Early Childhood Research Quarterly 44 (2018) 34–42

Contents lists available at ScienceDirect

Early Childhood Research Quarterly

Approaches to learning and science education in Head Start: Examining bidirectionality

Andres S. Bustamante*, Lisa J. White, Daryl B. Greenfield

University of Miami, 5665 Ponce de Leon Blvd, Coral Gables, FL 33146, United States

ARTICLE INFO

Article history:
Received 6 July 2016
Received in revised form 16 February 2018
Accepted 21 February 2018

Keywords:
Science education
Approaches to learning
Head Start
Preschool
School readiness

ABSTRACT

Recent national focus on early childhood science education highlights the need for research on early science, particularly with children from low-income families, as science is the lowest performing school readiness domain in that population. Given this achievement gap, the Office of Head Start has emphasized the development of children's domain-general skills, such as approaches to learning, because they help children succeed in the classroom regardless of academic content area. Recent research suggests a unique relationship between early science and approaches to learning, in that approaches to learning predicts gains in science readiness more so than math or language readiness. This study further explored this relationship by examining the potential bidirectionality between science and approaches to learning. Results obtained from hierarchical linear modeling suggest a significant bidirectional relationship, such that residualized change approaches to learning across the school year predicted gains in science across the year, and residualized change in science across the year predicted gains in approaches to learning across the year. These results suggest that development of children's approaches to learning relates to gains science knowledge, and that gains in children's science knowledge relates to the positive development of approaches to learning across the school year. This study provides support for future research examining the potential of science interventions to serve as a context for developing approaches to learning skills that will in turn help children engage in quality science learning. Such research would leverage the bidirectional relationships between these two constructs and could be a step in the national attempt to narrow the science and school readiness achievement gaps.

1. Introduction

There is a growing recognition of the need for more effective science education in the United States, starting in early childhood (Morgan, Farkas, Hillemeier, & Maczuga, 2016). Simultaneously, a national achievement gap exists between children from low-income backgrounds and their higher income peers (Magnuson, Waldfogel, & Washbrook, 2012). The gap begins in early childhood and increases throughout formal schooling (Ryan, Fauth, & Brooks-Gunn, 2006). Disparities are evident across academic domains but are even more pronounced in science readiness. The Head Start framework (U.S. Department of Health and Human Services, 2015) identifies four academic readiness domains for preschoolers—language, literacy, math, and science—of the four, science is the lowest performing among preschoolers from low-income backgrounds served by Head Start (Greenfield et al., 2009). This is unfortunate considering science is an interactive content area that capitalizes on children's natural curiosity about the world and relates positively to other school readiness domains (e.g. math, language, and executive functioning) and high-quality teaching practices for children from low-income backgrounds (Cabell, DeCoster, LoCasale-Crouch, Hamre, & Pianta, 2013; Fuccillo, 2011; Nayfeld, Fuccillo, & Greenfield, 2013). The Head Start framework defines science readiness as "the emerging ability to develop scientific knowledge about the natural and physical worlds, learn scientific skills and methods, and continue developing reasoning and problem-solving skills" (U.S. Department of Health and Human Services, 2015).

Given the achievement gap in this population, recent research has focused on identifying domain-general skills that facilitate children's learning, regardless of content area (Li-Grinning, 2007; McClelland et al., 2007). Approaches to learning are a set of domain-

* Corresponding author.
E-mail addresses: andres.bustamante5@gmail.com, a.bustamante@miami.edu (A.S. Bustamante), l.white@miami.edu (L.J. White), dgreenfield@miami.edu (D.B. Greenfield).

https://doi.org/10.1016/j.ecresq.2018.02.013
0885-2006/

general skills that have garnered increasing attention and have been recognized by the Office of Head Start as one of the foundational school readiness domains (U.S. Department of Health and Human Services, 2015). These skills involve persistence, motivation, and flexible thinking, and allow children to effectively engage in learning. Due to their domain-general nature, approaches to learning are difficult to teach in isolation, making it important to identify optimal learning contexts that provide opportunities to develop these skills.

Recent research suggests a unique link between science readiness and approaches to learning, such that children who have higher approaches to learning (i.e. persistent, focused, open-minded, and collaborative) make greater gains in science across the preschool year, as compared to gains in math and language (Bustamante, White, & Greenfield, 2016). This is an important finding suggesting that approaches to learning relate to children's development of science school readiness. However, the inverse relationship (i.e., if science readiness relates to the development of approaches to learning) has not yet been determined.

This relationship is important to understand the unique connection between approaches to learning and science school readiness and to identify content domains that can potentially promote development in approaches to learning. This study extended existing research by examining the bidirectional relationship between science readiness and approaches to learning across the academic year in a sample of diverse children attending Head Start. A bidirectional relationship would demonstrate that approaches to learning and science readiness share a unique connection and could be intentionally supported together to help children develop both domain-general learning skills and content knowledge.

1.1. Background

1.1.1. Approaches to learning

Approaches to learning refer to a set of learning styles and behaviors that affect how children approach any learning situation (Kagan, Moore, & Bredekamp, 1995; Vitiello, Greenfield, Munis, & George, 2011). Seven core sub-domains of approaches to learning have been identified; strategic planning, effectiveness motivation, interpersonal responsiveness in learning, vocal engagement in learning, sustained focus in learning, acceptance of novelty and risk, and group learning (McDermott et al., 2011). The development of these skills is grounded in the idea that children's learning experiences are greatly influenced by the motivational, attentional, and behavioral mechanisms they use to engage in learning tasks (McClelland & Morrison, 2003; McDermott et al., 2011).

Linking this conceptual background on approaches to learning with sociocultural and constructivist perspectives of child development (e.g. Vygotsky, 1986), this set of cognitive and behavioral skills can serve as "mental tools" that enable children to engage in learning and construct new knowledge (Bodrova & Leong, 2007; Paris & Winograd, 1990). Vygotsky's theory of sociocultural development also highlights the social context as critical for children's learning, which are inherent to some of the components of approaches to learning discussed above (e.g. vocal engagement and group learning). Thus, theoretical and conceptual background on child development and learning suggests that these skills play a key role in early learning and one would expect direct relationships with children's academic success.

