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Identity Complexes and Science Identity in Early Secondary: Mono-topical or in Combination with Other Topical Identities

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Abstract
Prior research suggests that students endorsing a science identity are more likely to participate in optional science experiences and choose STEM careers. Science identity is a topical identity, which refers to an identity related to a topic rather than a social or cultural group. However, studies of topical identities typically examine them in isolation. The current study identified typically occurring combinations of topical identities as identity complexes to determine whether science identity would tend to occur within STEM-only complexes or together within larger topical identity complexes. Over 1200 urban public-school students in 6th, 7th, and 9th grades from two different regions in the USA completed surveys asking about their topical identities, choice preferences, and optional science experiences. Latent class analyses revealed that students often endorse science identities in the context of other unrelated identities like athletic and artistic identities. Further, the frequency (overall and relative to each other) of the two high-science identity complexes varied substantially by gender, ethnicity, and grade. These patterns were not simple reflects of the commonly observed overall rates of science identity by demographics. Further, students in topical complexes with high science identity still had high participation in optional science experiences despite having many topical identities that could compete for time.

Keywords Science identity · Equity · Gender · Race · Secondary school · Science experiences

Introduction

A recent report on Women, Minorities, and Persons with Disabilities in Science and Engineering makes clear that science is still far from having an equitable distribution by gender,

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ethnicities, and disabilities (National Science Foundation and National Center for Science and Engineering Statistics 2017). In trying to explain differential persistence within science trajectories by demographic factors, many scholars have highlighted having a science identity as particularly important (Archer et al. 2010; Barton et al. 2013). Identity can be generally defined as the composition of self-views that emerge from participation in certain activities and self-categorization in terms of membership in particular communities or roles (Stets and Burke 2000). Our conceptualization of science identity is focused upon the self-views that emerge from participation in certain activities and self-categorization in terms of membership in particular communities or roles (Stets and Burke 2000). More generally, research has suggested that science not only involves whether an individual wants to become a "science-type person" but also as the socialization of individuals into the norms and discourse practices of science (Brown 2006). That is, identity is built through an internalization of experiences and is socially constructed with others in a particular context. Science identity is then be enacted through the expression of knowledge and choices people make (Aschbacher et al. 2010). Furthermore, science identity is a topical identity, which refers to an identity related to a topic rather than a social or cultural group. That is, we define topical identities as those that develop through experiences and related to specific areas of knowledge rather than those ascribed/imposed based on innate characteristics.

Closely connected to categorization into identities, there are also socio-cultural conditions that shape possible or expected roles of individuals due to personal attributes or characteristics. For example, there are expectations imposed on people due to their gender (Archer et al. 2013) and race (Fordham and Ogbu 1986). Therefore, an individual's identities are a constant negotiation of their goals, cultural expectations, and the different social identities they chose to endorse. Importantly, one individual has many identities including the possibility of multiple topical identities, henceforth called *identity complexes*. Little is known about which identity complexes tend to occur nor the consequences of endorsing multiple topical identities on later choices and development.

Researching identity complexes is important because before children develop career aspirations, they perceive and internalize ideas about professions, race, and expected social roles from their parents (Archer et al. 2013), the media (Steinke et al. 2012), and environment (Adams et al. 2014). These pressures may make certain identity complexes more likely to occur overall as well as more (or less) accessible to certain children. The primary objective of the current study is to characterize typical identity complexes and who endorses them among early secondary students. Of particular importance is understanding relative topical complex frequency and their demographic distribution that reflect the overlapping and interdependent systems of disadvantage in science across gender and race (Barton and Tan 2010; Carlone and Johnson 2007; Chang et al. 2011).

Topical Identity Complexes

Topical identity refers to self-classification or perceived recognition as someone that has access and participates in distinctive experiences, practices, and behaviors related to a specific topic.

Topical identities exist at many grain sizes. The ones that have been traditionally studied include discipline-specific topical identities (e.g., math, science, art), subdiscipline level (e.g., physics identity), or research area identities (e.g., high-energy physicist). Regardless of the grain size, particular topical identities are typically studied in isolation (Harrison et al. 2011; Kelly-McHale 2013; Langdon and Petracca 2010). Indeed, some individuals need to develop a unique topical identity when pursuing elite performance levels. However, the majority of people are likely to have fewer extreme requirements for basic identity development and therefore can develop identities related to multiple topics. An identity complex refers to the bundling of different identities as part of one's core self. Further, this framing recognizes that these different identities may interact with one another and the whole may have consequences for further participation and choices. In this study, we propose a way of studying topical identities at this larger grain size: topical identity complex. Topical identity complexes involve combinations of topical identities within a level (e.g., discipline, subdiscipline); they allow an individual to be multi-faceted and yet not generically everything.

