A POTENTIAL FIX FOR THE LEAKY STEM PIPLINE: THE DEVELOPMENT AND VALIDATION OF THE SCIID SCALE

A Dissertation

by

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ABSTRACT

Science, technology, engineering, and mathematics (STEM) influence almost every aspect of our daily lives. However, despite the high demand for STEM occupational talent, the STEM pipeline continues leaking, with less than one-sixth of high school students pursuing STEM majors and only 50% of entering STEM majors matriculating into STEM fields. Science identity has been identified as the most powerful predictor of high school students pursuing an undergraduate STEM major. Yet, the construct remains largely ill-defined and unexplored. The purpose of this study was to develop the SciID Scale, a valid and reliable new instrument that measures a high school student's science identity. Subject experts and a small group of high school students provided content validation for the scale. Exploratory factor analysis was used which revealed an optimal two-factor solution, reflecting the traditional two-dimensions of identity theory: Exploration and Commitment. Structural equation modeling, regression analysis and contingency tables were used to confirm the convergent and divergent validity of the instrument with external variables. Lastly, a latent class analysis provided further validation of the scale as it yielded an optimal four-class solution that reflected traditional identity theory statuses of: Achieved, Foreclosed, Moratorium, and Diffused. These validation measures combined with the good reliability scores of each factor yielded the SciID Scale a valid and reliable instrument specifically designed for high school students.

DEDICATION

To Yesu.

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To my children Eli, Joshua, Luke, our little one in Heaven, and any others that might bless my life, thank you for helping me continue to learn about the most important job I will ever have – being Mama. My love for each of you is beyond what words can even begin to express. I pray that nothing in this life, no success, no accomplishment,

nor any worldly gain will ever satisfy you until you fall into the arms of Jesus. I promise, nothing compares.

Most of all, thank you to my Lord and Savior, Jesus Christ. You are my one constant in life. Thank you for your unfailing love. Thank you for your constant pursuit of my whole heart. I can never repay you for what you have done. No gift would ever be enough. May every ounce of this be for you and your glory.

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CHAPTER I

INTRODUCTION

There is a call on our nation like never before for reform in STEM Education. America is losing its place as a global powerhouse amongst the advanced nations of the world, particularly in STEM (Science, Technology, Engineering, and Mathematics). The COVID-19 pandemic has only heightened the gravity of this issue. The Glenn Commission reported in 2000 that we have yet to capture the attention of our students in science and mathematics (National Commission on Mathematics and Science, 2000). Five years later, the report from the National Academies, "Rising Above the Gathering Storm," cited the national shortage of STEM majors as a priority one concern for America. According to the sequel report, "Rising Above the Gathering Storm, Revisited: Rapidly Approaching a Category Five" (National Research Council, 2010), the situation has not improved; in fact, it has worsened. "Today more than ever before, science and mathematics hold the key to our survival as a planet and our security and prosperity as a nation" (National Research Council, 2010).

The National Academies Gathering Storm committee concluded that a primary driver of the future economy, security of our nation, and concomitant creation of jobs will be innovation, largely derived from advances in science and engineering (National Research Council, 2007). Consistent with this notion and noting the consistent growth in industries with a STEM emphasis over the past two decades, employment in STEM-related occupations is projected to grow an estimated 8.9% by 2024 (Noonan, 2017).

However, despite the high demand for STEM occupational talent, the STEM pipeline continues to leak, with less than one-sixth of high school students pursuing a STEM major and only 50% of entering STEM majors matriculating into STEM fields (US Department of Education, 2015). Based on these figures, one can already foresee a substantial future shortage in the STEM workforce. The need to plug the leaky STEM pipeline is urgent.

Researchers and educators have labored intensely over the past twenty years to devise and implement curricular and programmatic changes within the traditional US educational system that would increase student interest and achievement in STEM. Growth has been seen. However, gender, racial/ethnic, and social class disparities exist in many science degrees and fields within the United States; girls, African Americans, Latinos, rural students, and students from lower socioeconomic (SES) backgrounds are less likely to pursue science classes, degrees, and careers (Alegria and Branch, 2015; Hill et al., 2018; National Science Board, 2016; Penner, 2015). Extending participation in science is important to increase innovation and reduce social inequality (Beede et al. 2011; Holdren 2011).

Part of the methodology employed as of late in measuring the effectiveness of STEM interventions designed to increase STEM persistence has been geared towards documenting changes in students' science identities. Several studies have found that identification with context relevant identities such as "student" or "scientist" actually provides a better prediction of academic performance and persistence than either racial or ethnic identity (Bonous-Hammarth, 2000; Eccles & Barber, 1999; Osborne & Walker, 2006; Chemers et al., 2011). As noted in Hazari et al. (2018), science identity-based frameworks have proven fruitful in studying science persistence as several studies have shown that science identity influences science persistence (Aschbacher, Li, & Roth, 2010; Basu, 2008; Carlone & Johnson, 2007; Calabrese Barton & Yang, 2000; Chinn, 2002; Cleaves, 2005; Gilmartin, Denson, Li, Bryant, & Aschbacher, 2007; Olitsky, 2007; Shanahan, 2009). A recent analysis by Chang and colleagues (2020) applied the machine learning approach to a large-scale national data set of high school students. The study revealed that the students' "science identity" was the single-best predictor of their pursuit of STEM majors.

The notion of science identity being the greatest predictor of STEM persistence holds extreme consequences for the future. If STEM educational interventions effectively target the cultivation of students' science identities, an increase in matriculation into STEM majors and careers should subsequently result. The research questions addressed in this study are:

1. How has science identity been defined and operationalized?
2. How is the theory behind the operationalization of the science identity construct rooted in identity and academic identity theory?
3. What are the psychometric properties of these instruments?
4. What is the factor structure of science identity?
5. Is the newly developed SciID Scale a valid and reliable instrument?

This study consists of two primary portions that address these research questions. Questions 1, 2 and 3 are largely answered through the investigation into the literature regarding science identity and instruments that have been employed to measure this construct. This investigation was initiated by broadly exploring the theoretical background of science identity which includes both identity theory and academic identity theory. The second portion of the study refers to the precise development and validation of the SciID Scale – a new instrument developed to accurately measure a high school student's science identity. This portion of the study addresses research questions 4 and 5.

CHAPTER II

LITERATURE REVIEW

Identity

Defining identity is no simple task. For decades, identity has been defined and interpreted in a myriad of ways (Beijaard, Meijer, & Verloop, 2004; Dugas et. al., 2018; Fitzmaurice, 2013). In psychology, personal identity is typically defined as a cognitive self-structure. It is through this cognitive self-structure that people seek to answer the question 'Who am I?' (Erikson, 1959; Marcia, 1980; McLean & Syed, 2014; Schwartz, Luyckx, & Vignoles, 2011). Though it is usually believed that the most drastic developments in identity formation occur during adolescence in which the individual experiences intense times of identity crisis, researchers commonly agree that there exists a lifelong nature to the identity formation process (Erickson, 1959, 1963, 1968; Fitzmaurice, 2013). Identity has been described as a learning trajectory with the goal of integrating past experiences and future expectations with present experiences. Thus, it is a process of forming, comprehending and reevaluating one's values and experiences through practice and over time (Beijaard, Verloop, & Vermunt, 2000; Dugas et. al., 2018).

According to Erikson (1959, 1963, 1968) as described by Was et al. (2009), late adolescence and early adulthood yield a time of crisis when individuals begin making independent choices regarding their values, beliefs, and goals by engaging in different options. The decisions that are made during this time result in commitments within a particular identity domain. The processes that are involved in establishing an identity and an identity status affect how an individual will cope with adversity, interact with others, and make decisions about vocational paths and other important life options (Was et al., 2009).

The basis of most research regarding identity was initiated by Erikson. Erickson (1968) believed that this primary task of adolescence derives itself as the young person begins to cope with social and developmental demands while seeking to provide meaning to their life choices and commitments (Bosma and Kunnen 2008; Hewlett 2013; Jensen 2011; McLean and Syed 2014; Schwartz et al. 2011; Was et al., 2009). According to Erikson (1959), this process of identity formation may result in either a mature identity synthesis or simply lead to role confusion or crisis. Adolescents must make important decisions in multiple identity domains, such as in their education and within their interpersonal relationships (Albarello, Crocetti, & Rubini, 2017; Branje et al. 2014; McLean et al. 2016).

Marcia (1966), is largely credited with operationalizing Erikson's theory regarding identity. Marcia postulated a theory that identity formation is based on two successive identity processes, Exploration and Commitment (Piotrowski, 2018). The period of Exploration generally refers to an individual experiencing a time of active questioning and consideration of various alternatives before making firm decisions regarding their values, beliefs and/or goals that they will ultimately pursue. The period of Commitment refers to an individual making a relatively firm decision within a particular identity domain and engaging in meaningful activities that are a direct expression of the implementation of that decision (Crocetti, Rubini & Meeus, 2008).

Marcia crossed these two identity processes with regards to their level of their presence or absence in an individual and developed a series of four identity statuses (Crocetti et. al, 2012). The Achieved status is characterized by individuals having made a commitment within a specific identity domain. This follows a period of active exploration. The Foreclosed status is defined for those who have made a commitment, but with little to no previous exploration. The Moratorium status defines those who are actively exploring various alternatives. These individuals have not made a commitment yet. Lastly, the Diffused status includes individuals who have not engaged in an actual exploration process of different alternatives, nor made a commitment (Crocetti et. al., 2012; Crocetti, Rubinin & Meeus, 2008; Marcia, 1966; Meeus et. al., 2011; Rahiminezhad et. al., 2011; Was et al., 2009). These statuses have been applied to various identity domains through the years and studied in regards to their relation to individuals attaining or not attaining an achieved status in that domain. The advantage of Marcia's research is that individuals can be measured and assigned to a particular identity status that definitively represents their level of achievement/non-achievement within the Commitment/Exploration identity process of a particular identity domain (Meeus et. al., 2011).

More recently, a group of researchers defined a third identity process called Reconsideration of Commitment. The Meeus-Crocetti Model focuses on the management of commitments. It postulates that three dimensions, instead of Marcia's two dimensions, underly the identity formation process. In this model, the Commitment and Exploration (termed In-Depth Exploration) dimensions remain somewhat consistent to Marcia's definitions. However, the Meeus-Crocetti Model introduces a new dimension deemed Reconsideration of Commitment. This dimension refers to an individual's willingness to abandon their present commitments and search for new commitments. Oftentimes this occurs when present commitments no longer satisfy an individual and, thus, they begin comparing their present commitments with attainable alternatives. This model is based upon the assumption that these three identity formation processes are in continuous "interplay" as individuals form an identity (Albarello, Crocetti, & Rubini, 2017; Crocetti et al., 2013; Meeus et. al., 2011; Mercer et al., 2012).

Congruent with Marcia's two-dimensions of the identity formation process, the three-dimension Meeus-Crocetti Model can be applied to assign individuals to specific identity status categories. These categories differ slightly from Marcia's. Crocetti et al. (2008) used cluster analysis to extract five statuses from continuous measures of commitment. These statuses include: Achievement, Foreclosure, Moratorium, Diffusion and a new status of Searching Moratorium. Searching Moratorium represents a combination of high commitment, high in-depth exploration, and very high reconsideration of commitment (Crocetti et. al., 2008; Meeus et. al., 2011). This status did not exist previously due to the introduction of the new phase, Reconsideration of Commitment. Individuals, particularly adolescents, who fall into the Reconsideration of Commitment status display intense commitments and explore these commitments extensively. However, these adolescents also exhibit an active pursuit of consideration of alternative commitments (Crocetti et al., 2008; Meeus et al. 2011). The focus of this three-dimensional model is primarily on the process of managing commitments and focuses less on the Exploration (Exploration In-Breadth) process of identity formation.

Some other main measures have been developed and are commonly used to assess identity formation. A few of these include the Dimensions of Identity Development Scale (DIDS; Luyckx et al., 2006, 2008) and the Identity Style Inventory (ISI; Berzonsky, 1990). These measures are not discussed here as they have not been used as recently nor extensively in the evaluation of academic identity.

Academic Identity

It is important to note that many studies have proposed that an adolescent can be classified under different identity statuses depending upon which identity domain is being examined (Archer, 1993). There have been numerous studies that support the proposition that academic identity should be distinguished from a more general identity (Was et. al., 2009). Notably, it is during adolescence that two critical domains of educational/academic identity and interpersonal identity are extremely important (Albarello, Crocetti, & Rubini, 2017; McLean et al., 2014). For the academic domain, adolescents make important choices while they investigate their talents, interests and potential in an area of study and are, thus, preparing themselves for their future career (Albarello, Crocetti, & Rubini, 2017; Marcia, 1980). Within the interpersonal domain, adolescents begin defining their personal way of relating and being in a relationship with others (Albarello, Crocetti, & Rubini, 2017). Crocetti et al. (2008) developed the Utrecht-Management of Identity Commitments Scale (U-MICS). This scale is comprised of 26 items. Thirteen of these items refer to an adolescent's academic identity and the other 13 items refer to an adolescent's interpersonal identity. These two domains can be summed together for an overall "identity score" and determines an individual's identity status (Mercer et al., 2017). This measure has been widely validated and used amongst various ethnic, gender, and age groups (Crocetti et al., 2008; Meeus et al., 2010; Meeus et al., 2011; Mercer et al., 2017; Piotrowski, 2018). Some relevant results from use of this measure suggest educational identity is a relatively more "closed" domain than interpersonal identity. This is believed to be due to external constraints that limit a student's range of opportunities for academic identity change (Albarello, Crocetti, & Rubini, 2017). However, interpersonal identity can be considered an "open" domain (in which adolescents have relatively more alternatives to explore) so they can more easily engage in commitment and reconsideration processes (Albarello, Crocetti, & Rubini, 2017; Klimstra et al. 2010). Evidence has pointed to a multi-faceted nature of identity development in adolescence, being both an individual and a social process.

Was and Isaacson (2008) first proposed this notion of an academic identity. They deemed it as constituting a "special" portion of Erickson's (1959) "ego identity." They support the notion that it is a distinctive component of an individual's identity development (Was & Isaacson, 2008). Was and Isaacson (2008) built upon Marcia's (1966) definition of the identity process formation and established identity statuses. They postulated four academic identity statuses in congruence with Marcia's statuses: Achieved, Foreclosed, Moratorium and Diffused. Specifically, an Achieved academic identity status signifies an adolescent's commitment to a set or series of academic values that are formed after a period of exploration. The Foreclosed academic identity status defines an adolescent whose commitment to their academic values is derived from influential people in their lives, but they have not yet personalized or explored this. The Moratorium academic identity status defines a period of time for which the adolescent is experiencing academic uncertainty and is attempting to draw conclusions regarding their academic goals and values. Lastly, the Diffused academic identity status refers to an adolescent who experiences failure in exploration and commitment (Was & Isaacson, 2008; Was et al., 2009). The Academic Identity Status Measure (AIM) was, thus, developed by Was and colleagues on the premise of these four statuses (Was et al., 2009). AIM contains four subscales, each designed to measure an academic identity status, and each consisting of ten items (Was & Isaacson, 2012). It was normed with a sample of American collegiate students and has been validated in North America and parts of Africa for use mainly with college students, but also some with secondary students (Ireri et al., 2015).