These relationships are indeed empirically supported through concurrent and predictive relationships between approaches to learning and academic outcomes in early childhood and beyond (Fantuzzo, Perry, & McDermott, 2004; Li-Grining, Votruba-Drzal, Maldonado-Carreño, & Haas, 2010; McClelland, Morrison, & Holmes, 2000; McDermott, Rikoon, & Fantuzzo, 2014; McWayne, Fantuzzo, & McDermott, 2004; Vitiello et al., 2011). For example, children rated by teachers as having higher approaches to learning also show higher competency in math, language, and fine and gross motor coordination (McWayne et al., 2004). Additionally, research shows that children with higher approaches to learning in preschool demonstrate higher proficiency in reading, vocabulary, language, math, and science in second grade (McDermott et al., 2014). Taken together, theory and evidence suggest that these skills set the foundation for learning early in childhood.

Further, preschool is a particularly important time to examine the development of approaches to learning. Generally, the preschool years are recognized as a critical period in development due to the rapid cognitive changes that occur. During these years, the mental processes that support approaches to learning form and develop quickly, and set the foundation for future learning (Welsh, Nix, Blair, Bierman, & Nelson, 2010). This critical period in development often co-occurs with a child's first experience in a formal school setting, which brings with it a number of novel learning experiences and challenges that elicit children's approaches to learning. In order to effectively navigate these new contexts and optimize learning, children must learn to embrace challenges, work cooperatively with peers, and demonstrate sustained engagement, focus, and attention during interactions with both teachers and peers.

Unfortunately, children from low-income families lag behind their middle to high-income peers in their approaches to learning, indicating that they demonstrate fewer positive learning behaviors than their higher income peers (Fantuzzo, Gadsen, & McDermott, 2011; McDermott et al., 2011). In addition to the challenges associated with the first school experience discussed above, these children are faced with a myriad of additional barriers to their school and life success (i.e. food insecurity, lack of materials and resources, less exposure to rich language in the home) (Heckman, 2006; Magnuson & Duncan, 2006). For these reasons, an even greater focus on approaches to learning should be made for children from low-income backgrounds during this critical period of development.

As evidence for the importance of approaches to learning for children served by Head Start, curricular interventions centered on approaches to learning have demonstrated the malleability of these skills and positive impact on math and language achievement (Fantuzzo et al., 2011). In order to promote the development of approaches to learning in this population and simultaneously address the national science achievement gap, more research is needed to determine how approaches to learning and science readiness are related and if these mutual relationships could provide a framework to help facilitate positive learning behaviors and science readiness for young children.

1.1.2. Early childhood science

Science is now recognized as a key component of Head Start's Early Learning Outcomes Framework (U.S. Department of Health and Human Services, 2015), highlighting the need for more research that examines science education in early childhood. Science education, as defined by the National Research Council's Next Generation Science Standards (NGSS), encompasses science content knowledge (core facts and content of science; e.g. living things need water), crosscutting concepts (core concepts that unify the study of science; e.g. patterns, cause and effect relationships, structure and function relationships), and scientific practices (behaviors that promote engagement in science activity; e.g. observing, constructing explanations, analyzing and interpreting data), providing a framework for what students need to know to demonstrate sufficient and effective science learning (National Research Council, 2012). This approach to science is designed to help children build on and revise their knowledge through active engagement, and integrate this knowledge and these abilities in a continuous cycle of scientific inquiry and engagement.

This newly defined framework of science education clearly relates to foundational theories of child development, such as sociocultural and constructivist learning (Paris & Winograd, 1990; Piaget, 1973; Vygotsky, 1986). For example, the behaviors children implement when engaging in science activities (i.e. scientific practices), can also be considered types of "mental tools" that help them think creatively and flexibly about the observations they are making and the content they are learning. As young children engage in hands-on science experiences (in contrast to more factual/rote learning), they implement these mental tools to help make sense of new phenomena, update existing schemas, and integrate new knowledge (Driver & Erickson, 1983; Howe, 1996; Piaget, 1973).

In his views of how children' develop science concepts in childhood, Vygotsky discussed how children's science learning builds over time and becomes integrated to create a coherent system of conceptual understanding (over the course of multiple experiences and with proper guidance from more experienced learners/teachers), which also fosters the development of language in context (Vygotsky, 1986). This Vygotskian approach is consistent with the NGSS science framework that advocates for science education in which children use a variety of scientific practices to understand both specific science content and more general scientific crosscutting concepts (National Research Council, 2012). Thus, theory and conceptual background on science education would suggest that science engagement and learning may facilitate general child development across cognitive, language, and socioemotional domains.

Indeed, the evidence suggests that science experiences support learning across multiple school readiness domains, including language development, mathematics, arts and executive functioning skills (Conezio & French, 2002; Nayfeld et al., 2013). Additionally, research shows that instructional support in the preschool classroom (i.e. advanced language modeling, high quality feedback, and use of open-ended questions and concept development) is higher during science instruction, as compared to other domains (i.e. language and math; Cabell et al., 2013; Fuccillo, 2011). These findings suggest that science is a useful content area for promoting school readiness and high-quality teacher–child interactions. Not only do early science activities inherently capitalize on young children's natural curiosity about their world, empirical research also suggests it is engaging, developmentally appropriate, and benefits the development multiple school readiness competencies for young children (Conezio & French, 2002; Greenfield et al., 2009; Morgan et al., 2016).

Science is ubiquitous in the preschool classroom as children explore and engage in their environment. For example, when children are building structures in the block area they are exploring early engineering and physical science. They also learn about earth science when they notice the changes in the temperature as winter approaches and connect this new knowledge to their own lives by understanding how this influences the clothes they wear. Children develop knowledge of life science when they plant seeds and document their growth over time, or feed the class pet on a daily basis. All of these examples provide context for preschool children to explore and learn new science content.

To effectively learn this content, children must utilize science practices, which are actionable behaviors that include asking questions, developing models, planning and carrying out investigations, constructing explanations, and designing solutions (National Research Council, 2012). By engaging in these practices, young children construct content knowledge and understanding of crosscutting concepts by going through an iterative scientific process of hands-on minds-on learning (Greenfield, 2015, Chapter 16). During this process, children begin to understand their world by devising and testing hypotheses, which requires persistence, engagement, and working cooperatively with peers in order to draw accurate conclusions about how things work. These behaviors are core components of approaches to learning and highlight a unique relationship between science school readiness and approaches to learning.