But little is known about the likelihood of, nor consequences of, endorsing multiple topical identities on later choices and development. Endorsing multiple topical identities could have a synergistic effect around natural clusters like science and math, where the expectations for behaviors and knowledge have a large overlap. Endorsing multiple identities could also have a conflicting effect like art and sports which have little overlap in underlying skills and yet both require substantial time commitments to reach proficiency. Clashes can also exist if the topical identities are associated with different stereotypical characteristics and behaviors (e.g., introvert or extrovert; physically strong or physically weak). However, having multiple identities could also help people buffer social pressure when endorsing identities that go against cultural expectations. For example, girls that have scientific and artistic identities might use the artistic identity to showcase they do have feminine attributes.

Topical Identity Complexes in Early Secondary School

After primary school, students often transition from the fantasy phase to a phase during which a combination of perceived ability and external messages increasingly influence possible career paths (Auger et al. 2005). This increasing role of perceptions of ability and external messages may lead to a narrowing of topical identities (and possible career paths) during the secondary school years. Indeed, from such external messaging, secondary students may endorse a mono-topic identity complex, and likely one that does not involve STEM (e.g., artistic or athletic). However, the environment also includes aspects that could support having multiple topical identities (such as informal learning opportunities), especially ones that include STEM (e.g., STEM+Athletic).

Furthermore, students are required to take science in the early secondary school years, providing opportunities to include science in their topical identity complex despite earlier conceptions built without experience. Specifically, in the American context, early secondary is the specific window of time during which all students learn foundational science content, but it is also before students make elective choices enroll in more advanced science courses. Since identity will likely drive choices in later high school course taking, studying topical identity complexes during this developmental period is important. Further, the use of the topical identity complex as an analytic frame can provide new views on patterns of participation in science, new views on how science identities might grow, and new views of systemic inequities in science. For example, if students have only science or only STEM topics in their topical identity complex, there is no conflict in choices, but if science or STEM typically occurs alongside other topical identities, there may be conflict in which choices are made, such as optional course enrollment or after school club participation.

In addition, there may be additional pressures to combine “unlike” topics. If students have topical identities that generally have negative stereotypes in popular culture (e.g., math and science as "geeks"), then students might find psychological safety in combining these identities alongside ideas that are more broadly acceptable (e.g., combining science with athletic or artistic identities), particularly if they have demographic identities that are otherwise marginalized in science (e.g., women and some race/ethnicities) (Bagwell et al. 2000; Kahan et al. 2007; Nichols and White 2014). By psychological safety, we mean being able to show one's self without fear of negative consequences for status or self-image. As a result, our first research question is: *what common topical identity complexes include science in early secondary*? In particular, will there be a STEM-only complex or will science tend to be included in complexes that include non-STEM identities as well? We hypothesized that there would be a STEM-only complex and perhaps a STEM plus artistic complex reflecting families tending to enroll students in both artistic and STEM camps in the summer (Akiva et al. 2017) plus elementary schools beginning to adopt STEAM activities into the curriculum (Kim and Park 2012).

Additional Key Questions Regarding Identity Complexes

There is an asymmetric relationship between demographic and topical identities: demographic identities tend to be construed long before and independently of any topical identity, but endorsement of topical identities tends to be developed much later and are influenced by demographic identities because of the social component and the unfortunately strong stereotypes in certain topics for demographic associations with who participates in certain experiences (Archer et al. 2012; Chang et al. 2011; Harrison et al. 2011). Therefore, personal preferences for topical identities may be curtailed by risk perceptions (Kahan et al. 2007). Based on prior research, it is likely that science identity will be lower in those who are currently under-presented in science (e.g., ethnic minorities and women). However, it is unclear how this will show itself within topical identity complexes. Will the general demographic trends for science identity be equally strong within each topical complex or are some topical complexes relatively more likely among those under-represented in science? In addition, since identities are developing, there may be changes in topical identity complex frequency across grades within secondary science. Therefore, the second research question is: *Are topical identity complexes that include science associated with specific demographic identities?* We hypothesize that gender, race/ethnicity, and grade will generally be associated with these complexes, mirroring general patterns previously observed for science identity. If multiple such complexes emerge, the relative association within those complexes may mirror broader patterns of the other identities within the complex (e.g., female associations with artistic identities if there is an identity complex that combines art and science).

