not statistically significant). As described by [Gutierrez et al. \(2022\)](#), bilingual families often apply multimodal learning strategies, including the use of symbols and charts, to communicate complicated subjects. This idea is consistent with the definition of language by [González-Howard and Suárez \(2021\)](#) as both linguistic and multimodal. Additionally, since problem-based learning is meant to be collaborative between participants (children and parents in this study), multimodal contexts may allow for a more student-centered context in which students have voice and choice (as described by [Blumenfeld et al., 1991](#); [Krajcik & Shin, 2014](#)). Further, in the context of Hispanic families with middle-school daughters, implementation of problem-based learning and multimodal learning strategies led to an increase in girls' career identity and aspirations in STEM ([Rillero et al., 2025](#)). Thus, the use of multimodal learning strategies is an excellent way to reach a diversity of learners including bilingual and multilingual students. Furthermore, the use of multimodal modeling in science through the inclusion of sketching and drawing may help students to develop conceptual understanding and scientific reasoning ([Pierson & Grapin, 2021](#); [Ainsworth et al., 2011](#); [Wilson & Bradbury, 2016](#)) and aids their comprehension of relationships between complex variables ([Caiman & Jakobson, 2024](#); [Krajcik & Sutherland, 2010](#)), important aspects of scientific reasoning and hypothesis writing. Finally, the use of artistic representations of scientific systems helps students, from kindergarten to college level, to develop more creative solutions and to visualize systems ([Gurnon et al., 2013](#); [Habeeb et al., 2024](#)). Given these past findings, and those from this study, the use of multimodal instruction is not only beneficial—it is an important tool for providing more equitable science education.

A child's gender may influence their interests, attitudes, behaviors, and self-efficacy in STEM ([Ford et al., 2006](#); [Garriott et al., 2014](#); [Simpkins et al., 2015](#)). Interestingly, gender differences (parent, child or dyad combination) were not observed for the science process scores in this study. This may largely be due to the age range of the 4th grade children recruited for this study. Standardized test scores in science for fourth grade children in the United States do not vary by gender—girls perform equally as well as boys in science until the 12th grade when boys score higher than girls in physical science (only). Similarly, a study of fourth-grade children in Singapore also found that interest and participation in science activities did not vary by gender, but noted that this may be due to the age of the students ([Jocz et al., 2014](#)). Therefore, gender may emerge as a factor later in the children's academic careers, but it was not found to be a factor at this stage of development.

5. Conclusions

Parents influence their children's interest and proficiency with science inquiry skills, particularly through their development of science capital, and this influence is related to many family variables, including language, ethnicity, and socioeconomic status. These variables are often highly related to one another and thus can be challenging to tease apart. Additionally, child gender may be an important factor during adolescence and beyond, but at the fourth-grade level the influence of gender is not apparent.

The most important message that science educators can relate to parents is that regardless of their expertise with science topics, parents can make positive impacts on their children's performance in science. From a young age, parents can talk about science topics with their children while engaged in regular activities such as animal (pet) care, cooking, observing the night sky, or gardening. Parents can also encourage their children's science interests and course-taking, set high expectations for their success in science classes, and provide positive out-of-school science educational environments and experiences. Furthermore, teachers and informal educational entities can play a critical role in conveying these ideas to parents.

Teachers should expect elementary students to exhibit a wide range of scientific reasoning skill levels and, as such, be prepared to provide scaffolding for students who struggle with these challenging cognitive tasks. This range of skills may be due to numerous factors, including language (for example, for immigrant families/children when the language of instruction is not their first language) and parent education. This study demonstrates that being from a family whose primary language is not the same as the language at school is not necessarily an educational disadvantage, particularly when coupled with low parental education, similar to the findings of [Solis and Callanan \(2021\)](#). Furthermore, exposure to two more languages (bilingualism or multilingualism) may serve as a cognitive or cultural resource, even in the absence of high parental education, supporting complex thinking or problem-solving in ways that standard assessments often overlook. Indeed, multilingualism is often accompanied by multimodal ways of learning and communicating, which is beneficial for students ([Pierson & Grapin, 2021](#); [González-Howard & Suárez, 2021](#)).