1.1.3. Connection between approaches to learning and science readiness

Emerging research suggests that approaches to learning are particularly useful for children's science learning across the preschool year (Bustamante et al., 2016), and predict science performance at the end of second grade (McDermott et al., 2014). There is also evidence to suggest that certain aspects of children's approaches to learning in kindergarten (in this particular study, motivation) predicted later science achievement (Saçkes, Trundle, Bell, & O'Connell, 2011). Additional research with older children also supports the link between approaches to learning and later science outcomes. For example, Lavigne, Vallerand, and Miquelon (2007) developed an intervention for high school students centered around motivation and persistence (two aspects of approaches to learning) and found that it was effective in increasing students interest and success in science classes. Further, Singh, Granville, and Dika (2002) demonstrated that motivation and attitudes towards learning science were strong predictors of science grades in middle school. This is a logical connection given the behaviors that make up approaches to learning and the practices that help children engage in effective science learning.

Consider an example in which a child is playing outside and trying to dig a big hole in the dirt. First, the child sits down and starts digging with her hands, but the soil is too hard and she does not make any progress. She finds a twig nearby and starts to use it to dig into the ground, but it soon snaps. Frustrated, she stands up looking around for other possible solutions, when her classmate approaches and asks what she's doing. After explaining that she wants to dig a hole her classmate proposes they ask their teacher if they can go into the classroom and look for tools. The teacher takes them inside and they grab a plastic spoon and a metal pot from the dramatic play area. When they get back outside and utilize their new tools, they discover that while the plastic spoon digs into the ground, the metal pot can also be used and in fact holds much more dirt in a single scoop. The children conclude that the metal pot is the best tool to use and proceed to take turns using it to dig a hole.

During this experience the two children learned science content, including concepts such as structure and function (the way a tool is built will affect how it is used), and the utility of different materials (fingers, wood, plastic, and metal) when trying to accomplish a specific goal. This example also highlights learning beyond science content, as the children drew upon and fortified their approaches to learning skills. The girl showed motivation, flexibility, and problem solving by brainstorming and testing multiple solutions to her problem. Throughout this process, she demonstrated persistence, building her tolerance for frustration and sustained focus in learning. Her willingness to engage with a friend to pursue a common goal allowed her to practice interpersonal responsiveness and group learning. Both children showed vocal engagement in learning when they asked the teacher to go inside to look for materials and they practiced their strategic planning when they decided which materials to take.

The example above illustrates how approaches to learning skills help children navigate a science experience, and how science as a context allows children to develop their approaches to learning, suggesting a possible bidirectional relationship between these two domains of school readiness. This bidirectional relationship is in line with recent integrative theories of children's school readiness that encourage researchers to examine interrelations between various domains of school readiness (Snow, 2007). Such integrative models suggest that while children's competencies across specific domains are distinct, they develop dynamically and influence each other over time.

When thinking more specifically about approaches to learning and science as school readiness domains, it is critical to pull on theoretical perspectives of how children learn in context – by doing (i.e. engaging with materials and other individuals) – to deepen conceptual knowledge and understanding, which is precisely the focus of high-quality early science education. Vygotsky asserts that development impacts learning (e.g. approaches to learning development impacting science learning), but also that learning can impact development (e.g. science learning influencing approaches to learning development; Bodrova & Leong, 2007). Thus, Vygotsky's theory of learning and development, combined with more recent integrative theories of children's school readiness, provide a solid foundation for examining the bidirectional relationship between science learning and children's approaches to learning.

To the extent that the relationship between gains in science readiness and approaches to learning is bidirectional, findings can offer support for more intentional experiences that simultaneously target these domains in the early childhood classroom. Ultimately, these experiences could provide children served by Head Start with rich learning opportunities that will promote a positive attitude towards learning, foster inquiry and curiosity about the world, and encourage higher order scientific thinking.

1.2. Current study

Despite theoretical support, no studies to date have examined whether the relationship between gains in science readiness and approaches to learning is bidirectional. The aim of this study is to test the bidirectionality of that relationship. Empirical evidence of bidirectionality would further support the unique relationship between young children's approaches to learning and science readiness, and provide justification for future research exploring the use of science as an ideal context for fostering approaches to learning, which is a critical domain-general skill that is difficult to teach devoid of academic content.

We hypothesized that residualized change in approaches to learning across the school year (the difference between actual change and the change predicted by our model) would significantly predict science readiness in the spring, controlling for age, gender, residualized change in vocabulary, and science readiness in the fall. Similarly, we hypothesized that residualized change in science readiness across the school year would significantly predict approaches to learning in the spring controlling for age, gender, residualized change in vocabulary, and approaches to learning in the fall. Hierarchical linear modeling (HLM) was utilized to control for the nested nature of the data.

2. Method

2.1. Participants

This study was conducted in various Head Start centers in low-income neighborhoods in a large urban county in the Southeast United States. The final sample consisted of 316 children, across 35 classrooms, in 9 Head Start Centers. Participants were stratified by age and gender prior to sampling, with 8–10 children sampled per classroom, to allow for the control of classroom-level effects and to ensure a representative sample across child characteristics. Mean age of children was 51.38 months (range = 37.9–62.7) and 52.5% of children were female (n = 166). Although ethnic demographic data was not able to be obtained in the current sample, the children were chosen at random, thus, it was expected that children were representative of the local population. Based on data previously collected in the same Head Start centers in this large urban county, it was estimated that the majority of participants were African-American (~60%), a substantial minority were Hispanic (~38%), and a small minority were Caucasian, Asian, or other ethnicity (2%). All children met the federal income requirement for enrollment in Head Start, indicating a sample of children from low-income families.