Students are required to take science in the early secondary school years, providing opportunities to broaden identities beyond conceptions built without experience. But these school-based experiences may produce negative reactions for some students. Early informal science experiences have been shown to be an important factor in students' career choices, and many researchers have suggested it as a way to diversify the STEM pool (Barton and Tan 2010). But there is a chicken-and-egg problem: marginalized populations may be less likely to choose to participate in optional science experiences (Akiva and Horner 2016). Further, if students have multiple topical identities, it is unclear how these multi-topic identity complexes lead to choices relative to having mono-topic identity complexes. Understanding how students' identities influence their choices is key to the development of interventions, programs, and activities that can increase the diversity of the STEM workforce (Vincent-Ruz and Schunn

2018; Crowley et al. 2001). This issue leads to the third research question: *In what ways are identity complexes with high science identity related to student's choice preferences and participation in optional science experiences?* Topical identity complexes that include many topics in addition to science may not lead to higher participation in science than complexes that are more narrowly focused on science. However, we hypothesize that all complexes that include science should be positively associated with participating in optional science experiences relative to those complexes that do not include science.

Research Questions

1. What common topical identity complexes include science in early secondary school?
2. Are topical identity complexes that include science associated with demographic identities (gender, race/ethnicity and grade?
3. In what ways are identity complexes with high science identity related to student's choice preferences and participation in optional science experiences?

Methods

The primary objective of the study was to identify common identity complexes including and not including science in early secondary students. With the specific goal of understanding relative topical complex frequency and their demographic distribution, quantitative measures of topical identity were obtained and then subjected to latent class analysis to classify individuals into distinct groups based on individual response patterns.

For the secondary goal of testing the consequential validity of identity complexes through examining their relationship to participation in optional science learning experiences, two groups of measures were used: (1) preferences for engaging such experiences and (2) reports of actual experiences.

Participants

The sample used for analysis is a subset of the ALES15 dataset (Activated Learning Enables Success 2015) that contains information about topical identities, participant demographics, and preferences for/participation in optional science experiences. This dataset was collected in strategically varying public schools in two urban/suburban regions of the USA with different demographic profiles: (1) Pittsburgh, a mid-sized city in the East Coast region with a high proportion of African American students; and (2) the Bay Area, a region in the West Coast with a high proportion of Latino students and recent immigrants. Altogether, there were twenty 6th-grade, forty-five 7th-grade, and thirty-seven 9th-grade classes drawn from 23 public schools that represent a range of school configurations (e.g., stand-alone middle schools or high schools vs. 6–12 schools, comprehensive schools, as well as topic-specific magnet schools). In terms of demographics, school make-up also varied widely by race/ethnicity (under-represented groups in science, 23–99%) and socio-economic status (students from low-income families eligible for free/reduced lunch at school, 26–84%).

Table 1 presents demographic characteristics of each group. Sample size varied across measures due to student absence at different data collection points (across two different points in a school year, separated by at least 3 months; see "procedures" for details). The primary sample of this study, those who completed the identity profile questionnaire and the demographics questionnaire, consisted of approximately 1200 students. The study was approved by The University of Pittsburgh Institutional Review Board. Students were allowed to opt-out from participating in the surveys. Furthermore, each student was given a passive consent permission slip that explained the research project as well as its implications.

Measures

A number of steps were taken to validate all of the instruments. We conducted cognitive interviews (Desimone and Floch 2004) in which at least ten students of varying ages (within the age range included in the current study) engaged in think-alouds to explain their thought process when answering each question. Item wordings were refined to ensure students' thought processes reflected the intended meaning of the items.

Second, to support complex statistical analyses, the psychometrics of the instruments needed to be strong (measuring students well across ability levels and age). For all surveys, we conducted confirmatory factor analyses (CFA) and item response theory analyses (IRT) to ensure validity cross gender, race/ethnicity, and grade. That is, all CFA and IRT analyses were run with the full sample and then by gender, race/ethnicity, and grade to ensure patterns were consistent across subgroups.