The results of this study, and those of other studies with multi- or bilingual students, indicate that regardless of ethnicity and gender, students may benefit from drawing diagrams and figures of how a process works to aid the development of their conceptual understanding of science topics ([Ainsworth et al., 2011](#); [Caiman & Jakobson, 2024](#); [Habeeb et al., 2024](#); [Jakobson & Wickman, 2015](#)). Additionally, inclusion of drawing in the curriculum will allow for a more equitable learning environment for bilingual/multilingual students or students from lower socioeconomic households ([Oliveira et al., 2019](#); [Poza, 2018](#)). Drawing and sketching is also a useful tool for students who struggle with scientific reasoning, as they can use sketches or drawings to describe how one variable impacts another using a multimodal practice ([Smith et al., 2019](#); [Wilson & Bradbury, 2016](#)). Finally, the inclusion of drawings may also assist struggling readers, as they would not need to rely on words and text ([Poza, 2018](#)).

5.1. Limitations

This study offers important insights into how parental language, ethnicity, and education relate to children's engagement in science problem-solving processes, yet a few limitations should be considered when interpreting the findings. The sample was drawn from a single metropolitan region in the southwestern United States and, although diverse, reflected the socioeconomic and linguistic patterns of that local context. Consequently, generalizability to other regions or populations should be made with caution. In addition, despite efforts to recruit families across ethnic and gender groups, the high correlation among socioeconomic status, parent education, and language made it difficult to fully isolate the influence of each factor. Measures of language use and science engagement relied on self-reported and written responses from family activities, which may not capture the full range of bilingual or multimodal interactions that occurred during parent-child collaboration. Finally, as designed, this study cannot establish causality between parental factors and children's science reasoning skills. Acknowledging these limitations underscores the importance of conducting future research using larger and more geographically varied

samples, longitudinal approaches, and richer qualitative methods to better understand how family contexts shape children's development of inquiry and reasoning in science.

5.2. Future Directions

These limitations also point to several directions for future research. Building on these findings, future studies should examine parent education and home language in greater depth, as their interrelationship appeared to influence children's science process skills in distinct ways, especially at lower levels of parental education. It would also be valuable to explore how bilingual and multilingual students benefit from the inclusion of sketching and drawing across grade levels, as these multimodal strategies may support the development of scientific reasoning and confidence in upper-level science courses.

In addition, future work should include more geographically and socioeconomically diverse samples to enable clearer comparisons across family contexts. Longitudinal designs could also help trace how early family interactions with science activities shape later academic interests and career choices. Further, studies that incorporate teacher and school-level factors or analyze parent–child dialog during science activities may offer a more complete understanding of how cultural and linguistic resources interact with instructional environments.

Finally, applying frameworks such as science capital (Archer et al., 2015) may allow future researchers to better account for overlapping influences of language, education, and socioeconomic status, while integrating parents' familiarity with and access to STEM experiences (Moakler & Kim, 2014). This approach would support a more comprehensive understanding of how families contribute to the cultivation of children's science inquiry and problem-solving skills across diverse educational and cultural contexts.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/educsci15121573/s1>. Questionnaires and Session Protocol used in this research.

Author Contributions: Conceptualization, S.S. and K.S.-M.; methodology, S.S., K.S.-M. and J.B.; software, J.B.; validation, S.S., K.S.-M., J.B.; formal analysis, S.S., K.S.-M. and J.B.; investigation, S.S., K.S.-M. and J.B.; resources, S.S. and K.S.-M.; data curation, S.S., K.S.-M. and J.B.; writing—original draft preparation, S.S. K.S.-M. and J.B.; writing—review and editing, S.S., K.S.-M. and J.B.; visualization, J.B.; supervision, S.S. and K.S.-M.; project administration, S.S. and K.S.-M.; funding acquisition, S.S. and K.S.-M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Science Foundation grant numbers HRD-1231872 and HRD-1232052. The APC was funded by Arizona State University and University of Wisconsin Oshkosh.