2.2. Measures

2.2.1. Science school readiness

The Lens on Science assessment (Lens; Greenfield, 2015) is a computer-adaptive, IRT-based direct assessment of science school readiness. Items measure science practice skills, cross-cutting concepts, and science content knowledge (i.e. life science, earth and space science, physical science, and engineering and technology), as defined by the National Research Council's conceptual framework for science education (National Research Council, 2012). All items are multiple-choice and require the child to select either one response or multiple correct responses, depending on the item type. Science practice skills require children to engage their knowledge of science practices. For example, in one science practice item, the child is shown a picture of a heavy box filled with toys and hears, "This heavy box of toys is hard to move." The child is then shown three possible answer choices: a basket, a wooden chest, and a red wagon, and asked "Touch what I can use to make it easier to move the box of toys across the room." Here, children must observe (a science practice) the features of the presented options and construct an explanation/solution (another science practice) to the problem described to identify the correct response. Crosscutting items require children to have an understanding of core concepts, such as cause and effect relationships. For example, in one item, the child is shown a premise picture of an ice cube with a strawberry frozen inside and is told "this strawberry is frozen inside the ice cube." The child is then shown three possible answer choices: an ice cube with no strawberry, a strawberry still in an ice cube, and a strawberry in a puddle of water. The child is then asked, "Touch what will happen if I heat this ice cube?" eliciting the crosscutting concept of cause and effect, in the domain of physical science. Other items focus on science content knowledge, across the four domains of science content. For example, a life science item presents the child with six pictures of various objects (e.g. plant, hat, frog, shoe, skateboard, child). The child is then asked, "Some of these things need air to stay alive, and some do not. Touch the things that need air to stay alive." Such items require the child to touch all correct answer choices and then a gold star to indicate they are done selecting to obtain credit for that item.

This assessment was specifically designed to detect growth in the Head Start population. Each item was sent out to a panel of early childhood science experts and independently judged on its developmental appropriateness at alignment with the Next Generation Science Standards. Items were then piloted in the field with children served by Head Start to ensure they were demonstrating adequate discrimination for that population. Lens currently contains an item bank of 499 items calibrated using the dichotomous Rasch model, scaled to have a mean item difficulty of zero and unit-logit metric. Item difficulties (b-parameters) ranged from −2.7 to 4.4, with 80% of items having difficulty values between −1.40 and 1.42. The item-measure correlation (correlation between the item and the ability estimate) exceed .20 for 87% of items, and exceed .30 for 65% of items, reflecting effective discrimination of the items in the bank and a common trait measured by the items in the assessment. For a sample of 1753 students, the average standard error of the Rasch ability estimate was .31 (on the unit-logit metric), which corresponds to a reliability of .87 (Greenfield, 2015).

During the assessment, children sit in front of a touch-screen tablet and are given headphones to listen to prompts instructing them to respond. Children first pass a readiness screening demonstrating their ability to follow instructions and respond to the three item formats. An IRT ability score is obtained in approximately 15 min with the administration of approximately 35–40 items. Multiple children can be assessed simultaneously (each child is given a computer tablet and set of headphones to complete the assessment), as trained researchers monitor the test administration processing in a quiet location in the Head Start center.

2.2.2. Approaches to learning

The Learning-to-Learn Scale (LTLS) is a teacher-report measure of children's learning behaviors (McDermott et al., 2011). It is a 55-item rating scale on which the teacher indicates whether a given behavior "does not apply," "sometimes applies," or "consistently applies" to each child. Items range from "Takes turns when working in a small-group, without needing to be reminded," to "Changes strategies when one solution to a problem doesn't work." The data were scored using a two-parameter logistic (2PL) item response theory (IRT) model. They produced standardized t-scale theta estimates ($M = 50$, SD = 10). This model utilized a bi-factor structure which allows for both a general factor of overall approaches to learning and an alternate model with several specific factors. The factor analysis revealed a unidimensional factor of general learning behavior, as well as, seven unique dimensions; strategic planning, effectiveness motivation, interpersonal responsiveness in learning, vocal engagement in learning, sustained focus in learning, acceptance of novelty and risk, and group learning. For this study we chose to use the general factor of approaches to learning because our aim was to examine the bidirectionality between overall approaches to learning and science readiness, instead of any particular sub-factor of approaches to learning. The measure demonstrates external validity and concurrent validity when compared with the cognitive subscale scores of the Learning Express, other norm-referenced tests, and teachers' assessments of language and numeracy, in addition to high reliability ($\alpha = .97$) (McDermott et al., 2011).

2.2.3. Vocabulary

The Quick Interactive Language Screener (QUILS; Golinkoff, Hirsh-Pasek, & De Villiers, 2011) is a 48-item direct assessment designed to measure language development in vocabulary and grammar for 3–6 year old children. For this study, we used residualized change in the vocabulary subtest as a covariate in all analyses. The QUILS utilizes a touch-screen laptop on which children indicate their answer choices by touching a picture. Interactive, cartoon-like animations are used to keep children engaged in the assessment which measures children's language products (i.e. word knowledge and grammar) and ability to use language process (i.e. strategies for learning new language). Items were developed by experts in child language development under a 4-year grant from the Institute of Education Science (IES; Grant # R305A110284 "Using Developmental Science to Create a Computerized Preschool Language Assessment;" Roberta Golinkoff, P.I.) and this measure has been administered to children served by Head Start.

The QUILS takes approximately 25 min to complete and does not require specially trained personnel as children only need adult supervision to complete the assessment (Golinkoff et al., 2011). The QUILS has displayed strong test–retest reliability, $r(29) = .923$, $p < .001$, as well as, convergent validity by significantly correlating with the Picture Peabody Vocabulary Test (PPVT-4; Dunn & Dunn, 2007), $r(22) = .714$, $p < .001$, and the Preschool Language Scale (PLS-5; Zimmerman, Steiner, & Pond, 2011), $r(23) = .782$, $p < .001$, after controlling for age (Pace et al., 2014).

2.3. Procedure

Consent was obtained from center directors, teachers, and parents. During the 2014–2015 school year direct assessments of early science school readiness and vocabulary were collected, along with a teacher rating scale of approaches to learning in the fall and spring. Child-level information (i.e. name, classroom, gender, and birthdate) were obtained for all children through center records. Trained research assistants administered direct assessments to children in a quiet space outside of the classroom and children received stickers for their participation. Teachers who completed the approaches to learning scale were compensated with 25 dollar gift certificates at both time points. These teacher-rating scales were verified in the field by a team leader, and then double verified by a graduate student prior to being entered into the database. Ten percent of the data were double entered and re-verified.