Another measure developed by Rahiminezhad et al. (2011) also applied Marcia's (1966) paradigm of ego identity status to develop a 16-item academic identity scale deemed the Academic Identity Status Scale (AISS). This four-factor model was deemed an acceptable and reliable instrument for assessing Iranian students' status in academic identity (Rahiminezhad et al., 2011). This instrument is not as widely validated, accepted nor used as Was and Isaacson's (2008).

Saxton et al. (2014) formed a committee and began preparations to form a common measurement system for STEM education. Within this measurement system, the committee deemed it important to develop a common measure of academic identity as this is part of a student being prepared to succeed in STEM college majors and careers. They believed that academic identity for a student who is capable in STEM is conceptualized as a fundamental transformation that students need to undergo in order to be prepared for STEM majors and careers. According to Saxton et al. (2014), the team based their measurement instrument upon the body of literature on academic motivation and self-perceptions presented in Wigfield et al.'s (2006) article on development of achievement motivation. They then chose four markers of academic identity that encompass a student's deep belief regarding themselves and their potential to enjoy and succeed in STEM courses and eventually STEM careers (Saxton et al., 2014). These four components included: (1) a sense of belonging in STEM; (2) perceived competence in STEM; (3) autonomy/ownership; and (4) purpose of STEM (Saxton et al., 2014). It should be noted that, as cited in Saxton et al. (2014) these four facets of academic identity have been shown through Wigfield et al.'s (2006) study to be strong predictors of students' motivation, engagement, learning, and success in school. Though these components certainly related heavily to academic motivation and self-perceptions, they lack in alignment with the theoretical perspectives regarding identity, identity formation, academic identity, academic identity formation and academic identity measurement that have previously been discussed. No mention of Erickson nor Marcia, two founders of identity theory, is made in their research. This is an interesting approach to measuring academic identity, but is lacking in an historical theoretical perspective.

Several studies have undertaken a longitudinal and/or predictive approach to exploring the link between student academic identity and related variables, especially the variable of academic achievement. The AIM has been the primary measurement instrument used in these studies. Also, the majority of these studies have taken place with university students. In a study conducted by Was et al. (2009) regarding the presumed link between academic achievement and academic identity, results showed that the most important variable in the academic identity subscale in predicting academic achievement, is academic identity diffuse. They also found that boys were more often classified as diffused than girls were. The study documented that boys were also assigned a Foreclosed academic identity more than girls. Reasons for this are unknown but proposed to be due to girls attempting to explore newer and more untraditional roles than boys (Was et al., 2009).

Furthermore, in more studies with both American and Iranian undergraduate students, the Achieved academic identity status had the strongest predictive value on academic achievement when compared to others statuses (Fearon, 2012; Was et al., 2009; Was & Isaacson, 2008). It was also found that the diffused and foreclosed academic identity statuses had negative predictive values on academic achievement (Hejazi, Levasani & Amani, 2012). Also, the moratorium academic identity status showed a significant, positive, predictive value for academic achievement as well (Fearon, 2012). In another study conducted amongst secondary Kenyan students by Ireri et al. (2015), researchers found that the achieved academic identity status had the greatest and the only significant predictive value on students' academic achievement. The reason for this discrepancy in findings of the Kenyan study compared to the American and Iranian study is unknown. Possible considerations are the differences in ethnicity and/or the differences in age groups studied.

Science Identity

While identity has been extensively studied over the past 70 years and academic identity has peaked researcher's interest over the last decade, research regarding science identity is scarce. Qualitative studies regarding science identity initiated around 20 years ago (Brickhouse, Lowery, & Shultz, 2000; Brickhouse & Potter, 2001; Eisenhart & Finkel, 1998; Hughes, 2001; Tan & Calabrese Barton, 2007). A commonly held definition of science identity is built around Gee's (2000) attempt to define identity generally as the "kind of person" one is recognized as "being" in any given context, either by oneself or with others. Gee was a linguist who attempted to provide a bridge from the study of identity to education. Carlone and Johnson (2007) employed a grounded theory approach that led the team to develop three interrelated "dimensions" of science identity: Competence, Performance, and Recognition (Carlone & Johnson, 2007). The work completed by Gee (2000) and Carlone and Johnson (2007) are commonly referenced in research regarding science identity.

The task at hand, however, is to accurately measure the construct of science identity. Thus, three questions emerge in reviewing existing instruments used to measure students' science identity:

1. How has science identity been defined and operationalized?
2. How is the theory behind the operationalization of the science identity construct rooted in identity and academic identity theory?
3. What are the psychometric properties of these instruments?

Methods

This part of the study instituted a systematic review process of science identity literature as outlined by Moher et al. (2009). To effectively and comprehensively identify and analyze instruments developed to measure science identity, a four-step process was conducted: Identification, Screening, Eligibility, and Inclusion.

Identification

Exclusion and inclusion criterion are listed in Table 1. Given that the majority of the instruments developed to measure science identity springboard from Gee's (2000) description of science identity, it was decided to begin the search in the year 2000. From here it was decided that the studies should be peer-reviewed, quantitative studies. This eliminated all qualitative studies. Furthermore, the instruments should focus on students and explicitly measure students' science identity. Thus, any studies that focused on student "science motivation" or "science interest", for example, and deemed this equivalent to "science identity" without just cause were excluded. Also excluded were instruments that focused on teacher science identity. No restrictions were placed on how science identity was defined or operationalized. Lastly, a list of equivalent terms for "instrument" were generated and then searched. These included: scale, measure, test, assessment, questionnaire, and inventory.

Table 1

Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Publications in English	Non-English publications
Students	Teachers or non-students in education
Peer-reviewed articles published from 2000 onwards	Conference papers, non-peer reviewed publications
Quantitative studies	Discussions, qualitative and theoretical studies
Instruments explicitly measuring student science identity	Self-efficacy, self-image, beliefs, motivation studies, generic identity studies
No restrictions on how student science identity is conceptualized or defined	Open-ended questionnaires

Using the PsycInfo and ERIC databases, an initial search yielded 98 hits that included “science identity” in the title and “scale” or the equivalent as part of the subject. Further refining the search by year, peer reviewed criterion, and English criterion yielded a set of 59 studies. A total of 51 studies remained after duplications were removed.

Screening

The abstracts for each of these 51 studies were reviewed independently. Inclusion and exclusion criterion were used to determine the article’s eligibility for this study. After reading the abstract, if any question remained as to whether or not the study should be included, the theoretical background and methods sections of the article were reviewed.

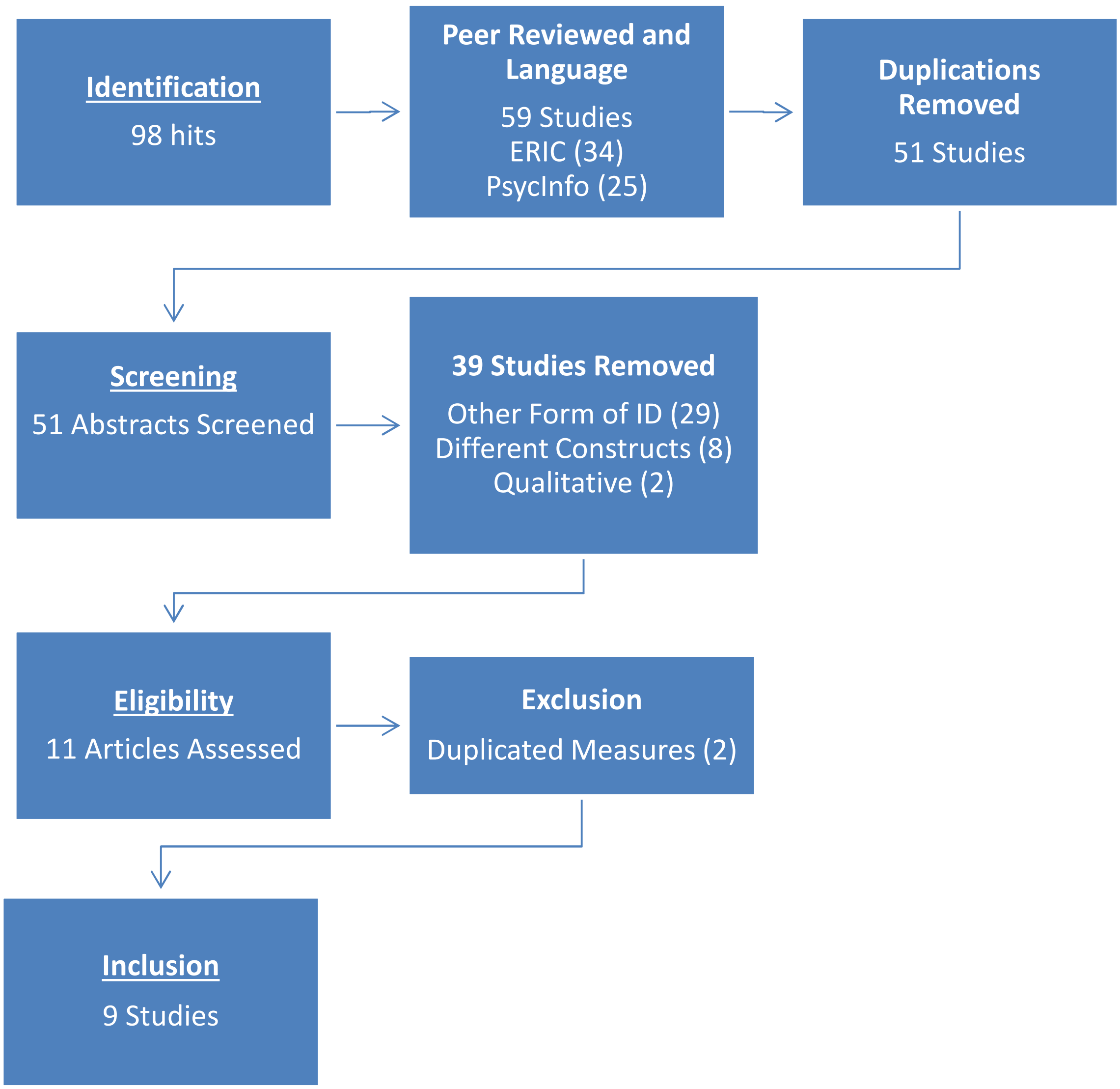
Of the 51 abstracts only 11 remained after applying the inclusion and exclusion criterion. The majority of the studies removed were excluded because they were not actually about science identity (29). These studies examined some form of identity while student participants were engaged in a science-based atmosphere, or simply included some type of science component in the research. Thus, the studies were a "hit" in the search criterion, but did not actually focus on science identity. Other studies discussed science identity, but then did not exclusively measure the construct (8). These studies often substituted science interest or achievement for identity. Lastly, a few of the studies excluded were qualitative case studies (2).

Eligibility and Inclusion

Each of these 11 articles were subjected to qualitative review to ensure they met the inclusion criterion. This review process consisted of three steps as outlined by Izadinia (2013). First, the full article was read. After this, the article was reread with a specific focus on the theoretical background and measurement sections. The article was then summarized. Lastly, if any question existed regarding the inclusion of the article in this study then the authors discussed this potential decision. Two articles were omitted as they measured science identity using an instrument already chosen for review in this study. Thus, nine articles were retained for inclusion. This process is summarized in Figure 1.

Figure 1

Flowchart of the Article Selection Process



Results

Results from the literature review regarding instruments measuring science identity are given below.

Instrument Basics

The nine instruments were used in groups ranging in size from 113 to 7505. The number of items per instrument ranged from one to fourteen, with 44.4% of the studies using four or less items to measure students' science identity. Most of the items were scored using a 5-point Likert scale usually ranging from "strongly disagree" to "strongly agree". Five of the studies examined some aspect of science identity amongst undergraduate students, two with high school students, and two with middle school students.

Theoretical Background

In examining the theoretical background of each of these studies (see Appendix A for details) it was found that the vast majority of them failed to establish any link between the work already accomplished in identity theory and academic identity theory with that of science identity. Only one study by Chemers et al. (2011) referred to Erickson's foundational work on identity theory. Erickson's work was only briefly mentioned and inconsequential to the overall study. Robinson et al. (2018) briefly referred to Marcia's expansion of Erickson's work. But again, this was only briefly mentioned and not foundational in operationalizing science identity. Lastly, Williams et al. (2018) did incorporate work on academic identity theory within its study. These researchers adopted a nine-item scale for academic identity developed by Saxton et al. (2014). They reworded the items so as to specifically address science identity. Thus, science identity and academic identity were assumed to be equivalent. The other studies' theoretical backgrounds primarily used Carlone and Johnson's (2007) work combined with Gee's (2000) definition of identity as being a "type of person".

Definition of Science Identity

Of the nine studies that were reviewed, one of them (Skinner et al., 2017) explicitly defined the construct of science identity (see Appendix A for details). Skinner et al. (2017) defined science identity as a subfactor of what they deemed "identity as a scientist." The researchers held that a student's science identity reflected their deeply rooted conviction that he or she belonged in the world of science and viewed himself or herself as the kind of person who resonated with the core values and pursuits of the science community (Skinner et al., 2017). Here we see the influential work of Gee (2000) referencing identity to a "type of person". A loose definition of the construct is given by three of the studies. Pugh et al. (2008) stated, "Science identity refers to the degree to which students view science as an important part of who they are, perceive themselves as science people, and can picture themselves pursuing science in the future" (p. 5). No references for the development of this definition were provided. Williams et al. (2018) mentioned that someone with a strong science identity refers to being someone who belongs in science and who may want to pursue science in college or career. Hazari et al. (2013) simply used Gee's (2000) theory that science identity refers to someone being a "science type of person."

Operationalization and Dimensionality

Skinner et al. (2017) proposed three subscales to measure students' identity as a scientist which included science identity, science career plans, and sense of purpose in science. Four of the studies noted Carlone and Johnson's (2007) three dimensions of science identity (Competence, Performance and Recognition) in attempting to measure the construct, but did not explicitly state the dimensionality of the construct nor analyze it. Only Syed et al. (2018) specifically addressed the dimensionality of science identity, claiming the three dimensions of Carlone and Johnson's study held. No other studies describe the dimensionality of the construct.