Institutional Review Board Statement: The study was conducted in accordance with and approved by the Institutional Review Board of University of Wisconsin Oshkosh (Protocol Number 972259, 11 June 2012).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: During the preparation of this manuscript/study, the author(s) used Chat GPT 4.0 for the purposes of generating R syntax for the creation of the paneled figures. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

For a few of the problems and strategies, inter-rater reliability agreement of >80% was not achieved, even after discussions, and so some of the rubric categories were collapsed into one category, while maintaining the same minimum and maximum score as the other problems and strategies. Below is the collapsed rubric.

Rubric for Scoring the Written Responses to the Hands-On Activities

Each problem employs 3 of the 4 following categories. All problems use categories B and D. (A) Plan for the problem-solving process OR a written hypothesis. (B) Results recorded and solved successfully? (C) Picture. (D) Discussion about how the process worked OR why it worked.

Activity 1: Separating Mixtures

Note, family was not asked to draw a picture for this problem

Table A1. Scoring rubric for separating mixtures activity.

		Score				
Problem-Solving Strategy		4	3	2	1	0
(A)	Family wrote out a detailed process about how they plan to separate the mixture (2 or more process thoughts, such as “we can separate the gravel from the sand by using the sand sifter” or “put the magnet in the container to get the iron out”)		Family wrote out a process about how they plan to separate the mixture (at least 1 process thought, such as “we can separate the gravel from the sand by using the sand sifter” or “put the magnet in the container to get the iron out”)	Family wrote a brief description of the process they will try to separate the mixture (partial phrase or thought, that does not describe complete process, such as “use a sifter with small holes”)	Family did not write enough to be a coherent thought, but they did write something related to process (such as “sand and gravel. . .”)	Family did not write anything about how they plan to separate the mixture
(B)	Family was successful in separating the mixture, or only 1 separation was partial (ex. some iron filings remained in the sand)			Family fully or partially separated 1 component from the other 2 in the mixture		Family was not able to separate any components in the mixture OR could not tell from what was written
(D)	Family indicated how well the process worked or did not work			Family indicated that they completed the activity or that the process worked or didn’t, but not a full explanation of how well it worked.		Family did not write anything about their process or whether it worked or not

Activity 2: Electric Circuit

Note: Family was not asked to make a prediction or plan how to construct the circuit.

Table A2. Scoring rubric for electric circuit activity.

Problem-Solving Strategy	Score				
	4	3	2	1	0
(B)	Family wrote that the circuit was assembled correctly and worked OR the circuit would work as drawn (i.e., it included a battery, a light bulb and 2 wires connecting these components to make a complete circuit), and assembled it in more than one way (i.e., wires were interchangeable)	Family wrote that the circuit was assembled correctly and worked OR the circuit would work as drawn (i.e., it included a battery, a light bulb and 2 wires connecting these components to make a complete circuit)	Family wrote that the circuit was assembled using all parts, but did not work OR the circuit would NOT work as drawn because all of the components (battery, light bulb and 2 wires) were not connected to make a complete circuit	Family wrote that they used some of the parts, but did not get circuit to work OR the circuit would NOT work as drawn because it was missing a component or 2 (i.e., it did not include a battery, a light bulb and 2 wires connecting these components to make a complete circuit)	Family did not write any explanation or result about their circuit set up on the paper or draw the circuit to show how it worked.
(C)	Family drew a picture of their circuit, with 2 or 3 of the 3 following: (1) all components (battery, 2 wires and light bulb), (2) labels on each component AND (3) correctly showing the direction of the current (from + end of battery to—end of battery through the light bulb)		Family drew a picture of their circuit, with only 1 of the following: (1) all components (battery, 2 wires and light bulb), (2) labels on each component AND (3) correctly showing the direction of the current (from + end of battery to—end of battery through the light bulb)		Family did not draw/sketch the circuit or the sketch was too simply to understand what they drew
(D)	Family wrote out a detailed process about how their circuit worked (2 or more sentences), including a correct description of how the electricity flowed around the circuit	Family wrote a brief description of how their circuit worked (1 phrase or 1 sentence), and it was correct in describing the flow of electricity	Family wrote out a detailed explanation (2 or more sentences), but it was not correct in describing the flow of electricity from the positive terminal, through the light bulb, back to the battery	Family wrote a brief explanation, but it was not correct in describing the flow of electricity from the positive terminal, through the light bulb, back to the battery	Family did not write an explanation of how their circuit works

Activity 3: Sink/float activity

Note: Family was not asked to draw a picture/sketch.