3. Results

Descriptive statistics are presented in Table 1, notably on average children gained approximately half of a standard deviation in science readiness and made small average gains in approaches to learning from fall to spring. Correlations among study variables are presented in Table 2, correlations within outcome variables (e.g. fall science and spring science, or fall approaches to learning and spring approaches to learning) are in the moderate rage (.53 and .57 respectively), while correlations between outcomes variables (e.g. fall science and spring approaches to learning, or fall approaches to learning and spring science) are in the low range (.23 and .19 respectively). Overall, while the percentage of missing data for fall approaches to learning (11%) and fall science readiness (12%) was relatively small, to maximize power in the sample we used a regression-based single imputation in SPSS (Allison, 2001). All available variables, including the outcome, were used to predict missing values on fall approaches to learning, fall science readiness. No outcome data were imputed. Ultimately, means and standard deviations of imputed variables were equivalent to the original data. The remainder of analyses were conducted in a HLM framework using the statistical software HLM 7 (Raudenbush, Bryk, Cheong, Congdon, & Du Toit, 2011), in order to account for the nesting of children within classrooms.

Table 1
Descriptive analyses for all variables.

	N	Mean	Standard deviation	Minimum	Maximum
Fall science	316	−.10	.85	−2.69	2.16
Spring science	302	.48	.96	−2.58	3.00
Fall approaches to learning	316	57.72	9.48	35.73	75.05
Spring approaches to learning	299	58.81	8.62	38.37	75.05
Age	304	51.38	6.95	37.90	62.70
Gender	316	.53	.50	0	1
Fall vocabulary	303	90.41	11.43	62.00	125.00
Spring vocabulary	291	92.54	11.19	62.00	125.00

Table 2
Correlations between all study variables.

	1. Fall science	2. Spring science	3. Fall approaches to learning	4. Spring approaches to learning	5. Age	6. Gender	7. Fall vocabulary	8. Spring vocabulary
1.	1	.53*	.22*	.23*	.53*	.11	.34*	.36*
2.		1	.19*	.25*	.42*	.16*	.37*	.37*
3.			1	.57*	.20*	.14*	.15*	.05
4.				1	.39*	.17*	.14*	.16*
5.					1	.07	.04	.02
6.						1	.06	.06
7.							1	.44*
8.								1

* $p < .05$.

Table 3
Hierarchical linear model using residualized change in science across the year to predict spring approaches to learning controlling for age, gender, change in vocabulary and fall approaches to learning.

Fixed effect	Coefficient	Std. error	*t*-Ratio	Approx. *d.f.*	*p*-Value
Intercept	58.952	1.094	53.898	32	<.001
Gender	.869	.516	1.685	181	.095
Fall approaches to learning	.319	.065	4.954	32	<.001
Age	.359	.056	6.451	181	<.001
Residualized change in science	.921	.304	3.028	32	.005
Residualized change in vocabulary	.045	.027	1.640	32	.111

Table 4
Hierarchical linear model using residualized change in approaches to learning across the year to predict spring science controlling for age, gender, change in vocabulary, and fall science.

Fixed effect	Coefficient	Std. error	*t*-Ratio	Approx. *d.f.*	*p*-Value
Intercept	.500	.061	8.198	32	<.001
Gender	.156	.099	1.568	181	.120
Fall science	.388	.094	4.138	32	<.001
Age	.034	.009	3.596	181	<.001
Residualized change in approaches to learning	.029	.012	2.221	32	.034
Residualized change in vocabulary	.018	.006	2.972	32	.006

The first model examined the ability of residualized change in science readiness from fall to spring to predict approaches to learning in the spring controlling for age, gender, change in vocabulary, and approaches to learning in the fall. Residualized change captures the extent to which children gained more or less in science readiness than would be predicted by our model, based on their demographic and other readiness data. The unconditional model indicated that 40% of the variance in approaches to learning was at the child level (level-1). Additionally, a model containing only covariates demonstrated that age, gender, change in vocabulary, and fall approaches to learning were all significant predictors of approaches to learning in the spring, thus, they were retained in the final model shown below:

$$\text{ATL\_Spring}_{ij} = \gamma_{00} + \gamma_{10}{*}\text{Gender}_{ij} + \gamma_{20}{*}\text{ATL\_Fall}_{ij} + \gamma_{30}{*}\text{Age}_{ij} + \gamma_{40}{*}\text{Science\_Change}_{ij} + \gamma_{50}{*}\text{Vocab}_{ij}u_{0j} + u_{2j}{*}\text{ATL\_Fall}_{ij} + u_{4j}{*}\text{Science\_Change}_{ij} + u_{5j}{*}\text{Vocab}_{ij} + r_{ij}$$

As hypothesized, residualized change in science readiness across the year significantly predicted spring approaches to learning controlling for age, gender, change in vocabulary, and fall approaches to learning [β = .921 (.304), p = .005]. Complete results for this model are presented in Table 3.

The next model examined the ability of residualized change in approaches to learning across the year to predict early science school readiness in the spring, controlling for age, gender, change in vocabulary, and fall science readiness. The unconditional model indicated that 95% of the variance in early science readiness was at the child level (level-1). Additionally, a model containing only covariates demonstrated that age, gender, change in vocabulary, and fall science readiness scores were all significant predictors of early science readiness in the spring, thus, they were retained in the final model shown below:

$$\text{Science\_Spring}_{ij} = \gamma_{00} + \gamma_{10}{*}\text{Gender}_{ij} + \gamma_{20}{*}\text{Science\_Fall}_{ij} + \gamma_{30}{*}\text{Age}_{ij} + \gamma_{40}{*}\text{ATL\_Change}_{ij} + \gamma_{50}{*}\text{Vocab}_{ij} + u_{0j} + u_{2j}{*}\text{Science\_Fall}_{ij} + u_{4j}{*}\text{ATL\_Change}_{ij} + u_{5j}{*}\text{Vocab}_{ij} + r_{ij}$$

Residualized change in approaches to learning across the year significantly predicted spring science readiness controlling for age, gender, change in vocabulary, and fall science readiness [β = .029 (.013), p = .034], confirming our initial hypothesis. Complete results for this model are presented in Table 4.