Psychometric Properties

Seven of the nine studies provided some reliability information pertaining to the portion of the instrument that measured science identity. These reliability measures were based off of Cronbach's alpha and ranged from .80 to .95, all good scores. However, only three studies made any mention of validity measures. Pugh et al. (2008) described the content validity of their instrument stating that their measure was tested with six students through cognitive interviews. Science identity was a part of larger instrument they developed where an overall four-factor model of the survey was tested and deemed valid using CFA and EFA (CFI=.95, SRMR=.05). Skinner et al. (2017) spoke to the unidimensionality of their instrument and validity measures conducted using CFA. Lastly, Hazari et al. (2013) mentioned their testing and adequate results of criterion related validity (adjusted R^2 ranged from .30 to .40). They further emphasized that their items were adapted from the PRISE survey which was deemed valid and reliable. Unfortunately, neither reliability nor validity information regarding the PRISE survey was able to be located. Also of importance, only one of the nine measures in this review evaluated their instrument for measurement invariance across gender and/or ethnicity. Robinson et al.'s (2018) instrument showed strict measurement invariance across these demographics.

Discussion

To the best of our knowledge, this review is the first to provide an overview of studies that sought to quantitatively measure the construct of science identity. In this section, we discuss the findings that emerged in response to our three research questions:

1. How has science identity been defined and operationalized?
2. How is the theory behind the operationalization of the science identity construct rooted in identity and academic identity theory?
3. What are the psychometric properties of these instruments?

In looking to answer the first question, it is noteworthy that none of the nine studies actually focused on defining nor operationalizing science identity. For each instrument reviewed, science identity was merely used as a component of a larger research investigation. The construct, including its definition and operationalization, was not the sole focus of any of the studies. Only one study by Skinner et al. (2017) explicitly defined science identity. Within this definition resonates Gee's (2000) work in connecting "identity" to the educational environment as being a "type of person." Gee derived an entirely new form of theory on identity that is absent of established identity theory work conducted by Erickson and Marcia. One particular question that arises when examining Gee's theory is how his definition of identity referring to a "type of person" differs from one's self-concept. This should be noted and explored in studies utilizing this particular definition of identity.

Furthermore, asking a student if they see themself as a "science kind of person" is somewhat broad and ill-defined; it lacks in depth of knowledge on what constitutes science identity and the process of its formation. How does a student interpret the word "science"? Will they interpret science simply in reference to the science course they are currently taking? Or, will they interpret science in a broader scope that spans all of the different scientific disciplines? To a student, does being a science person reference being a scientist in a lab, or does it also reference being an engineer, software developer, physician, geophysicist, meteorologist, etc.? It seems necessary that to measure students' science identity, one must first have a solid definition of science identity that is easily and explicitly communicated to, and understood by, the population of interest.

Furthermore, having only one of the nine studies describe the dimensionality of the construct is also concerning. The study by Syed et al. (2018) used Carlone and Johnson's (2007) grounded theory of science identity that proposed three dimensions to the construct. Yet, Carlone and Johnson's theory, though noteworthy, also utilized Gee's (2000) theory that referred to being a science "kind of person". It was not rooted in established identity theory where the dimensionality and actual status has already been thoroughly investigated. Additionally, only two of the studies reported any validity information that incorporated the findings from CFA or EFA. Again, this factoid points to the lack of evidence that this science identity has been accurately and quantitatively defined or operationalized.

In examining the theoretical backgrounds of these nine studies, it was found that they were absent in examining or utilizing the foundation of identity theory that was established by Erickson and Marcia, or that has been built upon in more recent decades. No mention of identity status or academic identity status was made. Gee's (2000) theory was foundational for most of the studies. As stated before, Gee took an entirely different approach to defining identity that did not cite the use of already established theory and has not been clearly distinguished from self-concept. Thus, no existing measure evaluated in this study is rooted in established theory regarding identity and/or academic identity.

The psychometric properties of the instruments provided by the studies included in this research were lacking. Though the reliability of the instruments was addressed in seven of the nine instruments and overall found to be good with measures greater than .80, validity information regarding measures of science identity within the instruments was scarce. Again, it should be noted that science identity was not the sole focus of any of these studies. It was simply a variable amongst other variables being measured.

Implications for Future Research

Our findings pose several facets for future research regarding science identity. Noting the lack of instruments that measure this construct combined with the lack of validity information and lack of consistency between instruments, it appears that solid research in this area is needed. To the best of our knowledge, no quantitative study has been conducted that focuses solely on defining and operationalizing the construct of science identity. Thus, studies seeking to explicitly define science identity and/or science identity formation, explore its dimensionality, and conduct factor analyses of the construct are needed.

Researchers seeking to define and operationalize the construct of science identity rooted in established identity and/or academic identity theory will produce groundbreaking results. This area of research is vastly unexplored. Further, attempting to measure the "process" of science identity development within students as defined by identity theory is unexplored. Given the rich body of identity theory that exists and the potentially drastic impact measuring science identity and its development process could have on STEM educational interventions, this is an area begging to be tapped.

Other researchers seeking to utilize Gee's (2000) work also have areas of study regarding science identity that are open. Again, creating a sound measure that explores the dimensionality of the construct under Gee's framework is needed. Also, distinguishing science identity from science self-concept under Gee's definition is also an area worthy of investigation. Furthermore, refining and testing the instrument to ensure the inclusion of items that are well defined and easily understood across the desired population is of importance and will enhance the overall validity of the measure.

Assessing the measurement invariance of new or existing science identity instruments is a worthy endeavor. As mentioned previously, there is a profuse gender and ethnic gap within the STEM disciplines. Thus, researchers must take extra caution in ensuring that instruments created to assess anything STEM related amongst students displays measurement invariance across these groups.

Limitations

Our findings should be interpreted under their limitations. There is a risk that we mistakenly overlooked studies or failed to acknowledge their relevance. This could have happened with studies that did not meet the inclusion or exclusion criteria, or it might have been due to search engines' unique algorithms and ranking strategies. Though precautions were taken to try to ensure neither of these happened, we acknowledge that there is a chance for this occurrence.

Conclusions

In this review, we aimed to identify the manner in which science identity and/or science identity formation has been defined and operationalized, investigate the theoretical backgrounds leading to those definitions, and evaluate the psychometric properties of the instruments that were available for measuring science identity. Our review of these instruments revealed an ill-defined nature to the construct that has been loosely operationalized and not grounded in traditional identity theory. Moreover, the validity of most of the instruments was questionable as information regarding this criterion was absent and/or lacking from most reviewed studies. The sound, quantitative measurement of science identity in students is vastly unexplored.

CHAPTER III

METHODS

The remainder of the study focuses on the developmental process and validation of a new instrument to measure high school students' science identity, the SciID Scale. Through this process, research questions 4 and 5 are addressed.

Crocker and Algina (2008) proposed a ten-step guideline for the instrument development process that has been restructured into six processes (Baek, 2017):

- Process 1: Identify Purpose(s)/Define Construct and Theory,
- Process 2: Test Specifications,
- Process 3: Item Development,
- Process 4: Pilot Test,
- Process 5: Reliability and Validity Studies, and
- Process 6: Technical Report.

Process 1: Identify Purpose(s)/Define Construct and Theory

This project included a two-part literature review to aid in defining of the construct of science identity and its underlying theory.

The first part of the literature review included an investigation into the theory underlying the constructs of identity, academic identity, and science identity. It seemed disjointed to investigate science identity and related measurement instruments without first researching the overarching construct of identity and its formation. From this, the construct of academic identity was then reviewed for its relation to identity theory and its distinction from science identity. Lastly, all devised theory regarding the construct of science identity was investigated.

After reviewing the underlying theory regarding identity, identity formation, academic identity, and science identity, a second literature review was conducted that included a systematic review of science identity instruments. These results were discussed previously.

In short, science identity formation should mimic the formation of the underlying personal identity as applied to a specific domain. Thus, the science identity formation consists of two primary dimensions: Exploration and Commitment. The SciID Scale was developed to accurately measure a high school student's standing on these two latent variables.

Exploration (or Crisis) was defined by Marcia (1966) as being a "period of engagement in choosing amongst meaningful alternatives" (p. 551). Thus, the Exploration dimension for the SciID Scale measured the degree to which the student has undergone a period of investigation and choosing amongst meaningful alternatives to science. Since "meaningful alternatives to science" is a broad base that can include different school subjects, hobby interests, collegiate interests and career interests, this scale was more general in nature.

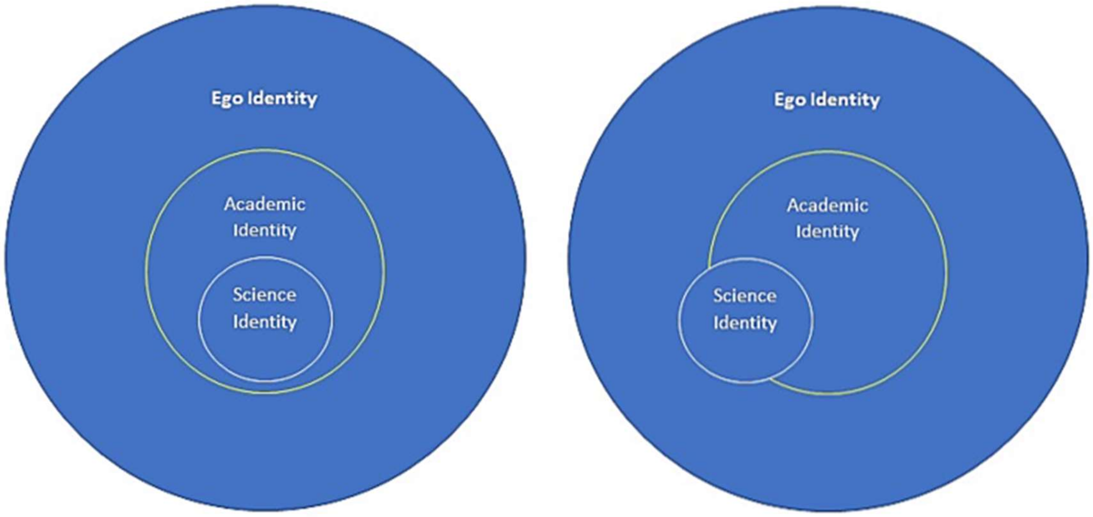
Marcia (1966) further defined Commitment as being "the degree of personal investment the individual exhibits" (p. 551). Thus, the SciID Scale measured a student's Commitment to science based on the degree of personal investment to science that they exhibited. This scale was specific in nature to science.

It follows that a student's science identity is the measure to which that student has experienced a time of exploration of meaningful alternatives to science and has decisively chosen to commit themselves to science. It is through an individual's standing of high or low on these two dimensions that they should be able to be classified into one of four science identity statuses: Achieved, Foreclosed, Moratorium, or Diffused. This classification will be critical for further study of science identity formation and cultivation within students.

An important distinction was made between the constructs of academic identity and science identity. Was science identity a subset of academic identity; thus, being capable of being accurately measured by a sound academic identity instrument or capable of predicting academic identity with precision? Consider the following two models provided in Figure 2:

Figure 2

Potential Models of Science Identity



Model 1: Subset (Science Identity can be either a proper or improper subset of Academic Identity)

Model 2: Not a subset (Science Identity is neither a proper nor improper subset of Academic Identity, though overlap exists)

Though initially Model 1 seems theoretically feasible, there existed an error in the conceptual framework that disproved this model. Consider, for example, the student who has an infatuation for science, but a tremendous dislike of school. Perhaps they had a bad experience in school, or science classes, or with bullying, or simply found school to be a waste of time. Whatever the case, they are not committed to school/academics. Thus, their academic identity level on Commitment would be low (Diffusion or Moratorium academic identity status). However, their science propensity, infatuation towards science and commitment to pursue some form of science in their future through school or not through school would be high (potentially demonstrating an Achieved or Foreclosed science identity). Therefore, science identity should be distinguishable of academic identity.

Process 2: Test Specifications

Through the combination of an examination of the literature regarding identity theory and the grounded theory research in science identity provided by Carlone and Johnson (2007), it was determined that science identity formation was likely a two-dimensional construct. However, the Commitment dimension could, potentially, be represented through a bifactor structure as outlined below in Table 2.

Table 2

Potential Dimensionality of Science Identity

	Exploration	**Commitment**
Five Commitment Subdimensions	Unidimensional	1. Recognition of Self 2. Recognition of Others 3. Competence 4. Performance 5. Path
Four Commitment Subdimensions	Unidimensional	1. Recognition of Self 2. Recognition of Others 3. Competence 4. Performance/Path
Three Commitment Subdimensions	Unidimensional	1. Recognition of Self 2. Recognition of Others 3. Performance/Path
Two-Dimensional	Unidimensional	Unidimensional – Recognition of Self, Recognition of Others, Competence, Performance, Path

Carlone and Johnson (2007) originally proposed that science identity was a three-dimensional construct comprised of a student's Competence (knowledge and understanding of science content), Recognition (recognizing oneself and being recognized by others as a "science person"), and Performance (social performances of relevant scientific knowledge). They later discovered that the Recognition component of the science identity was most important and diverged into two dimensions: Recognition of Self as being a science person and Recognition by Others as being a science person. These Recognition dimensions were believed to be critical for the development of a strong science identity for women in the sciences. As this concept was investigated, it was discovered that Carlone and Johnson's grounded theory of science identity largely represented a student's Commitment to science but neglected to reflect them having experienced a period of Exploration. Thus, it is conceivable that the Commitment dimension of the SciID Scale could itself include between three and four subdimensions based upon Carlone and Johnson's (2007) theory. Furthermore, a high school student who is committed to science should have a path or plan for their future in science. Thus, a potential fifth subdimension for Commitment could exist. This path or plan a student has for their future could likely overlap with their performances. Thus, these subdimensions could be combined. These potential five subdimensions could be classified individually, but could also be examined as a whole; thus, a bifactor model would be of consideration for investigation here.

Process 3: Item Development

Given that no true measure of science identity existed that was foundationally based upon identity theory, an entirely original item bank was developed to accurately reflect the dimensions of Exploration and Commitment. The SciID Scale was measured on a 5-point Likert scale ranging from "Strongly Disagree" (1) to "Strongly Agree" (5).

A series of 14 items was initially developed to represent a student's standing on the Exploration dimension. These items included questions about a student's level of exploration of activities and subjects in high school, to their exploration of college majors (or certificates) and even careers. Each question was developed based upon the definition of Exploration as provided by Marcia (1966) and reflected a student having undergone a period of engagement in searching out meaningful alternatives to science.

The Commitment Scale originally included 20 questions. These questions were developed to represent the five aspects of Competence (20%), Self-Recognition (30%), Others-Recognition (15%), Performance (20%) and Path (15%). Each question reflected a student's degree of personal investment exhibited to science through the framework of the subdimensions.