Table A3. Scoring rubric for sink/float activity.

Problem-Solving Strategy	Score				
	4	3	2	1	0
(A)	Family recorded a prediction for all of the objects	Family recorded a prediction for MOST of the objects	Family recorded a prediction for SOME of the objects	Family indicated they did not have a guess	Family did not list any of their predictions
(B)	Family recorded results and was correct in ALL of their predictions	Family recorded results and was correct in ALL BUT 1 of their predictions	Family recorded results and was correct in 3–4 of their predictions	Family recorded results and was correct with 1–2 of their predictions	Family was recorded results but was NOT correct with any of their predictions
(D)	Family records a “why” response for all of the objects, which goes beyond saying they are “light” or “heavy” for more than 3 of the objects.		Family records a “why” response but these explanations are not beyond “light” or “heavy” for most of the objects (so 2 or less).		Family did not record a “why” response for any of the objects.

Activity 4: New plants

Note: Family was not asked to write a hypothesis or plan out a process.

Table A4. Scoring rubric for new plants activity.

		Score				
Problem-Solving Strategy		4	3	2	1	0
(B)	Either in the text or the picture, the cactus was on the south/sunny of house and the flowers were NOT on south side (i.e., they are shaded), and near water.	Either in the text or the picture, the cactus was on the south/sunny side of house and the flowers were NOT on south (i.e., they are shaded), but not near a water source.	Either in the text or the picture, one plant was in the wrong place in terms of sun exposure (i.e., the cactus was not on the south of house OR the flowers were on the south in full sun) and proximity to water not shown/mentioned.	Either in the text or the picture, the directions and/or sun were not labeled, so it was not possible to determine if plants were placed appropriately.	The sketch did not include the cactus or plants.	
(C)	Family drew a picture of their house, including labels for the Sun, water access and the plants.		Family drew a picture of their house, including labels for 1 or 2 out of the 3 (Sun, water access, and the plants).		Family did not draw/sketch the house or plants or the sketch was very simple and it was challenging to understand what they drew	
(D)	Family wrote out a detailed explanation about why they chose the locations that they did for EITHER or BOTH the cactus and flowers.		Family wrote out a simple explanation (less than 5 words) about why they chose the locations that they did for the cactus and flowers.		Family did not write an explanation about the locations they chose for the plants.	

Activity 5: Taste test

Note: Family was not asked to draw/sketch a picture.

Table A5. Scoring rubric for taste test activity.

		Score			
Problem-Solving Strategy	4	3	2	1	0
(A)	Family recorded a prediction for both salty and tangy on the first tongue picture.	Family drew arrows but only labeled only one arrow as salty or tangy	Family labeled one part of tongue with a word “salty” or “tangy”	Family drew arrows, but did not indicate which went with which taste	Family did not list either of their predictions
(B)	Family recorded their findings on the 2nd tongue picture for BOTH tangy and salty OR recorded their findings for tangy AND salty in words in the “Observations” text box.		Family only labeled one as “salty” or “tangy” OR they recorded their findings for tangy or salty in the “Observations” text box and implied that the other was similar		Family did not list results for either tangy or salty (no writing, arrows only, or incomplete text that was unclear)
(D)	Family wrote an explanation about their findings (for ex., discussed location of taste buds) OR just restating where they tasted flavors. May or may not have referenced their predictions.				Family did not record an explanation about their findings.

Activity 6: Heart rate

Note: Family was not asked to draw/sketch a picture.

Table A6. Scoring rubric for heart rate activity.