Identity Profile Questionnaire The Identity Profile Questionnaire was designed to assess students' endorsement of different topical identity components. The identity items focused on the different components of STEM as middle and high school students might label them along with the most popular topical identities for those age groups: artistic, musical, and athletic (see Table 2). The scale was adapted from the research of Aschbacher et al. (2010) and Hazari et al. (2010). After designing the first version, cognitive interviews with a similar population of students to the current study were conducted to produce a final version in which the range of identities and their wording were a strong match to this target population. In the deployed version, students could also select "other" for an identity and write in an open response. But there were no commonly occurring specific other responses, suggesting the primary topical identities were represented in the instrument. The order of STEM and non-STEM items was purposely mixed to ensure that the discovered topical complexes reflected the content of the items and not simple item order effects. In all, the questionnaire consisted of seven questions responding to the prompt "How well do the following describe the way you think of yourself?" with a 4-point Likert scale from 1 to 4 with labels at the end points: 1 = "Not Me" and 4 = "Exactly Me."

Table 1 Within each grade level, mean and SD of participant age (in years) as well as percentages of participants by gender and by race/ethnicity

Grade	Age		% female	Race/ethnicity			
	M	SD		% White	% Black	% Asian	% Latinx
6	12.5	0.7	46	27	61	3	8
7	13.5	0.6	52	37	36	8	17
9	15.4	0.6	50	21	55	7	16

This questionnaire was designed with a person-centered approach in mind. In a variable-centered approaches, there is an assumption that the relationship between variables is the product of a homogenous population. In that case, an exploratory factor analysis would often be the method of choice to understand the patterns obtained from these variables. However, given there is the possibility of a categorical presence/absence of endorsement with these items, the underlying assumption of factor analysis of a homogenous, continuously varying population might be violated (Eye and Wiedermann 2015). In a person-center approach, the assumption is that the heterogeneity of observed patterns of behaviors may be the product of subpopulations or latent classes (Morin et al. 2011; Sangha et al. 2013).

Table 2 shows the percentage of students that selected answers of 3 or 4 = "Exactly Me" in each of the items, overall and by grade. All identities were endorsed by a plurality of students overall and at each grade level. The sum across identities is almost 360%; clearly, students regularly endorsed multiple identities. The decreasing endorsement of the science identity across grades is consistent with research showing that science-related attitudes often decrease with age (Osborne et al. 2003; Sorge 2007).

Demographics Participants provided basic demographic information in a survey that asked them about their gender, date of birth, and race/ethnicity.

- Gender—students were asked to select among four different options in the question "Which of these bests describes you": (1) boy, (2) girl, (3) do not identify as girl or boy, and (4) prefer not to answer. Students selecting the third and fourth options collectively accounted for 1% of the data. We created a new variable labeled female where 1 = girl, 0 = boy and removed from the dataset the rest of the students because they were so low in frequency.
- Race—students were asked to select among six different race/ethnicity categories with which they identified, and they were allowed to choose more than one. Students rarely identified as three or more racial groups or as "other" (less than 1% of the sample). To maximize power of the analysis by race/ethnicity, students were classified by giving priority to the minoritized aspect of their biracial identity (e.g., if a student identified as white and black, they were classified as black). See Table 1 for descriptive statistics.
- Age—students reported their month and year of birth. We did not collect birth day for improved participant anonymity. Age was calculated using the last day of the month when data collection was finished in the Spring semester as the reference point.

Table 2 Percentage of students overall and by grade level endorsing each topical identity

Item	Overall (%)	Grade (%)		
		6th	7th	9th
I am a *science* person	41	48	39	36
I am a *math* person	54	58	52	53
I am a person who *invents* or *makes* things	39	42	39	31
I am a *nature* person	52	52	53	46
I am an *athletic* person	66	70	67	56
I am a *musical* person	53	47	54	57
I am an *artistic* person	53	49	54	55
Did not endorse any item	3	3	2	2

Science Choice Preferences Choice preferences for optional science learning experiences was measured as a mean across ten items ($\alpha = 0.85$) on a Likert scale (4 = YES!, 3 = yes, 2 = no, 1 = NO!). These items provided students with future choices about participating in common optional learning experiences involving science at home (e.g., “Collect rocks, butterflies, bugs, or other things in nature”), at school (e.g., “Be part of a study group for science class”), or in other locations (e.g., “I would like to attend a science camp next summer”). The choices ranged from situations that could happen in the immediate future (e.g., “Watch TV about science topics”) to choices about preferences for the next year (e.g., “Join a science club at school next year”). This measure focuses on the child’s preferences per se, rather than a mixture of child preferences, adult preferences, and availability of opportunities that collectively influence the frequency of actual experiences. See Li et al. (2016) for the creation of the construct and Vincent-Ruz and Schunn (2018) for more details on the validation of this version of the scale.