An expert panel was convened that included three members: A STEM Curriculum Specialist (Ph.D.), a Master-Science High School Teacher (M.S.), and a High School Science Teacher/Science Department Head (B.S.). A fourth expert unexpectedly had to withdraw from the study. Consent was gathered from each panel member to participate in the study. Members were allowed to exit at any point. Members who completed the study were provided with a $100 gift card for their work. Panel members were asked to discuss the definitions of Exploration and Commitment provided by Marcia (1966). They were then asked to describe in detail a student who was committed to science. From this, discussions were held regarding the potential underlying framework of the Commitment scale and further development/refinement of potential subdimensions. Panel members were asked to rank order the top three and bottom three questions per each of the Exploration and Commitment scales that most accurately or inaccurately reflected the definition of those scales. Items were thoroughly discussed and deliberated. Item rankings were discussed.

After the conclusion of the expert panel discussion, revisions were made to the SciID Scale. Following this, a group of eight high school students was convened to serve as a focus group. District approval, parental consent and student assent were collected before the group was convened. Students were selected based upon the recommendation of a teacher. They were invited to participate in the focus group but given the option not to participate. They were provided with a $50 gift card if they chose to participate. All eight students chose to participate. Of the students, 25% were minority, 37.5% would be first-generation college students, 87.5% were advanced students, 75% were juniors, 12.5% were sophomores, and 12.5% were seniors. Juniors were largely the target of this focus group as the preliminary High School Longitudinal Study of 2009 (HSLS:09) data which provided the framework for this study was based upon juniors. Advanced students were largely selected for the focus group as it was believed that these students would be more likely to demonstrate a stronger science identity and could assist in the further development/refinement of the construct. Students were asked to engage in a descriptive analysis of each item, as they described what was understandable and relatable to the majority of high school students and what was not. Students were also asked to rank items as to their representation of the construct and relatability to high school students. Item refinement and development continued from this.

Process 4: Pilot Study

Caldwell ISD is a rural school district in southeast Texas. Approximately 38% of its students are "at risk" with 57% of the student body being economically disadvantaged. With approximately 49% Caucasian, 38% Hispanic, and 10% African American, Caldwell ISD boasts almost equivalent majority-minority proportions.

Due to the rise of Covid-19 concerns, all pilot study measures were performed via electronic means. With the help of Caldwell High School administerial staff, all Caldwell High School students (n≈450) were provided an opportunity to participate in the online SciID Scale survey. An email advertising the survey and the study along with a link to the survey was drafted and distributed to all high school students through the administerial staff. A "Remind" text was also sent to all students providing them the URL for the survey. The beginning of the survey included an advertisement video, opportunity for a virtual meeting with project personnel, parental consent forms, student assent forms and signature blocks. To proceed to the actual SciID Scale, all of the above had to be successfully completed. Students were allowed to withdraw from the study at any time simply by exiting the survey. Students who successfully completed the survey (answered all questions appropriately) were provided with a $10 e-gift card for their participation. A total of 303 students connected to the survey URL, with only 169 of these students completing more than 33% of the survey. Of the 134 students who did not complete more than 33% of the survey, the majority of them completed less than 5% of the survey. Thus, these students exited the survey before consent/assent signatures were attained. After cleaning the data, n=156 usable surveys were retained with only one survey having any missing data. Of the retained students, the following demographics were represented:

- 63% female
- 58% Caucasian
- 46% economically disadvantaged
- 38% potential first-generation college students
- 54% Pre AP/AP
- 24% in 9th grade
- 24% in 10th grade
- 26% in 11th grade, and
- 26% in 12th grade.

Due to the novelty of the Covid-19 situation, the survey remained open for one-month; allowing ample opportunity for participation. Students were blocked from ballot-stuffing, but were allowed a seven-day period of time to return to their saved survey to complete it. Student progress was recorded.

Process 5: Reliability and Validity Studies

SciID Scale

Items were initially reviewed based upon descriptive statistics. Individual items demonstrating extreme low or high averages were considered for removal or revision along with items demonstrating excessive non-normality (±6 for skewness and ±2 for kurtosis). Stata 16 was used for evaluation of descriptive statistics, correlational studies, regression analyses and chi-square contingency analyses. Mplus 8.4 was used for all exploratory, confirmatory, path and latent class analyses. Maximum Likelihood Robust (MLR) estimation method was used for appropriate analyses due to the slight non-normality of a few items, small sample size and the handling of one survey with minimal missing data.

Exploratory factor analysis (EFA) was implemented to investigate the internal structure of the SciID scale. Though research regarding identity and academic identity pointed to a two-dimensional construct, no true research regarding the exploration of the dimensionality of science identity had been conducted. Thus, it was important to explore the factor structure of the construct, including an exploration of a potential bifactor structure for the Commitment scale.

Acknowledging the likely covariance between the Exploration and Commitment dimensions, the Geomin oblique rotation method, the default rotation method for Mplus, was used. A Scree Plot was examined for initial consideration of factor retention. The significance of each item to each factor was investigated. The Chi-Square Test for modal fit, RMSEA, SRMR and CFI global indicators were evaluated. Respective values less than .08 for RMSEA and SRMR and greater than .90 for CFI indicate an adequate model fit (Hu & Bentler, 1999). The optimal solution for a 2-dimensional Commitment/Exploration construct model was compared to the optimal solution of an overall 2-dimensional Exploration/Commitment model with a bifactor structure for the Commitment dimension. Structural Equation Modeling (SEM) was used for model validation with external measures. The Chi-Square Test for modal fit, RMSEA, SRMR and CFI global indicators were evaluated. Furthermore, the significance of each individual path was tested at the a=.05 significance level.

The variance between the Exploration and Commitment dimensions for the 2-factor model was constrained to be one and then tested for model fit and compared to the unconstrained model. This tested the discriminant validity of whether these are indeed two different factors or not. The reliability of each dimension of the SciID Scale was calculated using Cronbach's alpha.

For a further check of the validity of the SciID Scale, a latent class analysis was conducted. From prior research regarding identity theory, it was found that four latent classes emerged due to an individual's classification of high or low on the Exploration and Commitment scales. Thus, a four-class solution for the SciID Scale was also expected. Class solutions were examined based upon AIC, BIC, SABIC, VLMR test, ALMR test, BLRT values, class size and entropy. Since BLRT has shown to be more accurate than VLMR in identifying the optimal number of classes, it was given more attention (Nylund et al., 2007). Since the sample size was small, results were not expected to be optimal. However, the data was expected to demonstrate strong potential for an optimal four-class solution.

STEM-CIS

The STEM-Career Interest Survey (STEM-CIS) was used to measure changes in students' interest in STEM subjects and careers (Kier et al., 2014). It was based upon the social cognitive career theory with subscales in science, technology, engineering, and mathematics. Rated on a 5-point Likert scale, the 44-item survey was tested with over

1,000 students who primarily resided in rural, high-poverty districts in the southeastern USA. Confirmatory factor analyses indicated that the STEM-CIS was a strong, single factor instrument and also had four strong, discipline-specific subscales, which allow for the science, technology, engineering, and mathematics subscales to be administered separately or together. The science subscale was used for convergent validity purposes with the Commitment dimension of the SciID Scale. A composite score was produced based upon the 11 items. Measurement error was accounted for by regressing the composite score on the underlying latent factor, Science Career Interest, where the error variance was fixed to the product of the observed score variance (.56) and one minus the sample reliability (1 - .8713). A strong, positive relationship was expected between the Science Career Interest Latent Factor and the Commitment factor of the SciID Scale.

Science Achievement

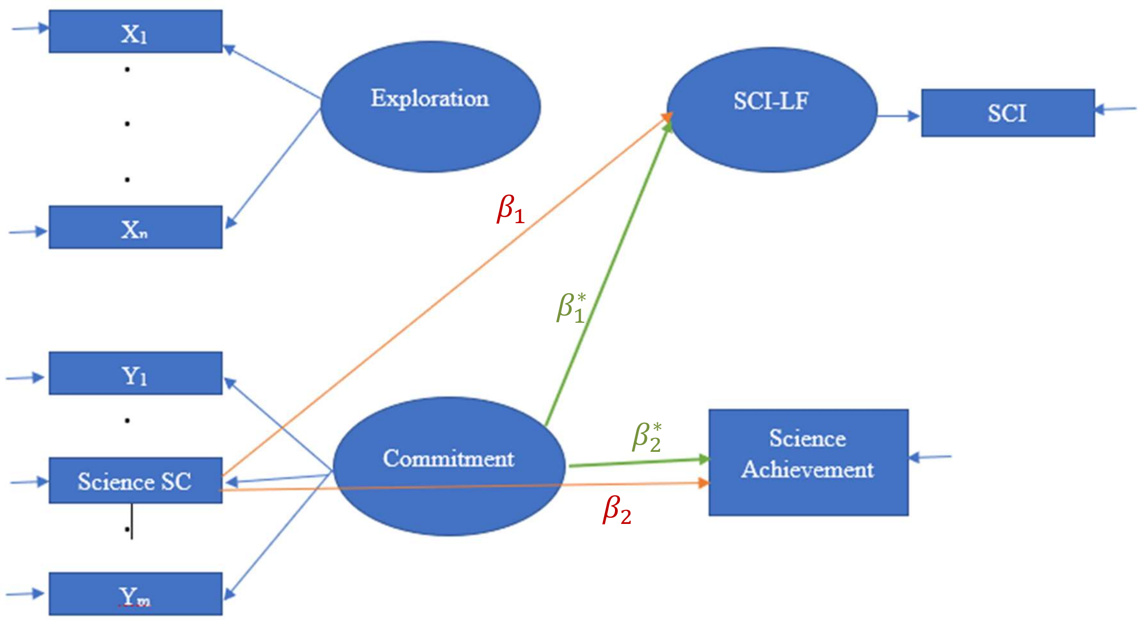
Research regarding academic identity has noted significant correlations between academic identity status and academic achievement. Moreover, there has existed a predictive nature of the different academic identity statuses on academic achievement that have been well documented (Fearon, 2012; Was et al., 2009; Was & Isaacson, 2008; Hejazi, Levasani & Amani, 2012; Klimstra et al., 2012; Lounsbury et al., 2005). Though science identity was not conjectured to be a subset (rather proper or improper) of academic identity, there was believed to be a portion of it that was relatable to academic identity. It seemed sensible to conjecture that a student's science identity status, or even more simply their level of science Commitment, was correlated to their science achievement and/or predictive of their science achievement. Thus, students' science achievement was measured as a weighted variable based upon students' academic success in science and the rigor of the science courses they pursued. The variable was measured on an 11-point scale where scores of 0-9 represented their average science grades (9:95+, 8:90-94,7:85-89, and so on) and a 2-point increase was given to those in advanced science courses. Thus, a score of 11 represented a student averaging marks of 95+ in advanced science courses. Science Commitment was expected to be a positive, significant predictor of science achievement.

Science Self-Concept

Researchers, at times, have suggested the equivalency and, thus, interchangeable nature of the constructs of self-concept and identity (Archer, 1993; Was et al., 2009). Self-concept refers to one's view of themself while identity refers to the degree of Exploration and Commitment an individual has experienced within particular identity domains. Gee's (2000) conjecture of identity applied to educational domains as being a "kind of person" aided this confusion. Gee's definition diverged from traditional identity theory. Moreover, several studies that alluded to science identity based their operationalization of science identity on Gee's theory and constituted this construct as being a student's view of themself as a "science kind of person" (Hill et al., 2018; Skinner et al., 2017; National Center for Education Statistics, 2015). In reviewing this operationalization, it was determined that this science self-concept reflected a student's "recognition of themselves" as being a science person. Thus, it constituted a portion of their Commitment to science and mimics Carlone and Johnson's (2007) self-recognition dimension of science identity. Differences were expected to exist, however, between a student's Commitment to science and their science self-concept. Their Commitment to science should be quite more extensive. Thus, the discriminant validity between these two constructs was analyzed as outlined in Figure 3. This was evaluated by first including the variable "I view myself as a science kind of person" in the Commitment dimension of the SciID Scale. Paths between this variable and student Science Career Interest (β_1) and student Science Achievement (β_2) were freely estimated and then constrained to be equal to the corresponding paths from student Commitment to student Science Career Interest (β_1^*) and student Science Achievement (β_2^*). Using the Satorra-Bentler correction, a Chi-Square Difference Test was performed to determine if indeed being a "science kind of person" was equivalent to being Committed to science.

Figure 3

SEM Illustrating Evaluation of Equivalency for Science Self-Concept and Science Identity

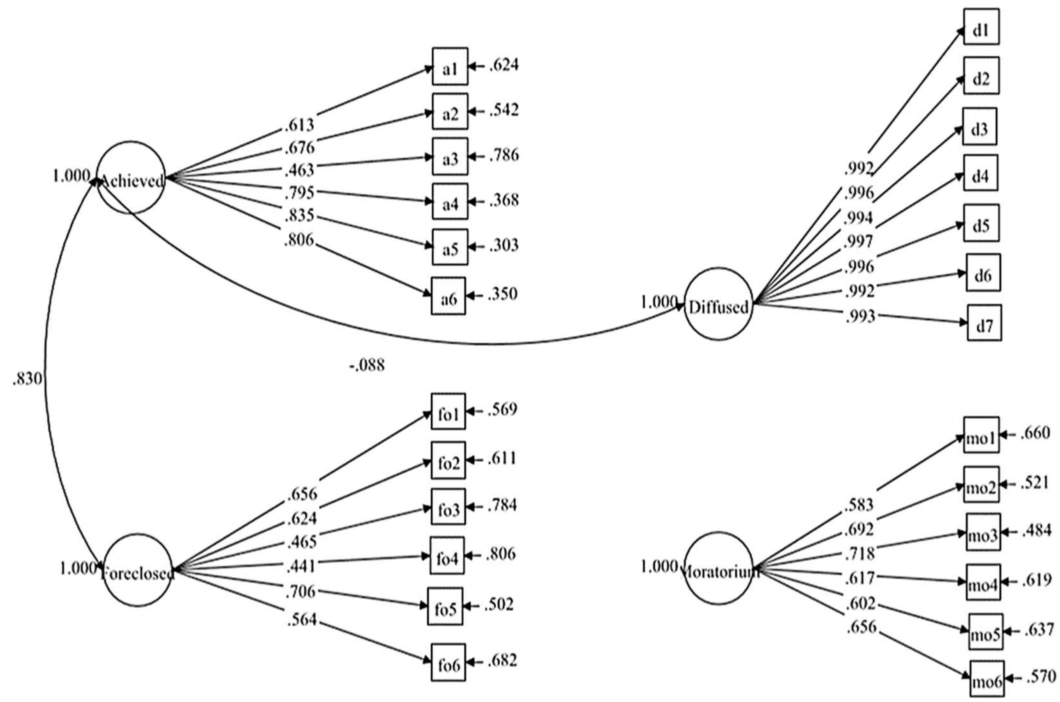


Academic Identity

Lastly, the Academic Identity Measure (AIM) was developed by Was and Isaacson (2008) to determine a student's academic identity classification of Achieved, Foreclosed, Moratorium, or Diffused. Largely used and validated with college students, the instrument boasted original internal reliability measures for the four subscales as follows: Moratorium = .85, Foreclosed = .77, Diffused = .76, and Achieved = 76. The scale was simplified for this study as questions that pertained directly to college students were eliminated. The shortened form yielded internal consistency measures of: Moratorium = .81, Foreclosed = .75, Diffused =. 99, and Achieved = .85. CFA results for the short-form yielded adequate model fit (X^2 p-value<.001, RMSEA=.082, CFI=.944, SRMR=.065) with all significant factor loadings as shown in Figure 4.