4. Discussion

This study examined the bidirectional relationship between approaches to learning and science school readiness in a sample of children attending Head Start. Consistent with our hypotheses, findings indicated significant bidirectional associations between these two domains, such that gains in approaches to learning predicted gains in science readiness across the school year and gains in science readiness predicted gains in approaches to learning across the school year both controlling for age, gender, and gains in vocabulary. It is important to note that a bidirectional effect is not necessarily a causal effect, but rather there is a predictive relationship between approaches to learning and science readiness in both directions. Specifically, children who improve more on their approaches to learning over the year learn more science, and those children who improve more on their science readiness, demonstrate greater development of their approaches to learning, beyond gains due to a child's natural cognitive maturation, gender, and vocabulary.

Results indicating that gains in approaches to learning predicted gains in science readiness are consistent with results from a previous study demonstrating that approaches to learning predicted gains in science school readiness more strongly than gains in math or language readiness for preschool children in Head Start (Bustamante et al., 2016). This evidence is indicative of a unique relationship between approaches to learning and science readiness, and highlights approaches to learning as a critical set of cognitive and behavioral skills that can serve as mental tools to help children understand science content and engage in science learning (Bodrova & Leong, 2007; Vygotsky, 1986). Results are also consistent with research conducted in older children, suggesting that motivation and persistence (key indicators of approaches to learning) are important predictors of success in science education (Lavigne et al., 2007; Singh et al., 2002). Additionally, results provide empirical support for theory that the iterative – trial and error – nature of science learning provides consistent opportunities to practice approaches to learning skills (i.e. persistence, strategic planning, group learning, and sustained focus) (Greenfield, 2015).

Indeed, our results go beyond what previous research has shown by being the first study to demonstrate that gains in science readiness predicted gains in approaches to learning across the year. In other words, children who demonstrated greater gains in science knowledge and reasoning skills across the year showed greater improvements in their approaches to learning skills over the school year. There is far less research exploring how readiness in a particular domain may facilitate the development of children's approaches to learning skills. Few studies have examined how prior strengths in certain cognitive or social skills may promote approaches to learning. One study, for example, examined how profile membership in kindergarten (based on various aspects of school readiness, including health, socioemotional, language, and cognitive outcomes) predicted approaches to learning at the end of first grade. They found that children in both health risk and socio/emotional risk profiles demonstrated lower approaches to learning in first grade compared to the health and socioemotional strength profiles (Hair, Halle, Terry-Heuman, Lavelle, & Calkins, 2006). Although the authors did not specifically examine how school readiness from a specific domain influences approaches to learning, they do suggest that it is important to identify early knowledge and skills that can promote the development of these critical learning skills prior to kindergarten entry. Specific to science school readiness, our study suggests that the competencies involved in observing, predicting, and consolidating science knowledge may be important as children learn to engage in new content, cooperate in a group setting, develop persistence, and become active learners. Thus, we provide preliminary support that school readiness in the domain of science may facilitate the development of approaches to learning.

The bidirectional nature of our findings support theoretical models of child development and school readiness, such as Snow's integrative model of school readiness, which stresses that multiple aspects of child development dynamically influence each other and interact over time (2007). They also support Vygotsky's theory that development and learning interact over time, particularly in the development of children's conceptual knowledge and understanding (i.e. scientific reasoning and content knowledge; Bodrova & Leong, 2007; Vygotsky, 1986). Specific to approaches to learning and science readiness, our findings suggest that these two important constructs, develop together over time, highlighting a unique and intricate relationship between children's scientific skill development and their behavioral approaches to learning new content.

These results have important implications for early childhood education. An intentional focus on approaches to learning may allow children to more effectively engage in, and learn from, early science experiences. Activities like puzzles can offer children a chance to exercise their persistence, sustained focus, and tolerance for frustration, all approaches to learning skills that can serve children during science learning experiences. Further, collaborative group games where children have to communicate effectively, make strategic plans, and work cooperatively with peers towards a common goal, can foster approaches to learning skills, which children can directly apply to science activities. Indeed, entire early childhood curricula have been developed with approaches to learning as a major focus. Fantuzzo et al. (2011) developed the EPIC curriculum, which included lessons specifically targeting approaches to learning skills and successfully boosted approaches to learning in preschoolers served by Head Start.

However, approaches to learning can be difficult to teach devoid of academic content, and with limited hours in the school day, teachers often feel pressure to focus on academic skills first. To the extent that domain general skills like approaches to learning can be integrated into academic learning experiences, they might be more represented in the preschool classroom. Effectiveness motivation, strategic planning, and group learning, three components of approaches to learning, can be developed and targeted within the context of academic lessons, and results from this study suggest that science may be an ideal domain in which to help children develop these skills. Children have to use strategic planning to develop and test hypotheses, they have to remain motivated and revise their hypotheses when they do not unfold as they predicted, and these experiences are typically conducted in a group setting. Similarly, as children develop their approaches to learning, they can apply prior knowledge and scientific reasoning skills in the context of hands-on science experiences in order to optimize learning.

Not only could science experiences in the early childhood classroom help children develop approaches to learning, there is also evidence to suggest that it supports children's math and language learning, as well (Greenfield, 2015; Morgan et al., 2016). However, due to time constraints, early childhood educators have limited opportunity to intentionally focus on all school readiness domains (e.g. math, language, science, approaches to learning, social and emotional development). This reality makes it particularly important for teachers to design and implement fun and engaging experiences that will address multiple school readiness domains at once. Such an approach is also supported by the idea that children learn best when engaged in integrated, hands-on, minds-on experiences that encourage higher order thinking and are relevant to their daily lives, all of which occur during high quality early science education.

Therefore, combined with previous research suggesting a link between science readiness and approaches to learning, and other school readiness domains, (Bustamante et al., 2016; Nayfeld et al., 2013) and recent calls for an increased focus on science education in preschool and beyond (Brenneman, 2011; Greenfield, 2015; Morgan et al., 2016), this study offers support for science as an ideal domain for early childhood teachers to focus on to help children develop their approaches to learning and other school readiness skills in a hands-on, engaging context.