Science Recent Experiences Across 23 items, students reported on a wide range of recent STEM-related optional experiences they had recently had during the summer (in a fall survey) or fall (in a winter survey). All items were measured on a 4-point Likert regarding amount of exposure to the experience (4 = Many days, 3 = A few days, 2 = 1 day, 1 = Never). Following prior psychometric work on natural groupings (Lin and Schunn 2016), these recent experiences were conceptually grouped by time (summer vs. school year) and by location (related to school, at home, or informal outside the home).

- STEM camps during the summer—Measured as the maximum value (since long camp experiences can be expensive and therefore competing with other long camp experiences) across three items: (a) “I went to a science camp”; (b) “I went to a camp about making or engineering”; and (c) “I went to a computer programming camp”.
- Informal science experiences during the summer—Measured as a mean across seven items ($\alpha = 0.82$) that asked about common things students might be able to do on the summer in or near the home (e.g., “I built or took things apart (like motors, computers, clocks, etc.)”).
- Formal recent science experiences during the school year—Measured as a mean across seven items ($\alpha = 0.72$) (e.g., “I did an extra-credit research project for science class”). Formal experiences were defined as optional science learning experiences that were school related (i.e., happened in school after class hours or related to science class) but were not just regular homework activities.
- Informal recent science experiences at home during the school year—Measured as a mean of five items ($\alpha = 0.77$). Informal experiences refer to those experiences related to science that were not closely connected to formal curriculum and where students were free to explore the topics at their own pace (e.g., “I read books about science or science fiction”).

Table 3 shows descriptive statistics and intercorrelations between the optional science preferences and recent experiences scales. Choice preferences had overall a higher mean than actual participation on science-related experiences; for children at this age, it may be more likely that they do not have access to desired experiences than they are taken to experiences they do not want. Furthermore, choices preferences and participation in optional science experiences was correlated but not highly, showing the importance of separately examining each. In general, participation in the various optional science experiences were highly correlated with one another except for the home informal experiences, which may be most dependent upon caregiver educational factors.

Data Collection Procedure

Students completed paper-based surveys across at two points within a school year, each time as a packet to be completed in one class period by the research team. All but the school-year recent experiences were collected at the first time-point. The demographics survey was given last in the first time-point packet to avoid the effect of stereotype threat on attitudinal survey responses (Steele and Aronson 1995). The recent school-year optional science experiences survey was given at a second time-point to enable analyses of identity predicting future events, which provides a better approximation of causality than from measures all collected at the same time-point.

Model Building Procedure

Latent class analysis (LCA) (Magidson and Vermunt 2004) was used to reveal different identity complexes using the poLCA package in R (Linzer and Lewis 2011). LCA is a powerful tool for identifying subgroups through analysis of the structure of relationships among categorical variables. It is similar to exploratory factor analysis (EFA), except that LCA clusters individual respondents into complexes, rather than items into factors (i.e., it is a person-centric grouping technique rather than a variable-centric grouping technique). As with EFA, there are no a priori assumptions about number of complexes. For the LCA analyses, the Likert-scale responses were converted to a binary where a 0 was assigned to the "Not me" responses (1 and 2) and it was relabeled to "No." A code of 1 was assigned to the "Exactly me" responses (3 and 4) and was relabeled as "Yes." This recoding maximizes sample size per response level and thus the sensitivity of LCA to detect complexes, particularly by demographic subgroups. LCA with small sample sizes can fail to identify a substantively important but low prevalence complexes. Such mischaracterizations have negative consequences for generalizability of results (Collins and Lanza 2009). Indeed, running the analysis using all four response levels failed to identify the latent group with the least number of students, although all other results were similar. To find the optimum number of complexes, the analyst tests different number of complexes and selects the best fitting model using four criteria:

1. Parsimony—Using global fit indices—(1) Bayesian Information Criterion (aBIC), which penalizes models with higher number of complexes to account for over-fitting; (2) Akaike Information Criterion (bAIC), which estimates the relative information lost by a given model; (3) and the chi-square goodness of fit (through a likelihood-ratio test) to compare

Table 3 Means, standard deviations, and intercorrelations of optional science preferences and recent experience scales

Scale	M	SD	Intercorrelations				
			CP	STEM camp	Summer informal	School formal	Home informal
Choice preferences (CP)	2.45	0.62	1				
STEM experiences							
STEM camp	1.62	1.06	0.20	1			
Summer informal	1.88	0.66	0.25	0.75	1		
School formal	1.44	0.78	0.22	0.88	0.80	1	
Home informal	2.48	0.74	0.37	0.33	0.43	0.35	1

the goodness of fit relative with another model—to identify the best model with the least number of complexes (Cochran et al. 2017).
2. Entropy—The extent to which the complexes are distinct from one another (Celeux and Soromenho 1996).
3. Substantiveness—How much meaningful information does an additional complex provide for the analysis (Celeux and Soromenho 1996).
4. Interpretation—There must be a theoretical basis for the observed complexes (Cochran et al. 2017; Magidson and Vermunt 2004).