Figure 4

Academic Identity CFA (all paths significant $\alpha = .05$)



A contingency table was used to compare student classifications between the AIM and ScID Scale. A Pearson's Chi-Square Test was implemented to determine if significant differences existed between classifications on these two measures. It was expected that differences would exist as underlying theory suggested that Academic Identity and Science Identity are not equivalent.

Process 6: Technical Report

Before the generation of a true technical report for the SciID Scale, a larger field test is needed. This test will further substantiate the factor structure of the SciID Scale using CFA, the external and internal validity of the measure, use Item Response Theory (IRT) for item-level analysis, and examine items for Differential Item Functioning (DIF) corresponding to measurement invariance on the item-level of the overall instrument. This will be part of a future study.

CHAPTER IV

RESULTS

Expert Panel

An original set of 34 items was initially developed (14 for Exploration and 20 items for Commitment). Expert Panel members were asked to characterize a student who was "committed" to science. They were then asked to group these characteristics. After this, Experts compared their groupings to those developed by the research team which included Carlone and Johnson's theory (2007). From this, came the five potential groupings of Recognition of Self, Recognition of Others, Competence, Performance and Path. It was believed that each of these reflected an aspect of a high school student's Commitment to science.

The 34 items were then reviewed. Three of the Exploration questions and five of the Commitment questions were refined in an effort to clarify their specific meaning. An additional three items were comprised for the Commitment scale to represent a student's interest in current events and real-life uses of science as it was believed that this was an important component to their level of Commitment. One item was recommended for deletion but was retained for the focus group.

Focus Group

Focus group members convened to take the extensive survey which included external measures used for validation purposes. Completion time averaged 16 minutes. Student behavior was monitored during the survey so as to identify problematic questions. The eight high school students who formed the Focus Group recommended the deletion of three items on the SciID Scale due to wording problems. One of these items had also been recommended for deletion by the Expert Panel. Each of these three items was deleted. Further revisions of wording were made to several questions so as to more accurately reflect a high school student's interpretation of those questions.

After the conclusion of the Expert Panel and Focus Group, 14 Exploration items and 20 Commitment items resulted, including three new Commitment items and 10 total revised items. These were used for the pilot study.

Pilot Study

Descriptive statistics were analyzed for each of the 34 questions on the 156 retained surveys. Three Exploration items were immediately removed due to excessive non-normality resulting from high means and low variability, insinuating low discrimination of the items. Descriptive statistics of the remaining 31 items are provided in Table 3.

Table 3

Descriptive Statistics (n=156)

Variable	*Mean*	*SD*	*Skewness*	*Kurtosis*
V1	3.37	1.52	-0.52	1.79
V2	4.35	0.91	-1.62	5.53
V3	3.74	1.19	-0.57	2.26
V4	4.21	0.99	-1.35	4.63
V5	3.87	1.14	-0.58	2.20
V6	3.70	1.31	-0.76	2.41
V7	3.53	1.41	-0.53	1.92
V8	4.15	1.04	-1.18	3.76
V9	4.15	1.02	-1.14	3.60
V10	3.08	1.48	-0.08	1.59
V11	3.99	1.24	-1.22	3.50
V12	3.92	1.11	-0.91	3.05
V13	3.53	1.12	-0.60	2.73
V14	3.67	1.13	-0.81	3.07
V15	3.58	1.05	-0.68	3.12
V16	3.74	1.05	-0.61	2.93
V17	3.16	1.40	-0.19	1.79
V18	4.18	0.82	-0.84	3.63
V19	3.72	1.11	-0.59	2.58
V20	3.85	1.07	-0.98	3.56
V21	3.19	1.24	-0.17	2.06
V22	2.89	1.16	0.04	2.25
V23	3.49	1.09	-0.52	2.67
V24	3.83	1.07	-0.93	3.49
V25	2.04	1.32	1.04	2.85
V26	3.54	1.35	-0.62	2.18
V27	3.44	1.18	-0.67	2.65
V28	3.31	1.17	-0.31	2.23
V29	3.74	1.16	-0.62	2.50
V30	2.93	1.44	-0.01	1.70
V31	3.32	1.34	-0.32	1.94

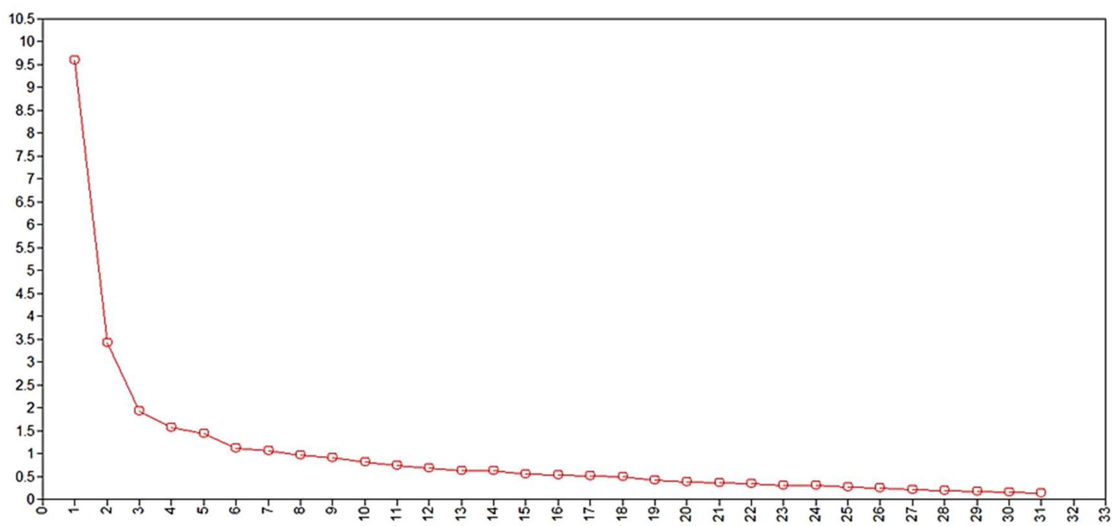
A sample correlation matrix was then observed (see Appendix B). Furthermore, the Bartlett Test of Sphericity p-value<.001 and Kayser-Meyer-Olkin Measure of

Sampling Adequacy (KMO)=.870 indicated sufficient evidence to pursue the identification of the underlying factor structure.

An EFA was conducted on the 31 items with a range of two to six factors. Initial results yielded all but one variable loading significantly onto one of the two hypothesized factors. However, the model fit was inadequate (X^2 p-value<.001, RMSEA=.095, CFI=.750, and SRMR=.074). Furthermore, the Scree Plot insinuated two strong factors underlying the data with high eigenvalues resulting before the elbow of the graph as illustrated in Figure 5.

Figure 5

Scree Plot of 31 Items



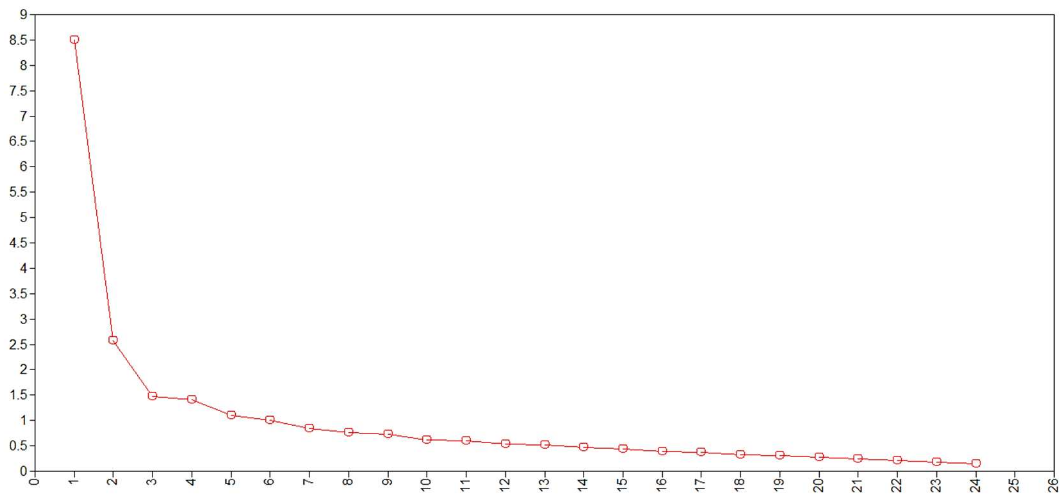
This gave reason to believe that there was a strong underlying 2-factor solution that was currently being disrupted by some potentially problematic items. The higher-factor solutions were problematic. Thus, questions were re-evaluated.

Upon re-examination of items, it was discovered that three of the Exploration items were written in present-tense (ex. “I don't like to spend time thinking about my future.”) while the remaining eight items were written in past tense (ex. “I have thought about what major (or certificate) I want to pursue in college.”). This was deemed problematic. Thus, these three items along with the item that had an insignificant loading were removed. A total of seven items remained for evaluation of Exploration. For the evaluation of Commitment, four items were initially deemed as problematic due to poor fit and significant cross-loadings. These items were deleted.

A new EFA varying from one to six factors was conducted using the seven Exploration items and 16 Commitment items. Initial results yielded Bartlett’s Test of Sphericity p-value<.001 and KMO=.883, indicating sufficient results to pursue the identification of the underlying factor structure. Results were again mixed, but pointed to a strong 2-factor solution underlying the model. The Scree Plot given in Figure 6 showed these two factors as being stronger than the others and occurring before the elbow of the graph.

Figure 6

Scree Plot of 23 Items



The 2-factor solution showed all significant loadings on each hypothesized factor with non-significant cross-loadings and a significant factor correlation of .362. However, the global-fit model statistics were still not entirely adequate (X^2 p-value<.001, RMSEA=.091, CFI=.794 and SRMR=.064). Notably, the five-factor solution showed some hints towards a potential bifactor model with all of the Exploration items loading significantly on one factor and the Commitment items loading significantly onto four factors. Global fit statistics were adequate for the 5-factor model (X^2 p-value<.001, RMSEA=.057, CFI=.941, and SRMR=.034). Factor correlations are given in Table 4.

Table 4

Geomin Factor Correlations

	1	2	3	4	5
1	1.000				
2	.205	1.000			
3	.279*	.620*	1.000		
4	.194	.370*	.532*	1.000	
5	.008	.307	.285	.239	1.000

Note. 1: Exploration, 2: Other's Recognition, 3: Performance, 4: Self-Recognition/Path, 5: Interest, * significant at 5% level

The Competence aspect dissolved in the analysis while a somewhat different aspect of Interest appeared. The Self-Recognition and Path aspects of Commitment were combined in the five-factor solution. Basically, Self-Recognition split into Interest and then Self-Recognition/Path. This makes sense as recognizing one's self as a science person would involve planning for the future. Four potential groupings for the Commitment factor thus emerged. This provided enough evidence to further investigate a potential bifactor structure for the Commitment scale.

Results of a bifactor EFA for the Commitment scale using the Bi-Geomin rotation method with two to five potential solutions yielded good global fits for each of the potential solutions with RMSEA<.05, CFI>.95, and SRMR<.05. However, factor loadings were problematic. Each solution yielded all significant factor loadings on the first general factor, but few significant loadings on any of the specific factors, indicating a very strong general factor. The solution with four specific factors was purposefully evaluated with results highlighted in Table 5 and Table 6. Global fit indices were good (X^2 p-value<.001, RMSEA=.044, CFI=.986, and SRMR=.020).

Table 5

Bi-Geomin Rotated Factor Loadings

	1	**2**	**3**	**4**	**5**
V14	0.645*	0.337*	-0.026	-0.027	-0.135
V15	0.705*	0.674*	-0.037	-0.010	0.007
V16	0.697*	0.325*	0.115	-0.018	-0.018
V17	0.658*	-0.036	0.035	0.401	-0.128
V18	0.507*	0.213	0.285	0.064	0.139
V19	0.744*	-0.092	0.332	0.057	0.092
V20	0.705*	-0.027	0.498	-0.109	-0.002
V22	0.766*	0.044	0.002	0.201	-0.019
V23	0.609*	-0.017	0.038	0.054	0.442*
V24	0.675*	-0.002	0.011	-0.063	0.595*
V25	0.469*	-0.088	-0.106	0.173	0.021
V26	0.424*	-0.011	-0.336*	-0.020	0.205
V27	0.766*	0.053	-0.049	-0.339	-0.085
V28	0.815*	-0.175	-0.173	-0.131	-0.003
V29	0.605*	-0.017	-0.027	0.467	0.104
V31	0.652*	0.134	0.014	0.466*	-0.071

Note. 1: Commitment, 2: Other's Recognition, 3: Performance, 4: Self-Recognition/Path, 5: Interest, * significant at 5% level