Problem-Solving Strategy	Score				
	4	3	2	1	0
(A)	Family recorded a prediction about their heart rate when they exercise AND a statement about WHY this happens.		Family recorded a prediction (even if vague). It may include what they expect to happen ("it will increase") OR a short explanation about WHY (without stating what they expect to happen) such as "heart will pump more blood".		Family did not list a prediction.
(B)	The heart rate went up from the resting to the exercise measurement, and the family wrote some explanation about this increase.		The heart rate went up, but they did not discuss the increase. OR the heart rate did not change or went down after exercising (typically an equipment issue) and family did not redo test.		The family did not record both measurements to compare findings.
(D)	Family recorded their findings and some explanation about findings, related to exercising or physiological causes.				Family did not discuss their results (only recorded their findings/number).

Appendix B

For Process A, the figures below are examples of low-scoring (Figure A1) and high-scoring (Figure A2) hypotheses about how exercise influences heart rate.

Materials: Timer/stop watch, heart monitor (if available):

First, pick who will monitor heart rate and who will exercise. Take the resting heart rate of the exerciser. If you do not have a heart monitor, count the pulse in the wrist for 30 seconds, and multiply this number by 2. Record it below.

Resting heart rate: 82 beats/minute

What do you think happens to your heart rate when you exercise? Why do you predict that?

It increases

Now, try jogging in place or doing jumping jacks for 1 minute. Then take the heart rate again.

Heart rate after exercise: 160 beats/minute

What happened? Why?

It started at 82 when I was resting and when your resting it goes slower. Then, it increased when I did jumping jacks because if your muscles need more blood /

Materials: Temporizador/cronometro, monitor del corazón (si está disponible): Oxigeneo to exercis.

Primero, decida quién va a monitorear el ritmo cardíaco y quién va hacer ejercicio. Tome el ritmo

Figure A1. An example of a low-scoring hypothesis statement for the heart rate activity. In this example, the hypothesis was scored low based on the rubric because the family did not explain why the heart rate was expected to increase.

Materials: Timer/stop watch, heart monitor (if available):

First, pick who will monitor heart rate and who will exercise. Take the resting heart rate of the exerciser. If you do not have a heart monitor, count the pulse in the wrist for 30 seconds, and multiply this number by 2. Record it below.

Resting heart rate: 93 beats/minute

What do you think happens to your heart rate when you exercise? Why do you predict that?

① My heart rate will be higher. because when I exercise the blood is moving higher.

Now, try jogging in place or doing jumping jacks for 1 minute. Then take the heart rate again.

Heart rate after exercise: 153 beats/minute

What happened? Why?

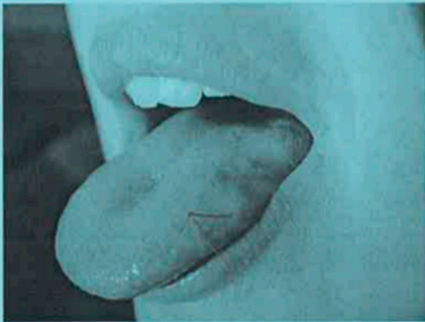
It got higher because I exercised and my blood is going faster to my heart.

Figure A2. An example of a high-scoring hypothesis statement for the heart rate activity. The family provided an explanation about why they expected the heart rate to increase.

For Process B, the figures below are examples of a low-scoring (Figure A3) and a high-scoring (Figure A4) statement about the results from the taste test activity.

Materials: salt water, lime juice, cotton swabs, tasting dishes

What part(s) of your tongue tastes "salty" and "tangy?" Please note your predictions by drawing arrows to the areas of the tongue below.



Now use the cotton swabs to put drops of salt water and lime juice, separately, on different parts of your tongue. Do you taste these flavors on only certain parts of the tongue? Tell us where you can taste each flavor by labeling the tongue below. Can you explain your observations?



Your observations:

It's the tip

Figure A3. An example of a low-scoring results statement for the taste test activity.