Considering the multiple fit criteria (see Fig. 1), the LCA revealed that four topical identity complexes provided the optimal fit to the identity data: relatively high entropy and relatively low cAIC, aBIC, and log-likelihood. Note that the model with only five identity theory complexes, close in overall fit statistics and better on entropy, produced similar complexes to the four-complex model. However, theoretically the five-complex model did not provide additional information about how students endorse these items differently. The difference between the four and five complex model resided on a complex focused on athletic identities. In the five-complex model, one obtains two athletic-focused complexes. In the first athletic complex, students have a 60% chance of endorsing an athletic topical identity and a 9% chance of endorsing a science topical identity. In the second one, students have a 70% chance of endorsing an athletic topical identity and a 26% of endorsing a science topical identity. That is, if we were to choose the model with five complexes, we would not get any additional theoretical or practical insight into students' relationship with different topical identities, only a complex where students are slightly more athletic leaning than the other.

In order to test the effects of gender and race, it is necessary to conduct a Type II Permutational Multivariate Analysis of Variance (PERMANOVA) with the posterior probabilities obtained from the LCA (Anderson 2001). PERMANOVA and subsequent post-hoc analysis were conducted using the *vegan* package in R (Dixon 2003). The posterior probabilities in LCA refer to the probability of that observation that is classified in a given identity complex. That is, for each possible complex, the students get a probability of belonginess and the total sum across the four possible complexes is 1. Based on this, individuals are classified to the complex with the highest probability. Using posterior probabilities in lieu of the category classification has several advantages: (1) Individuals' posterior probabilities of latent class account for the possible error with which individuals can be assigned to latent classes when they do not fit any latent class perfectly (Lanza et al., 2007); (2) Running a multinomial logistic regression (a regression where the complex membership categorical variable is used as the dependent variable) produces biased estimates and incorrect standard errors (Bolck et al., 2004).

PERMAMANOVA allows testing hypotheses regarding the effect of independent variables (race/ethnicity, gender, and grade) on multiple dependent variables that are correlated with one another (e.g., each of the identity complexes posterior probabilities) rather than assuming the dependent variables are uncorrelated with one another; this approach has greater statistical power. Type II refers to the test of the main effects (of gender, race/ethnicity, and gender). Furthermore, permutational refers to the measure of dissimilarity between the gender, race/ethnicity and grade distributions between identity complexes; the particular measure of dissimilarity used in this case were Bray Curtis distances, which is often used to characterize dissimilarity in population composition (Anderson 2001). The magnitude of the demographic differences in each identity complex's frequency were computed using Cohen's *d* as a measure of effect size (Lakens 2013).