Table 6

Bi-Geomin Factor Correlations

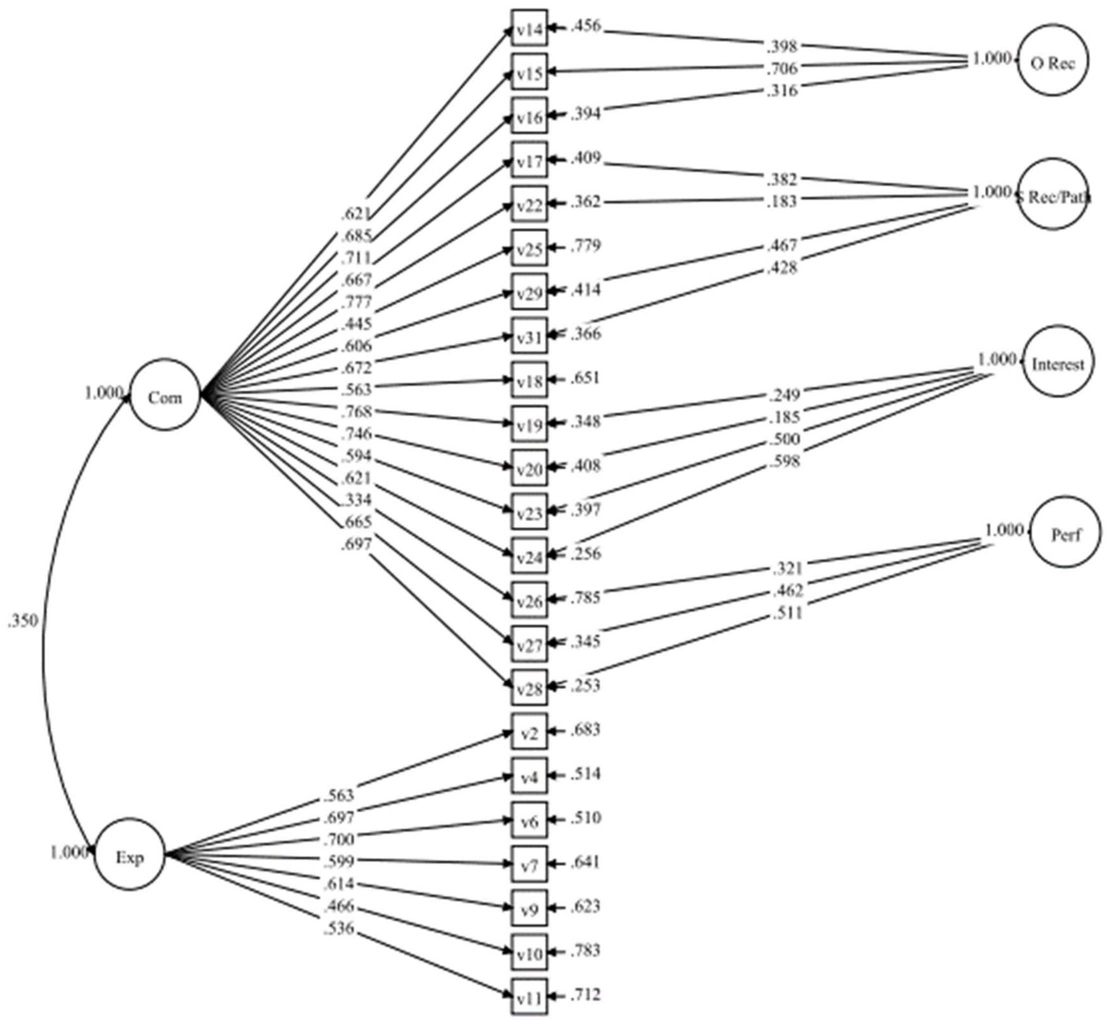
	1	2	3	4	5
1	1.000				
2	0.000*	1.000			
3	0.000*	0.004	1.000		
4	0.000*	-0.025	0.319*	1.000	
5	0.000*	-0.245	0.275	0.023	1.000

Note. 1: Exploration, 2: Other's Recognition, 3: Performance, 4: Self-Recognition/Path, 5: Interest, * significant at 5% level

Though an interesting investigation, there was not enough evidence to statistically provide reason to retain the bifactor structure. However, a CFA was run for the proposed bifactor model with 4 specific factors combined with the proposed Exploration scale. The model is provided in Figure 7 with only significant paths (*a*=.05) showing.

Figure 7

Bifactor Model



Results were adequate (X^2 p-value<.001, RMSEA=.067, CFI=.912, and SRMR=.064). However, two of the four proposed specific factors (Interest and Performance) showed insignificant variances (p=.401 and p=.164, respectively). Thus, only the specific factors of Other's Recognition and Self Recognition/Path were significant. This is in conjunction with what Carlone and Johnson (2007) discovered in stating that the components of Self-Recognition and Other's Recognition were the most critical for the development of a strong science identity, particularly in women. Modification indices deemed V27 ("I can explain science concepts in a way that my friends understand.") potentially problematic as it was suggested for cross-loading onto the Other's Recognition and Self-Recognition/Path specific factors (MI=18.215 and MI=11.880, respectively), along with having a correlated residual with V28 (MI=11.604). This variable should be further investigated.

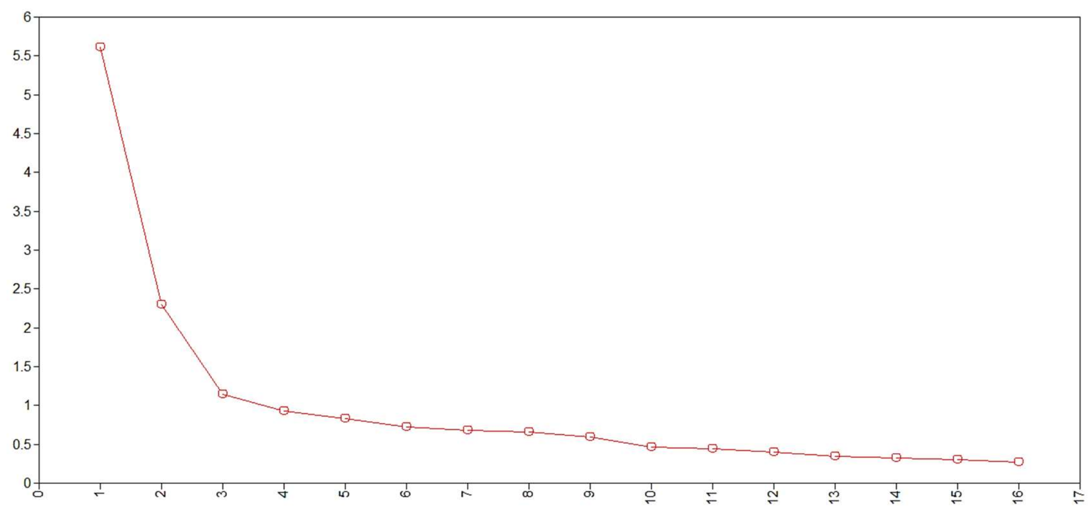
Statistical evidence and theoretical reason still pointed to an optimal, strong, 2-factor solution that was perhaps being somewhat compromised due to the inclusion of some poorly worded items or mimicking questions. Thus, the bifactor model with the four specific factors was not retained for this study. However, it should be kept in consideration for a follow-up study when confirming factor structure with a larger sample.

Upon re-examination of the 16 Commitment items, it was discovered that one of the items was subjective in nature and yielded poor discrimination (ex. "I work hard in my science class."). Several other items had similar meanings to one another (ex. "I enjoy learning about current events that involve science." "I like seeing how science is used in the real world."). For these, it was decided to retain only one of the items. The decision on which item to retain was based upon mean, variance, interpretability and ranking by Expert Panel and Focus Group members. This led to the deletion of five items. Expert Panel and Focus Group members previously had noted an item ("I like to participate in conversations/discussions that involve science topics.") as being potentially problematic as it might not accurately reflect a high school student's commitment to science. Their belief was that some high school students who were scientifically-oriented were also shy. Since other items remained that reflected that particular aspect of science Commitment, this item was also deleted. After this evaluation, a total of nine items remained for the Commitment dimension, with at least one item representing each of the five originally hypothesized aspects of Commitment.

A new EFA was conducted with the revised scale ranging from one to three factors. The Bartlett's Test of Sphericity p-value<.001 and KMO=.883 indicated strong evidence to pursue investigation of the underlying factor structure. The related Scree Plot is provided in Figure 8. The 2-factor model showed superior fit with all significant factor loadings for each item on their hypothesized factor and a significant factor correlation of .395. Global fit indices were adequate (X^2 p-value<.001, RMSEA=.062, CFI=.928, and SRMR=.048). Furthermore, the X^2 Difference Test yielded evidence in support of the 2-factor model compared to the 3-factor model with X^2 p-value=.0767.

Figure 8

Scree Plot of Final Model with 16 Items



Reliability and Validity Studies

The retained SciID Scale now had seven items representing the Exploration factor and nine items representing the Commitment factor (see Appendix C). The average interitem reliability was .783 and .8813 for the Exploration and Commitment scales, respectively. To further check the discriminant validity of the two-factor model, the unconstrained, significant, factor correlation of .395 between the two factors was constrained to 1.0 and then evaluated for model fit in comparison with the original model. The chi-square difference test using loglikelihood values resulted in a Satorra-Bentler scaled chi-square difference test value of 49.5 with associated p-value<.001. Thus, the models were not the same and the two factors should be allowed to covary.

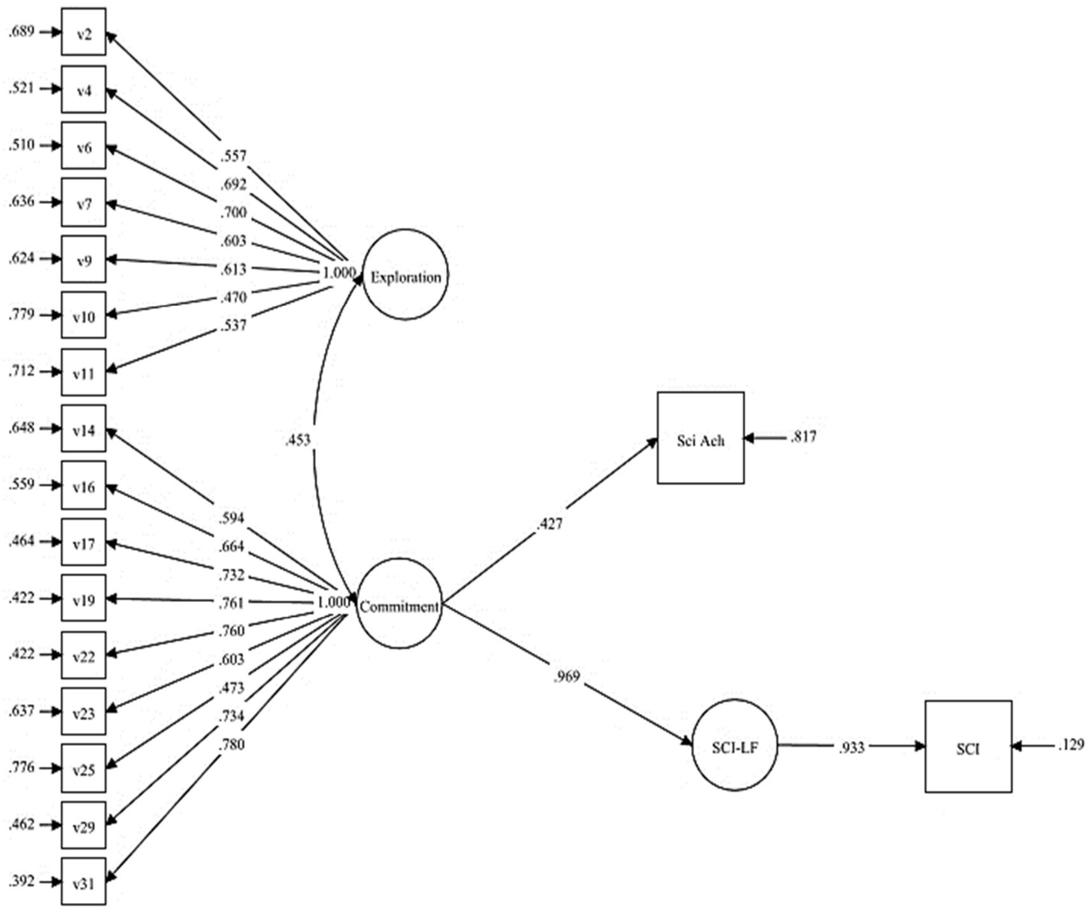
SEM was used to evaluate the strength of the hypothesized relationship between a student's Commitment to science with their Science Career Interest (SCI) and Science

Achievement (Sci Ach). The model used SEM to confirm the relationships between a student's Commitment to science and their SCI and Sci Ach.

First, all standardized factor loadings per SciID variables on their appropriate factor were significant ($p<.001$). Furthermore, all variables' R^2 values were significant with $p<.01$ for the Exploration factor and $p<.001$ for the Commitment factor suggesting that each observed variable has a significant amount of its variance explained by its related latent factor. The model confirming the relationship between science Commitment, SCI and Sci Ach with standardized results is highlighted in Figure 9 with all paths significant ($\alpha=.05$) and adequate global fit statistics (X^2 p-value<.001, RMSEA=.058, CFI=.929, and SRMR=.058).

Figure 9

SEM of Science Identity with Science Achievement and STEM Career Interest (all paths significant a=.05)

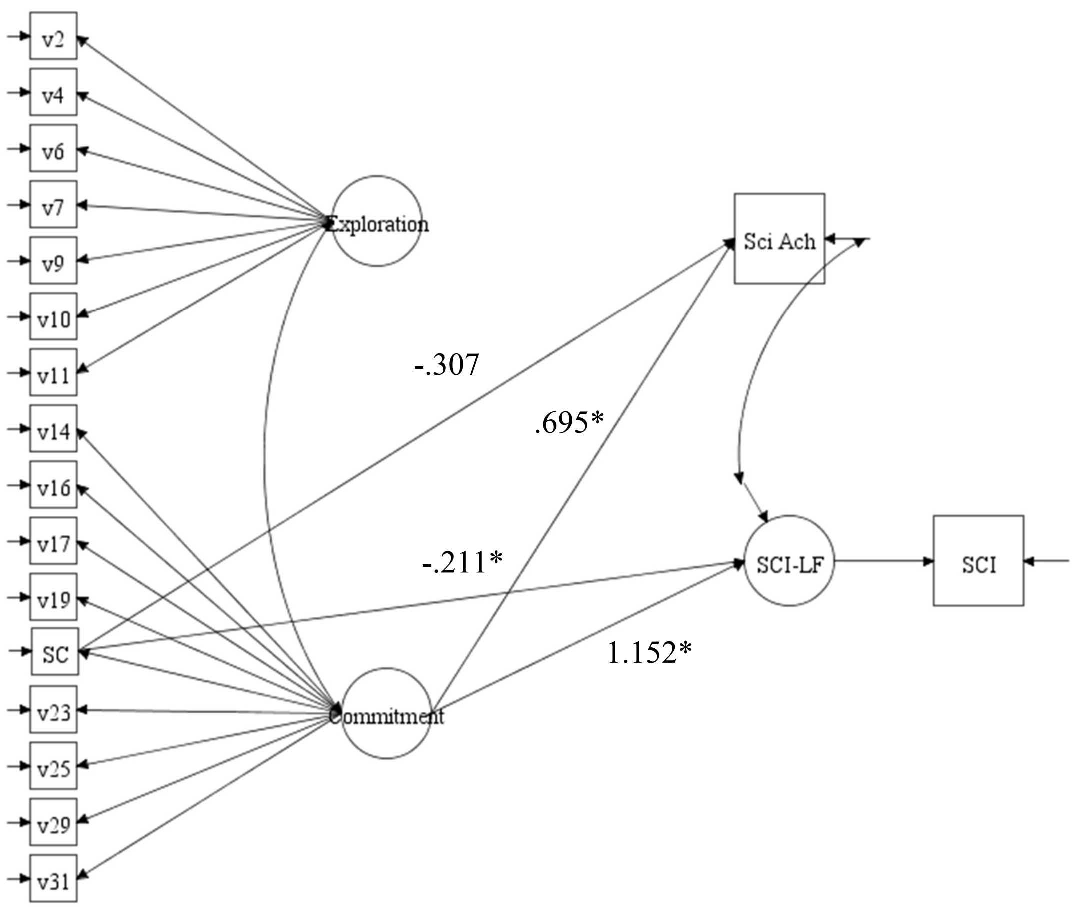


Results indicated strong evidence in support of positive, predictive nature of the Commitment factor of the SciID Scale to students' Science Career Interest and Science Achievement. The Exploration factor was not believed to be predictive of student's Science Career Interest or Science Achievement due to the general nature of its definition and the specific nature of the other variables. This was tested in a follow-up model using SEM and both paths from Exploration to Science Career Interest and Science Achievement were deemed insignificant (p=.335 and p=.185, respectively).