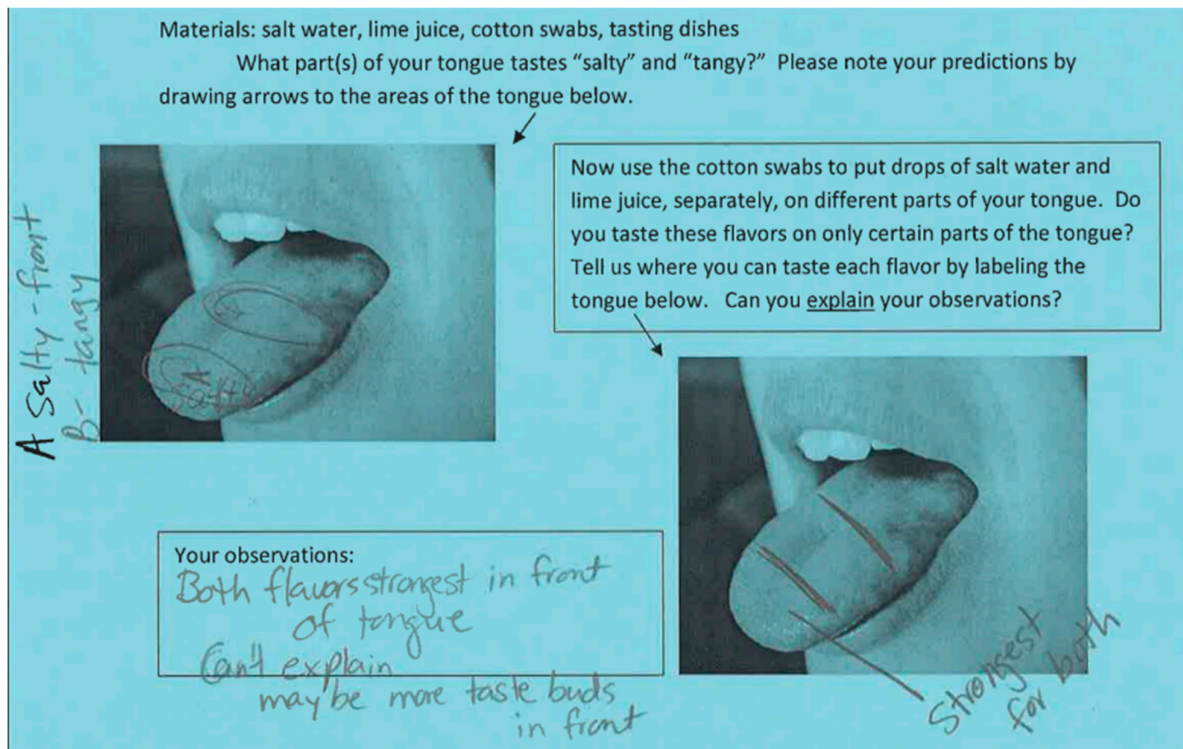


Figure A4. An example of a high-scoring results statement for the taste test activity.

For Process C, the figures below are examples of a low-scoring drawing (Figure A5) and a high-scoring drawing (Figure A6) of how their electric circuit was constructed.