4.1. Limitations and future directions

This study suggests a unique bidirectional relationship between approaches to learning and science school readiness in the preschool years. These findings, along with previous research, suggest that science may be an ideal base for early childhood curricula and interventions due to its potential to improve not only children's approaches to learning and science readiness, but also their math, language, executive functioning, and social and emotional skills (Cabell et al., 2013; Greenfield, 2015; Morgan et al., 2016; Nayfeld et al., 2013). However, this study has several limitations that should be addressed.

First, the sample was not nationally representative as African American and Latino children from low-income families in an urban environment made up the vast majority of participants. While this provides us with important insight into an at risk population it does not allow for broader generalizations. Future research should replicate these results in other populations from varying racial, ethnic, and socioeconomic backgrounds.

Second, although we were able to control for age, gender, and gains in children's vocabulary over the school year, there is the potential for omitted variable bias. Covariates that have established relationships to the outcome variables in this study, such as executive functioning or child temperament, could explain additional variance and potentially alter our models results. Unfortunately, we were unable to collect those data in the current sample. Future research, should endeavor to include additional relevant covariates in order to further illuminate the relationships between approaches to learning and science school readiness.

Lastly, data from this study are correlational, as they were not collected in the context of an intervention. Thus, precluding any drawing of causal conclusions on the relationship between approaches to learning and science readiness. Future research should explore the extent to which science instruction improves children's approaches to learning development across the year, and the extent to which a focus on approaches to learning within the context of science experiences further bolsters children's science readiness across the year. To this end, preschool science interventions that intentionally target children's approaches to learning should be developed in order to capitalize on the unique relationship between these domains. It is also important to note that both science and approaches to learning are typically underrepresented in preschool classrooms (Greenfield, 2015; Morgan et al., 2016; Nayfeld et al., 2013), and this study was not conducted in the context of an intervention targeting these skills. Thus, we might expect stronger relationships between science readiness and approaches to learning in a context where children are exposed to more instruction specific to these domains.

Additionally, future research should explore how different subdomains of approaches to learning may differentially impacts children's science readiness and ability to engage in science learning. For example, particular aspects of approaches to learning (i.e. strategic planning, sustained focus in learning, or acceptance of novelty and risk) may play an even stronger role in fostering science readiness and if that was indeed the case interventionists and educators could take that into account during program development.

5. Conclusion

In summary, findings from this study suggested a unique relationship between science readiness and approaches to learning. Theory suggests science experiences provide children opportunities to practice their approaches to learning, and approaches to learning aids children in navigating science experiences. Results from this study represent a first step in providing empirical evidence for this symbiotic relationship. Science is an ideal context for teachers to capitalize on the bidirectional relationship between these two critical readiness domains. While the importance of science education is nationally recognized, there is an urgent need to improve the infrastructure of science education in the United States. Promoting preschool science is a necessary starting point. In this endeavor, science-based curricula should be developed and disseminated to capitalize on the relationship between science and approaches to learning, which could have profound implications for narrowing the school readiness achievement gap.

Acknowledgments

This research was made possible by Grant Number 90YR0081-01 from the Office of Planning, Research and Evaluation, Administration for Children and Families, U.S. Department of Health and Human Services and a collaboration with Miami-Dade County Head Start. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Office of Planning, Research and Evaluation, the Administration for Children and Families, or the U.S. Department of Health and Human Services. We would also like to thank Dr. Annemarie Hindman of Temple University for sharing her considerable expertise on statistical methodology which greatly enhanced the quality of this manuscript.

References

Allison, P. D. (2001). . *Missing data* (Vol. 136) Sage Publications.

Bodrova, E., & Leong, D. J. (2007). *Tools of the mind*. Upper Saddle River, NJ: Pearson.

Brenneman, K. (2011). Assessment for preschool science learning and learning environments. *Early Childhood Research & Practice*, *13*(1), 1–9. http://files.eric.ed.gov/fulltext/EJ931225.pdf

Bustamante, A. S., White, L. J., & Greenfield, D. B. (2016). Approaches to learning and school readiness in Head Start: Applications to preschool science. *Learning and Individual Differences*,. 25.10.16. http://www.sciencedirect.com/science/article/pii/S1041608016302333

Cabell, S. Q., DeCoster, J., LoCasale-Crouch, J., Hamre, B. K., & Pianta, R. C. (2013). Variation in the effectiveness of instructional interactions across preschool classroom settings and learning activities. *Early Childhood Research Quarterly*, *28*, 820–830. http://dx.doi.org/10.1016/j.ecresq.2013.07.007

Conezio, K., & French, L. (2002). Science in the preschool classroom. *Young Children*, *57*(5), 12–18.

Driver, R., & Erickson, G. (1983). *Theories-in-action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science*.

Dunn, L. M., & Dunn, D. M. (2007). *Peabody picture vocabulary test, fourth edition (PPVT-4)*.

Fantuzzo, J. W., Gadsden, V. L., & McDermott, P. A. (2011). An integrated curriculum to improve mathematics, language, and literacy for Head Start children. *American Educational Research Journal*, *48*(3), 763–793.

Fantuzzo, J. W., Perry, M. A., & McDermott, P. A. (2004). Preschool approaches to learning and their relationship to other relevant classroom competencies for low-income children. *School Psychology Quarterly*, *19*(3), 212–230.

Fuccillo. (2011). *Higher-level instructional interaction in Head Start classrooms: Variation across teacher-directed activities and associations with school readiness outcomes*. Psychology (Arts & Sciences), University of Miami. ProQuest Dissertations and Theses (3456335) (Doctoral dissertation).

Golinkoff, R., Hirsh-Pasek, K., & De Villiers, J. (2011). *Using developmental science to create a computerized preschool language assessment*. IES; Grant # R305A110284.

Greenfield, D. B. (2015). Assessment in early childhood science education. In K. Trundle, & M. Saçkes (Eds.), *Research in early childhood science education* (pp. 353–380). New York, NY: Springer Publishing.

Greenfield, D. B., Jirout, J., Dominguez, X., Greenberg, A., Maier, M., & Fuccillo, J. (2009). Science in the preschool classroom: A programmatic research agenda to improve science readiness. *Early Education and Development*, *20*(2), 238–264.