For testing the divergent validity of Science Identity with Science Self-Concept, the model in Figure 10 where $\beta_1$and β_2 were freely estimated was compared to the model where these paths were constrained to equal the corresponding paths from Commitment to Sci Ach and SCI-LF (β_1^* and β_2^*, respectively).

Figure 10

Unconstrained SEM with Standardized Coefficients Used for Testing Divergent Validity of Science Identity and Science Self-Concept



Note: * *p<.05*

A Satorra-Bentler correction for the chi-square difference test was calculated ($X^2(1)$=68.461, p<.001). This result indicated that the constrained model was too constricting for the data. Thus, a student's science self-concept was not equivalent to their science Commitment and, hence, their science identity. Furthermore, a baseline model constraining the paths from Commitment to Sci Ach and SCI-LF (β_1^* and β_2^*, respectively) to zero was estimated and R^2 values for Sci Ach and SCI-LF were observed (R^2=.060, p=.151 and R^2=.495, p<.001, respectively). Next, the R^2 values for Sci Ach and SCI-LF for the unconstrained model provided in Figure 10 were observed (R^2= .238 and R^2=.985, respectively) with both being significant (p<.01). This led to R^2 changes of .178 for Sci Ach and .49 for SCI-LF between the baseline model and the unconstrained model, insinuating a substantial more amount of the variance of these two factors was explained by the Commitment factor than by Science Self-Concept itself. Indeed, a student's science identity was a significantly better predictor of both their science achievement and their science career interest.

Furthermore, a follow-up path analysis was conducted to test Chang et al.'s (2019) findings that a student's science identity and calculus plans in high school were substantial predictors of their pursuit of STEM majors. Calculus plans were indeed a significant predictor of STEM career interest, with a significant path value of .136 (p=.004). In conjunction with Chang et al. (2019), the model substantiated that a student's Commitment to science (p<.001) and plans to take Calculus in high school (p=.004) were significant predictors of their interest in science careers, with Total R^2 value of .888 (p<.001). Gender and minority status were included in a further analysis. Neither were found to be significant predictors of science career interest (p=.265 and p=.069, respectively). These results warrant further investigation.

A latent class analysis was conducted based upon the level of Exploration and Commitment a student demonstrated. Exploration and Commitment scores were transformed into z-scores and then used for the analysis. Results are given in Table 7. Evidence in conjunction with theory suggested the four-class solution was representative of the data.

Table 7

Science Identity LCA Results

	2-Classes	3-Classes	4-Classes	5-Classes
AIC	871.824	868.596	**862.158**	856.493
BIC	893.173	899.094	**901.806**	905.291
SABIC	871.016	867.441	**860.657**	854.646
VLMR Test (p-value)*	26.583 (.0092)	9.228 (.1351)	**12.038 (.0474)**	11.665 (.0848)
ALMR Test (p-value)*	24.937 (.0120)	8.657 (.1518)	**11.668 (.0570)**	10.943 (.0984)
BLRT (p-value)*	26.583 (<.001)	9.228 (.1053)	**12.438 (.0128)**	11.665 (.0500)
Entropy	.693	.591	**.726**	.803
Class Size	121/35	26/92/38	**9/18/94/35**	31/4/9/74/38

The four-class solution was further investigated as seen in Table 8. Graphical representations of the classes and their related means on Exploration and Commitment are provided in Figure 11.

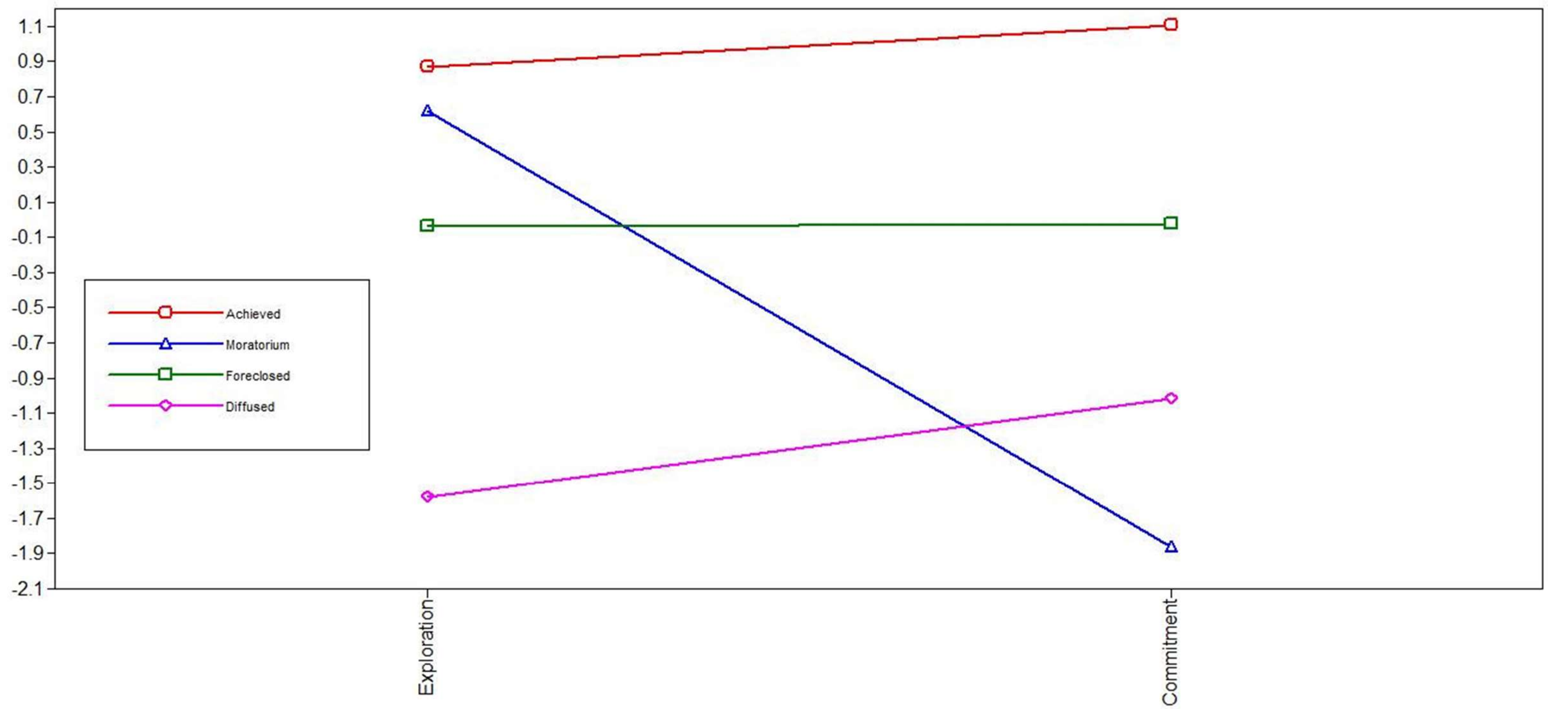
Table 8

Descriptive Statistics of 4-Class Solution

	n	Exploration Mean (Z-Score)	Commitment Mean (Z-Score)
Achieved (Class 1)	35	.865	1.102
Moratorium (Class 2)	9	.618	-1.862
Foreclosed (Class 3)	94	-.035	-.027
Diffused (Class 4)	18	-1.580	-1.020

Figure 11

Graphical Representation of 4-Class Solution with Related Z-Score Converted Means



Multivariate analyses of variance (MANOVA) with Tukey post hoc tests on the Z-scores of the identity dimensions revealed that the four-class solution explained 60% of the variance in Exploration and 70% of the variance in Commitment. All z-score class means were significantly different on the Commitment dimension ($F=117.18$, $p<.001$) and all but the Achieved and Moratorium classes differed significantly on the Exploration dimension ($F=77.15$, $p<.001$).

Demographic statistics of the four classes are presented in Table 9.

Table 9

Demographic Statistics of the 4-Classes

	Achieved	Foreclosed	Moratorium	Diffused
Male	17%	40%	33%	61%
Minority	29%	41%	56%	61%
Low SES	40%	44%	66%	61%
1st Generation College Student	40%	37%	44%	39%

Furthermore, a regression analysis revealed that student Science Career Interest (SCI) measured on a 5-point scale was significantly predicted by student class assignment ($F=67.24$, p-value$<.001$, and Total $R^2=.5703$). Results revealed that the Achieved class showed the greatest SCI at 4.47 ($p<.001$) followed by Foreclosed at 3.67 ($p<.001$), Diffused at 2.93 ($p=.002$) and Moratorium at 2.29 ($p<.001$).

A Chi-Square Test was used to determine if there was a difference between classifications of students' Academic Identity Status and Science Identity Status. With

X^2=24.31 and p=.004, there was indeed a difference in the proportions of students within classifications pertaining to these domains. As seen in Table 10, of those being given an AIM classification of Moratorium or Diffused (n=53) demonstrating low Commitment to academics in general, a total of 37 of these were classified as Foreclosed or Achieved on the ScID Scale insinuating a high Commitment to science. This is suggestive of the distinguishable nature of the Science Identity from the Academic Identity as was hypothesized.

Table 10

AIM and SciID Scale Classifications

SciID Scale	**AIM**				
	Diffused	Moratorium	Foreclosed	Achieved	**Total**
Diffused	7	5	2	4	**18**
Moratorium	2	2	2	3	**9**
Foreclosed	6	23	29	36	**94**
Achieved	1	7	9	18	**35**
Total	**16**	**37**	**42**	**61**	**156**

CHAPTER V

CONCLUSION

Discussion

The purpose of this study was to develop and validate a sound instrument that accurately measures a high school student's science identity. In an effort to fulfill this purpose, the following research questions were addressed:

4. What is the factor structure of science identity?

5. Is the newly developed SciID Scale a valid and reliable instrument?

Rooted in traditional identity theory, science identity was believed to be a two-dimensional construct; thus, reflecting the interplay of Exploration and Commitment. Though some research produced by Crocetti et al. (2008) attempted to broaden the dimensionality of traditional identity theory, this research was not found to be an accurate representation of the construct. The development of the "new" third dimension of Reconsideration of Commitment/Exploration in Breadth more accurately reflects Marcia's (1966) original dimension of Exploration. Crocetti et al.'s (2008) Exploration in Depth dimension is indeed the dimension that diverges from traditional identity theory. This Exploration in Depth dimension is believed to be captured by a theoretically sound Commitment dimension, as it reflects a student's level of performance/path. Thus, this managing of commitments theory produced by Crocetti et al. (2008), though interesting, was not used for this study.

Through a series of factor analyses and scale revisions, this hypothesis was confirmed. The two-factor model fit the data well and demonstrated a discriminant, though covaried, nature of the two factors. Furthermore, a 4-class solution was extracted from the data to reflect the traditional identity statuses of Achieved, Foreclosed, Moratorium, and Diffused.

Through path analyses, the SciID Scale showed convergent validity with students' STEM career interest and science achievement. Furthermore, the HSLS findings were also confirmed that highlighted a student's science identity and calculus plans in high school as being significant predictors of their pursuit of a STEM career. Moreover, divergent validity was shown between academic identity and science identity through the diverging of student status assignment on the two constructs.

With good internal consistency measures of the Exploration and Commitment scales and the substantiation of convergent and divergent validity of the SciID Scale, it is believed that the SciID Scale is indeed a valid and reliable instrument.

Implications for Future Research

The findings from this study pose several implications for future research regarding science identity. The emergence of the four-class solution is perhaps the most vital aspect to this research. A larger field-test of the instrument is needed where the four-class solution can be thoroughly investigated. Assuming this optimal solution reemerges, this opens-up a tremendous amount of research capabilities regarding science identity. The accurate classification of students within science identity status allows for a thorough investigation into:

- What events have led students into these statuses?
- How do these statuses differ in relation to external variables?
- Do the five aspects of Commitment differ depending upon classification?
- What is the stability of these classifications over time?
- What predictive relationship do these statuses have with STEM career pursuit?
- Do women and minorities constitute greater proportions of certain classes?

These are just a few of the questions available for future research.

Limitations

An important limitation of this study that must be addressed is the time at which the pilot study was conducted. The pilot study occurred during the beginning of the COVID-19 pandemic. Thus, it must be taken into consideration that some questions on the Commitment portion of the scale might have received heightened responses due to the centrality of the pandemic. For instance, the item "I enjoy learning about current events that involve science." might reflect a higher average student response than what would have occurred if the survey was administered before the pandemic began. However, it is difficult to know how the pandemic will shape our world for the future. Thus, this question and others that are similar need to be monitored over-time to gain a more accurate view of actual student response.

Continuing with the impact of the pandemic, all pilot study measures were conducted via electronic means. This could also introduce some bias into the study as there were certainly students who were unable to connect to the survey. Though attempts were made to have students of all ethnic and racial backgrounds, all SES levels, and all academic achievement levels complete the survey, certainly this was not entirely feasible. A much larger study is needed that can help to reduce some of the potential bias introduced into this research due to its electronic nature.

Another limitation of this study was the unexpected removal of three questions from the Exploration scale due to verb-tense. The discrepancy in verb-tense was simply missed by the research team and Expert Panel. Though this scale was deemed valid and reliable, the inclusion of an additional two or three quality items would likely increase the scale's discrimination and reliability. Increasing the discriminative nature of this scale should aid in the distinguishability of means between the Achieved and Moratorium classes, and further separate them from the Foreclosed class as well. This would likely decrease the relatively high percentage of students being classified as Foreclosed. This should be accomplished and tested in a larger field-test.

Lastly, this study was conducted with a rural school district and cannot be generalized across all districts. A larger study with a more diverse sample would be beneficial.