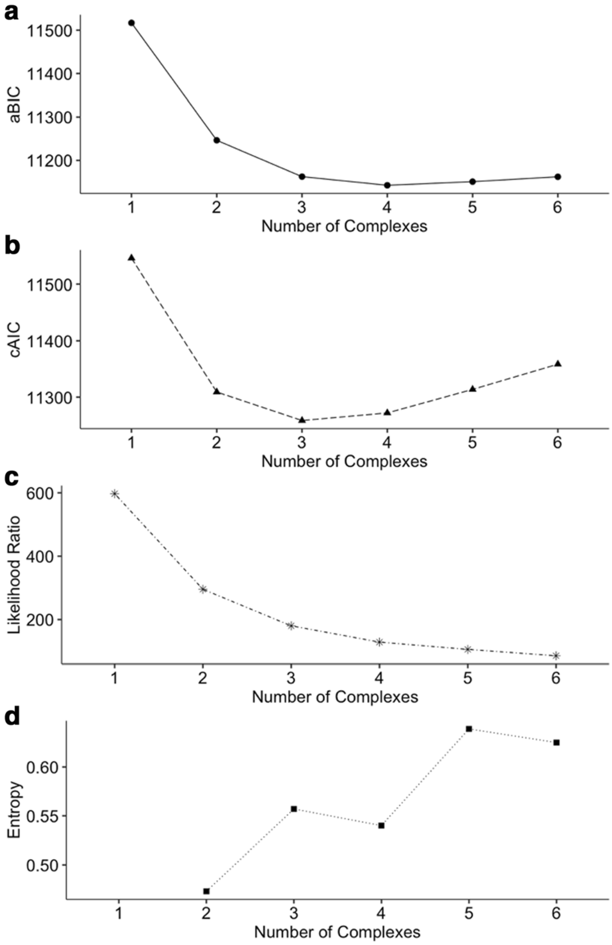

Fig. 1 Model fit statistics for testing different number of identity complexes: **a** aBIC, **b** cAIC, **c** Likelihood ratio, and **d**) entropy. Lower is better for all but entropy

Results

Research Question 1: in What Ways Is Science Typically Present in Identity Complexes?

The identity component with highest endorsement was "Athletic person," while the lowest identity components were "Science person" and "person who invents or makes things" (as shown in Table 2), reflecting typically-reported emphases on athletics over STEM within US schools (Biddulph 1954; Guest and Schneider 2003; Harrison et al. 2011; Veliz et al. 2017). However, all identity components were endorsed by a large plurality of students. Importantly, there were enough students endorsing the science identity in particular and STEM identities in general that a science-focused or STEM-focused identity complex could have emerged.

Table 4 presents the make-up of the four complexes provided the optimal fit to the identity data: the average probability of answering yes to each topical identity within each complex. Most saliently, two of the complexes had a narrow topical focus, but none of the complexes focused only on science or only on STEM. Instead, two of the complexes had high levels of science or STEM as part of a multi-topic identity complex.

Specifically, the four main complexes had the following characteristics:

1. STEM+Athletic+Artistic: This complex had the highest probability of science identity endorsement, but also the highest probability of endorsement of all other identities.
2. STEM+Athletic: This complex represents students with STEM (math, science, nature, and maker) and athletics identities, but not artistic and musical identities.
3. Athletic: Members of this complex had a less than 1% chance of endorsing a science identity and overall tend to identify only with an "Athletic" identity.
4. Artistic: Members of this complex were only approximately 30% likely to see themselves as having a science identity, instead endorsing musical and artistic identities with very high rates.

The relative frequencies of the four topical identity complexes are shown in Fig. 2. The first two complexes involve many topical identities (i.e., multi-topic), and they involved high levels of STEM identity; these were the less-common complexes. The last two complexes had levels of only one (or two closely related) topical identity (i.e., mono-topic), and these did not involve high levels of STEM; these were the two most common complexes.

In sum, in contrast with the initial hypothesis, there was neither a pure science topical complex nor a pure STEM topical complex, even though almost two thirds of students had complexes that were narrowly focused (on other topics). In other words, students were often narrow in their topical identities but not commonly in ways that focused on science. Since latent class analysis is sensitive to sample size, we also conducted a simple count of students endorsing only the STEM identities (in any combination). There were 83 such students, representing less than 5% of the sample. These STEM-focused students did not form a coherent complex because the 83 students endorsed different combinations of the science, math, maker, and nature items. For example, just three students endorsed only a science identity, and 19 endorsed only a math identity. Thus, affinities toward STEM came in different forms rather than a unified complex, and all forms were quite rare in this population (e.g., much less common than artistic-only or athletic-only complexes).

Table 4 Probability of endorsing each topical identity by topical identity complex

Identity complex	Number	Science (%)	Nature (%)	Maker (%)	Math (%)	Athletic (%)	Artistic (%)	Musical (%)
STEM+Athletic+Artistic	167	88	98	79	69	83	91	81
STEM+Athletic	299	71	52	47	74	73	27	32
Athletic	408	0	28	15	38	64	24	33
Artistic	335	30	53	36	43	55	91	82