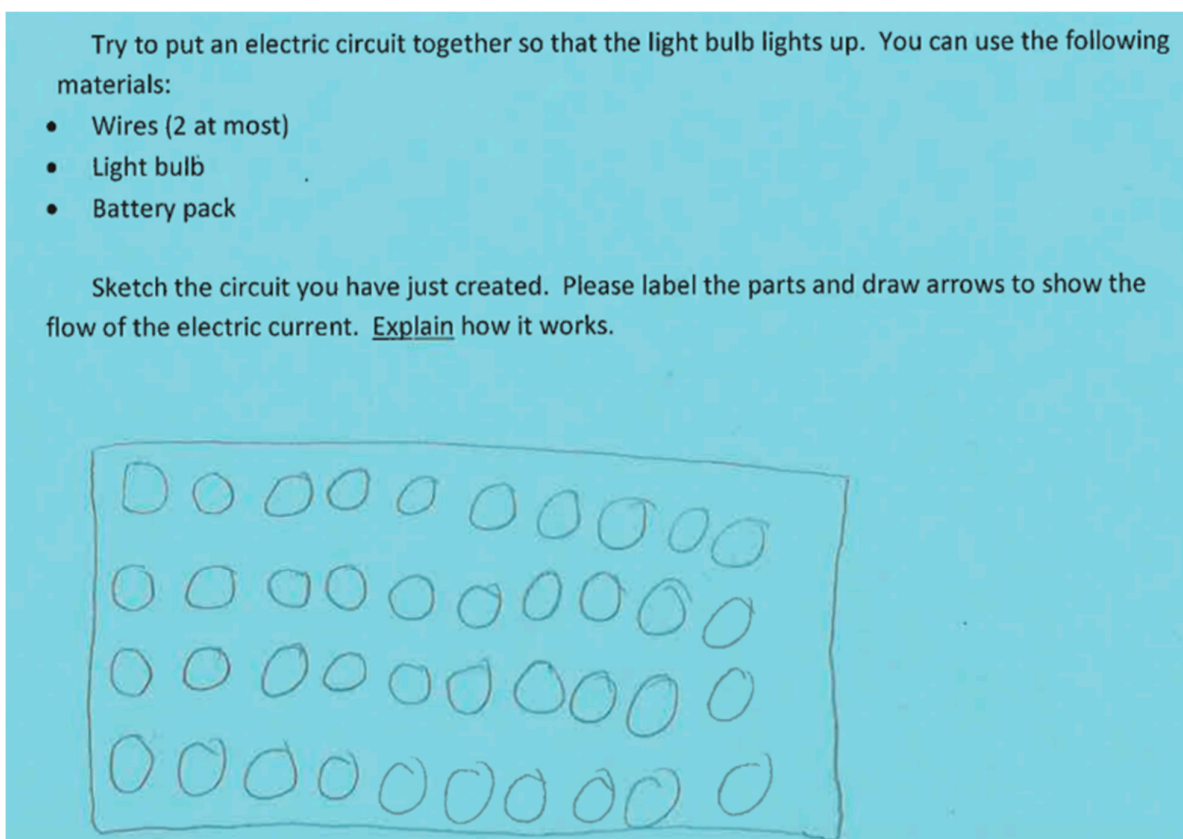


Figure A5. An example of a low-scoring drawing of the electric circuit activity.

Try to put an electric circuit together so that the light bulb lights up. You can use the following materials:

- Wires (2 at most)
- Light bulb
- Battery pack

Sketch the circuit you have just created. Please label the parts and draw arrows to show the flow of the electric current. Explain how it works.



Figure A6. An example of a high-scoring drawing of the electric circuit activity.

For Process D, the figures below are low-scoring (Figure A7) and high-scoring (Figure A8) examples of families' discussions about how their separating mixture activity worked.

Materiales: arena, limaduras de hierro, grava, barra de imán, cedazo de arena

El jarro grande contiene una mezcla de arena, grava y limaduras de hierro. Además, tienes muestras de cada material por separado en frascos de muestra pequeños. Utilizando las herramientas/artículos disponibles para usted, ¿cómo se puede separar los materiales (arena, grava y limaduras de hierro)? Primero, escriba su mejor idea.

EL METAL LO SEPARAMOS CON IMANES
LA ARENA LA VAMOS A SEPARAR USANDO CEDAZO

(no tienen que separarlo completamente; sólo intentarlo)

¡Bien, ahora inténtelo! ¿Funcionó? Si no, piense en una idea diferente e inténtelo.

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Figure A7. An example of a low-scoring response about how the separating mixture activity worked (discussion). In this case, the family left the results section blank (lowest score).

Materials: sand, iron filings, gravel, bar magnet, sand sifter

The large container has a mixture of sand, gravel and iron filings. Also, you have samples of each material separately in little sample jars. Using the tools/items available to you, how can you separate the materials (sand, gravel and iron filings)? First, write your best idea.

1. use the bar magnet to separate the iron filings.
2. use the blue sifter with the smallest holes to separate the sand.
3. use the small red sifter to collect the rocks.
4. use the lid to catch the material we don't want

OK, now try it! Did it work? If not, think of a different idea and try it.

It worked a little. we had to separate the rocks first with the sifter with the smallest holes. Then we used the bar magnet to separate the iron filings. Then we use our fingers to pick out the smaller rocks that came through the sifter

Figure A8. An example of a high-scoring response about how the separating mixture activity worked (discussion).

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