Concluding Remarks

The call for reform in STEM education remains an urgent call. The novelty of the COVID-19 pandemic has made this call dire. Before the pandemic, employment in STEM-related occupations was projected to grow an estimated 8.9% by 2024 (Noonan, 2017). One can only conjecture what those numbers will be now. Alarmingly, however, the STEM pipeline remains unstable. Given that a high school student's "science identity" is the single-best predictor of their pursuit of a STEM degree, it is imperative that a valid, reliable and measurement invariant instrument is created that accurately assesses this construct. Though a larger field-test is needed in the future, preliminary EFA findings along with other convergent and divergent evidence indicates that the SciID Scale is a valid and reliable instrument that does indeed accurately measure a high school student's standing on this construct. The soundness of this instrument will enable policy makers and practitioners to design more effective intervention programs aimed at cultivating high school students' science identity. The culmination of this effort will serve to increase the future STEM workforce and reduce the leak in the STEM pipeline.

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APPENDIX A

TABLE OF REVIEWED STUDIES

Author(s) (Year)	Cultural context & population (*n*=number of respondents)	Description of the instrument	Underlying theoretical framework	Reliability scores (*α*) & validity (content, construct, discriminant)	Adopted and/or modified questionnaires	Focus of the study
1. Chemers et. al. (2011)	Undergraduate students (*n*=327) and graduate students (*n*=338)	Identity as a scientist part of a larger instrument. 6 items, 5-point-Likert scale (strongly agree to strongly disagree)	Influenced by Erickson (1968), Arnett (2004), and Syed et al. (2008) – not specific about science	α =.89 undergraduates, α =90 graduates, validity not stated	Adopted items from Sellers et al. (1998) – racial identity, Luhtanen and Crocker -self-esteem (1992), and Chemers et al. (2010) – unable to locate.	Predictor/mediator variable. Explore factors that mediate relationship between science support experiences and science career.

Author(s) (Year)	Cultural context & population (*n*=number of respondents)	Description of the instrument	Underlying theoretical framework	Reliability scores (α) & validity (content, construct, discriminant)	Adopted and/or modified questionnaires	Focus of the study
2. Syed et al. (2018)	Undergraduate STEM majors (*n*=502)	Identity as a scientist part of a larger instrument. 13 items, 5-point-Likert scale (strongly agree to strongly disagree)	Carlone and Johnson (2007) – multidimensional construct based on competence, performance and recognition; Chemers et al. (2011) – sense of fit	α =.89, Construct validity with CFA: CFI=.99, RMSEA=.07, SRMR=.02	Adopted items from Sellers et al. (1998) – racial identity (7 items), Luhtanen and Crocker (1992) -self-esteem (2 items), and Chemers et al. (2010) – unable to locate.	Mediation of science efficacy and identity between science support experiences and science career and exploration of moderation by gender and URM
3. Robinson et al. (2018)	Undergraduate students (*n*=1,023)	Science identity: 4 items, 5-point Likert scale (strongly agree to disagree)	Influenced by work of Eccles (1983, 2009) on expectancy value theory	α = .83-.90 Validity not stated.	Adopted science identity items from Pugh et al. (2009) and attainment value scale items by Conley (2012)	Science identity trajectories, not science identity itself. Science identity not explicitly defined.

Author(s) (Year)	Cultural context & population (*n*=number of respondents)	Description of the instrument	Underlying theoretical framework	Reliability scores (α) & validity (content, construct, discriminant)	Adopted and/or modified questionnaires	Focus of the study
4. Pugh et al. (2009)	High school biology students (*n*=166)	Science identity: 4 items, 5-point Likert scale (strongly agree to disagree)	Focus on transformative experiences; identity is based on theory of "this is who I am" and "this is who I can become" (Markus and Nurius, 1986),	α=.93, Content validity – cognitive interviews with six students. Science identity part of larger instrument where overall four-factor model of the survey was tested and deemed valid using CFA and EFA (CFI=.95, SRMR=.05).	None	Prevalence of transformative experiences, antecedents (science identity and goal orientation) of transformative experiences, relation between transformative experience and deep-level learning in biology

Author(s) (Year)	Cultural context & population (*n*=number of respondents)	Description of the instrument	Underlying theoretical framework	Reliability scores (α) & validity (content, construct, discriminant)	Adopted and/or modified questionnaires	Focus of the study
5. Hill et al. (2018)	Middle school students (*n*=441)	Science self id: 1 item (How much do you think you are a science kind of person?), 4-point Likert scale; Science other id: 1 item (How much do you think other people see you as a science kind of person?), 4-point Likert scale	Built upon social and cognitive theories of identity; Gee (2000)-science kind of person; Carlone and Johnoson (2007); split science self id and science others id	Not explicitly stated; science self and other identity used as part of a larger validated model regarding discovery orientation	None	Relationship between discovery orientation and science identity, and the mediation of the relationship by science interest, importance, perceived ability and self-reflected appraisal. Examine differences in these relationships between gender and ethnicity.

Author(s) (Year)	Cultural context & population (*n*=number of respondents)	Description of the instrument	Underlying theoretical framework	Reliability scores (α) & validity (content, construct, discriminant)	Adopted and/or modified questionnaires	Focus of the study
6. Fraser et al. (2014)	Teenagers (*n*=1502)	Fourteen items, 5-point Likert scale (strongly agree to strongly disagree).	Based upon Carlone and Johnson's (2007) work	Not stated	None	Explore associations amongst science identity, science understanding, and gaming preference.
7. Skinner et al. (2017)	Undergraduate students (*n*=1013)	Thirteen items, 5-point Likert scale (strongly agree to strongly disagree).	Self-determination theory basis of entire study	α=.80 to .87; discriminant validity low between science identity and relatedness (correlation of .740 and .703). Construct validity with CFA.	None	Self-determination theory of motivation. Identity as a scientist - deeply held view of self and potential to enjoy and succeed in science.

Author(s) (Year)	Cultural context & population (*n*=number of respondents)	Description of the instrument	Underlying theoretical framework	Reliability scores (α) & validity (content, construct, discriminant)	Adopted and/or modified questionnaires	Focus of the study
8. Williams et al. (2018)	Middle school students (*n*=113)	Nine items, 5-point Likert scale (strongly agree to strongly disagree)	Self-determination theory	α=.90 to .92; validity not discussed	All items adopted from Saxton et al.'s (2014) measure on academic identity	Role of students' views of themselves as competent, related, and autonomous, as well as their engagement and re-engagement in the garden, as potential pathways by which garden-based science activities can shape science motivation, learning, and academic identity in science.

Author(s) (Year)	Cultural context & population (*n*=number of respondents)	Description of the instrument	Underlying theoretical framework	Reliability scores (α) & validity (content, construct, discriminant)	Adopted and/or modified questionnaires	Focus of the study
9. Hazari et al. (2013)	Undergraduates (*n*=7505)	One item (three versions), 6-point Likert scale (not at all to very much)	Not explicitly provided.	No reliability information provided. Criterion related validity tested (adjusted R^2 ranged from .30 to .40)	Items adapted from PRISE survey (unable to locate reliability or validity information on the survey)	Examining student self-perceptions of science across gender and ethnicity and across subject-specific science disciplines.
10. White et al. (2019)	Undergraduate African American students (*n*=347)	Uses science ID scale by Chemers et al. (2011)				
11. Robinson et al. (2019)	Undergraduate students (*n*=1669)	Uses science ID scale by Robinson et al. (2018)				

APPENDIX B

CORRELATION MATRIX OF 31 ORIGINAL ITEMS

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18	V19	V20	V21	V22	V23	V24	V25	V26	V27	V28	V29	V30	V31
V1	1																														
V2	-0.061	1																													
V3	-0.1737	0.2982	1																												
V4	-0.0733	0.544	0.2774	1																											
V5	-0.0949	0.3626	0.4532	0.4325	1																										
V6	0.0233	0.3526	0.2985	0.4813	0.3923	1																									
V7	0.0999	0.2712	0.1626	0.4104	0.3673	0.4288	1																								
V8	0.0051	0.4192	0.5789	0.4083	0.5165	0.4331	0.2319	1																							
V9	0.184	0.3002	0.1976	0.3878	0.2398	0.5201	0.3109	0.3001	1																						
V10	0.1768	0.1987	0.1948	0.204	0.1554	0.3534	0.3421	0.2064	0.3237	1																					
V11	0.0563	0.2131	0.3378	0.3857	0.2473	0.3328	0.3765	0.4289	0.3067	0.3766	1																				
V12	-0.1692	0.232	0.3799	0.139	0.2972	0.2081	0.1641	0.2575	0.119	0.0743	0.1872	1																			
V13	0.0331	0.2197	0.1527	0.1603	0.2808	0.1146	0.1331	0.1856	0.137	0.1428	0.1569	0.0671	1																		
V14	0.1228	0.1808	0.1103	0.1543	0.1462	0.1506	0.2181	0.1258	0.1942	0.1919	0.3121	0.2858	0.1848	1																	
V15	0.1459	0.2429	0.1502	0.1296	0.2108	0.1359	0.2293	0.1546	0.1804	0.1778	0.2653	0.3439	0.2751	0.706	1																
V16	0.0793	0.2889	0.1538	0.1576	0.2298	0.1025	0.2745	0.1784	0.1507	0.0953	0.1673	0.3397	0.2598	0.5577	0.7101	1															
V17	0.0269	0.2373	0.052	0.1519	0.1472	0.1841	0.1597	0.0406	0.1715	0.1305	0.194	0.1367	0.1637	0.4602	0.4434	0.4824	1														
V18	-0.0064	0.3041	0.2283	0.2164	0.3188	0.2862	0.2716	0.3186	0.1987	0.1272	0.1996	0.4078	0.313	0.337	0.4646	0.43	0.3415	1													
V19	0.0577	0.2571	0.0672	0.2713	0.2455	0.0962	0.1737	0.1836	0.2142	0.068	0.1113	0.2416	0.2883	0.4187	0.4317	0.5166	0.5545	0.5261	1												
V20	0.1102	0.3122	0.1159	0.1037	0.2158	0.1181	0.1651	0.2944	0.1922	0.117	0.2036	0.3081	0.3115	0.405	0.4673	0.5363	0.4753	0.4893	0.6992	1											
V21	-0.0536	0.2039	0.0942	0.0993	0.1646	0.1658	0.0732	0.0882	-0.0584	0.21	-0.0034	0.3578	0.2689	0.2233	0.2832	0.2497	0.2688	0.3183	0.3617	0.3472	1										
V22	0.1039	0.2563	-0.077	0.1611	0.0968	0.1739	0.2377	0.0949	0.2215	0.1968	0.1665	0.2186	0.2354	0.5252	0.5657	0.5442	0.6156	0.3838	0.5482	0.5848	0.3884	1									
V23	0.1061	0.2274	0.0672	0.1784	0.1727	0.1391	0.1597	0.1899	0.273	0.0723	0.1074	0.1291	0.2465	0.302	0.3372	0.3899	0.3739	0.4373	0.5548	0.5104	0.1377	0.5378	1								
V24	0.0338	0.2581	0.1441	0.2586	0.2042	0.111	0.2127	0.1338	0.3357	0.1584	0.1015	0.297	0.28	0.301	0.3775	0.4313	0.3702	0.4189	0.6215	0.5618	0.189	0.4804	0.6822	1							
V25	0.1077	0.0722	-0.075	0.111	0.0427	0.0599	0.2232	-0.0663	0.1666	0.2154	0.1621	-0.0194	0.1675	0.2473	0.2686	0.2634	0.4068	0.2201	0.3556	0.3235	0.0737	0.3706	0.2842	0.3154	1						
V26	0.1322	0.2039	-0.0129	0.2558	0.1616	0.1551	0.2625	0.0642	0.3638	0.1625	0.1644	0.0733	0.1489	0.2821	0.2673	0.2487	0.1614	0.1157	0.262	0.1562	0.0046	0.2862	0.3	0.3533	0.3333	1					
V27	0.1289	0.1831	0.0631	0.0243	0.1743	0.049	0.1658	0.0969	0.2368	0.2086	0.0991	0.2882	0.3244	0.5577	0.602	0.5689	0.3578	0.3591	0.4737	0.4765	0.1771	0.5077	0.3667	0.4666	0.2764	0.3776	1				
V28	0.0659	0.101	-0.0626	0.1039	0.1681	0.0327	0.1579	-0.0402	0.2129	0.1684	0.122	0.1691	0.3511	0.4589	0.4702	0.4751	0.4533	0.2859	0.5405	0.4918	0.227	0.5843	0.4808	0.5527	0.3919	0.3978	0.6977	1			
V29	0.0183	0.2523	0.1244	0.2061	0.2424	0.2403	0.2751	0.1038	0.1975	0.0794	0.1384	0.183	0.1438	0.2933	0.3785	0.4468	0.5856	0.419	0.5479	0.4292	0.2051	0.537	0.4075	0.4584	0.2984	0.224	0.3115	0.4139	1		
V30	0.006	0.1951	-0.0484	0.1867	0.191	0.1319	0.1583	0.0937	0.1211	0.1443	0.1228	0.125	0.2	0.417	0.4219	0.3918	0.6883	0.4226	0.6073	0.5228	0.3399	0.6921	0.4193	0.4228	0.4249	0.2385	0.3705	0.4804	0.6837	1	
V31	0.0913	0.3023	0.0074	0.2453	0.2066	0.1508	0.2866	0.1921	0.138	0.1694	0.2662	0.1523	0.127	0.4572	0.5448	0.4889	0.5941	0.4494	0.5508	0.4747	0.2673	0.5978	0.3865	0.348	0.36	0.206	0.346	0.4341	0.6199	0.7235	1

APPENDIX C

SCIID SCALE

Exploration - Period of engagement in choosing among meaningful alternatives to science.

2. I have thought about what I want to do after high school.

4. I have thought about what major (or certificate) I want to pursue in college.

6. I have researched different college majors (or certificates) online.

7. I have talked with someone about a college major (or certificate) that I am interested in.

9. I have researched different careers online.

10. I have talked with a professional in a career that I am interested in about what they do in their job.

11. I have asked someone what they think of me pursuing a particular career.

Commitment - Degree of personal investment in/to science that the individual exhibits.

14. My friends ask me to help them with their science homework.

16. My parents think I am good at science.

17. Other people expect me to pursue some type of science career (ex: healthcare, forensics, ecologist, environmentalist, computer science, meteorology, veterinarian, Chemist, Chemical Engineer, Biologist, etc…)

19. I want to learn more about science.

22. I view myself as a science person.

23. I enjoy learning about current events that involve science.

25. I am involved in an extra-curricular science activity.

29. I will use some form of science in my future career.

31. Science will be a part of my future after high school.