Hair, E., Halle, T., Terry-Humen, E., Lavelle, B., & Calkins, J. (2006). Children's school readiness in the ECLS-K: Predictions to academic, health, and social outcomes in first grade. *Early Childhood Research Quarterly*, *21*(4), 431–454.

Heckman, J. J. (2006). Skill formation and the economics of investing in disadvantaged children. *Science*, *312*(5782), 1900–1902.

Howe, A. C. (1996). Development of science concepts within a Vygotskian framework. *Science Education*, *80*(1), 35–51.

Kagan, S. L., Moore, E., & Bredekamp, S. (Eds.). (1995). *Reconsidering children's early development and learning: Toward common views and vocabulary*. Washington, DC: National Education Goals Panel.

Lavigne, G. L., Vallerand, R. J., & Miquelon, P. (2007). A motivational model of persistence in science education: A self-determination theory approach. *European Journal of Psychology of Education*, *22*(3), 351.

Li-Grinning, C. P. (2007). Effortful control among low-income preschoolers in three cities: Stability, change, and individual differences. *Developmental Psychology*, *43*, 208–221.

Li-Grining, C. P., Votruba-Drzal, E., Maldonado-Carreno, C., & Haas, K. (2010). Children's early approaches to learning and academic trajectories through fifth grade. *Developmental Psychology*, *46*(5), 1062–1077.

Magnuson, K., & Duncan, G. (2006). The role of family socioeconomic resources in the Black–White test score gap among young children. *Developmental Psychology*, *25*(5), 787–793.

Magnuson, K., Waldfogel, J., & Washbrook, E. (2012). SES gradients in skills during the school years, From parents to children. *The intergenerational transmission of advantage*, 235–261.

McClelland, M. M., Cameron, C. E., Conner, C. M., Farris, C. L., Jewkes, A. M., & Morrison, F. J. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology*, *43*, 947–959.

McClelland, M. M., & Morrison, F. J. (2003). The emergence of learning-related social skills in preschool children. *Early Childhood Research Quarterly*, *18*(2), 206–224.

McClelland, M. M., Morrison, F. J., & Holmes, D. L. (2000). Children at risk for early academic problems: The role of learning-related social skills. *Early Childhood Research Quarterly*, *15*(3), 307–329.

McDermott, P. A., Fantuzzo, J. W., Warley, H. P., Waterman, C., Angelo, L. E., Gadsden, V. L., et al. (2011). Multidimensionality of teachers' graded responses for preschoolers' stylistic learning behavior: The learning-to-learn scale. *Educational and Psychological Measurement*, *71*, 148.

McDermott, P. A., Rikoon, S. H., & Fantuzzo, J. W. (2014). Tracing children's approaches to learning through Head Start, kindergarten, and first grade: Different pathways to different outcomes. *Journal of Educational Psychology*, *106*(1), 200.

McWayne, C. M., Fantuzzo, J. W., & McDermott, P. A. (2004). Preschool competency in context: An investigation of the unique contribution of child competencies to early academic success. *Developmental Psychology*, *40*(4), 633–645.

Morgan, P. L., Farkas, G., Hillemeier, M. M., & Maczuga, S. (2016). Science achievement gaps begin very early, persist, and are largely explained by modifiable factors. *Educational Researcher*, *45*(1), 18–35.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

Nayfeld, I., Fuccillo, J., & Greenfield, D. B. (2013). Executive functions in early learning: Extending the relationship between executive functions and school readiness to science. *Learning and Individual Differences*, *26*, 81–88.

Pace, A., Yust, P., De Villiers, J., Iglesias, A., Wilson, M., Golinkoff, R., et al. (2014). Evaluating the reliability and validity of a computer-based language assessment. *Poster presentation at the annual American Speech-Language Hearing Association (ASHA) meeting, Orlando, FL.*

Paris, S. G., & Winograd, P. (1990). *How metacognition can promote academic learning and instruction*. pp. 15–51. *Dimensions of thinking and cognitive instruction* (Vol. 1).

Piaget, J. (1973). *To understand is to invent: The future of education*.

Raudenbush, S. W., Bryk, A. S., Cheong, Y. F., Congdon, R. T., & Du Toit, M. (2011). *HLM 7 for windows [Computer software]*. Lincolnwood, IL: Scientific Software International, Inc.

Ryan, R. M., Fauth, R. C., & Brooks-Gunn, J. (2006). Childhood poverty: Implications for school readiness and early childhood education. In B. Spodek, & O. Saracho (Eds.), *Handbook of research on the education of children* (2nd ed., Vol. 1, pp. 323–346). Mahwah, NJ: Erlbaum.

Saçkes, M., Trundle, K. C., Bell, R. L., & O'Connell, A. A. (2011). The influence of early science experience in kindergarten on children's immediate and later science achievement: Evidence from the early childhood longitudinal study. *Journal of Research in Science Teaching*, *48*(2), 217–235.

Singh, K., Granville, M., & Dika, S. (2002). Mathematics and science achievement: Effects of motivation, interest, and academic engagement. *The Journal of Educational Research*, *95*(6), 323–332.

Snow, K. L. (2007). Integrative views of the domains of child function: Unifying school readiness. In R. C. Pianta, M. J. Cox, & K. L. Snow (Eds.), *School readiness and the transition to kindergarten in the era of accountability*. Baltimore, MD: Paul H. Brookes Publishing Co., Inc.

U.S. Department of Health and Human Services. (2015). *Head start early learning outcomes framework*. http://eclkc.ohs.acf.hhs.gov/hslc/hs/sr/approach/pdf/ohs-framework.pdf

Vitiello, V. E., Greenfield, D. B., Munis, P., & George, J. L. (2011). Cognitive flexibility, approaches to learning, and academic school readiness in Head Start preschool children. *Early Education & Development*, *22*(3), 388–410.

Vygotsky, L. S. (1986). *Thought and language – Revised edition*. Cambridge, MA: MIT Prep.

Welsh, J. A., Nix, R. L., Blair, C., Bierman, K. L., & Nelson, K. E. (2010). The development of cognitive skills and gains in academic school readiness for children from low-income families. *Journal of Educational Psychology*, *102*(1), 43–53.

Zimmerman, I. L., Steiner, V. G., & Evatt Pond, R. (2011). *Preschool language scales, fifth edition (PLS-5).*