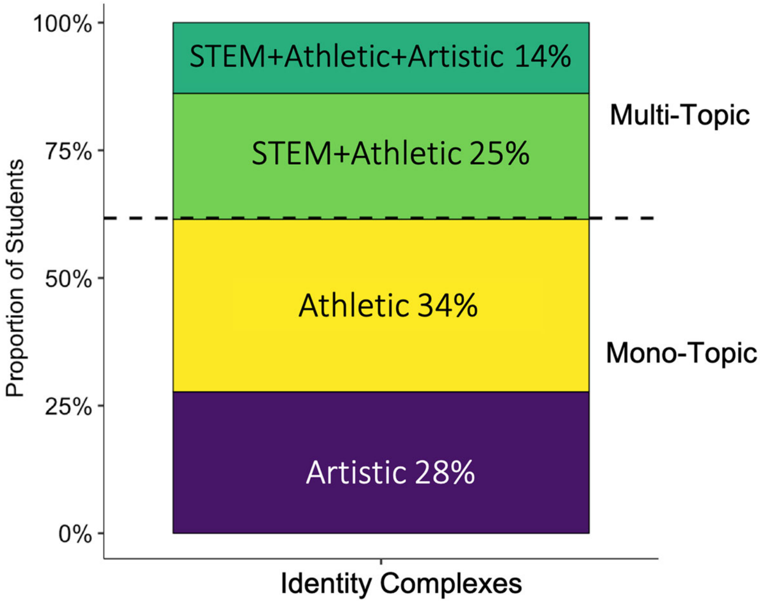

Fig. 2 Relative frequency of each identity complex

Research Question 2: How Are Science-Related Identity Complexes Distributed Across Race/Ethnicity, Gender, and Grade?

Figure 3 presents the mean posterior probabilities of being in each identity complexes as a function of the three key demographic variables. In terms of grade, there was an overall decrease of students being classified on STEM-related identity complexes from 6th to 9th grade (Fig. 3), consistent with the general decrease in the science identity in this data and the general decline in attitudes towards science that are often described in the literature (Osborne et al. 2003). The identity complexes provide more insight into the nature of the decline. The decline in the STEM+Athletic+Artistic was not statistically significant, while the athletic STEMer identity complex showed a medium-sized significant decrease ($d = 0.30$, $p = 0.006$). The decline in STEM was matched by an increase in the artistic identity complex ($d = 0.36$, $p = 0.006$) (Fig. 4).

Turning to gender (see Fig. 3), the largest identity complex differences were observed. Girls were overall less likely to be classified into an identity complex related to science, as would be expected by the prior literature. But again, the form of the difference by identity complex is more nuanced. In terms of the STEM+Athletic+Artistic identity complex, the difference between boys and girls is not significant and actually goes in the opposite direction (i.e., girls were higher). Instead, it was specifically within the STEM+Athletic complex that a medium-sized statistically significant effect is observed ($d = 0.57$, $p = 0.001$). The matched higher identity complexes in girls were to be found in the Artistic identity complex ($d = 0.70$, $p = 0.001$). Note there was also a small difference in the Athletic identity complex; however, the real pattern is athletic-related complexes was the large difference in the STEM+Athletic complex.

Finally, the differences by race/ethnicity in probabilities for complexes were less common and smaller. As expected from prior literature (Norman et al. 2001), white students had the

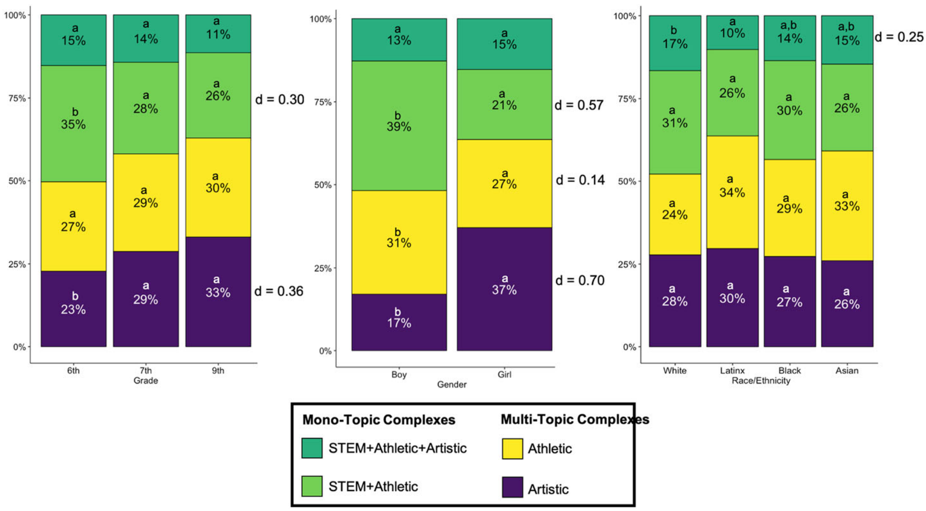

Fig. 3 Identity complex distribution across different key variables: **a** grade, **b** gender, and **c** race. Cohen's d is reported for statistically significant differences at $p < 0.01$. Note: When comparing between two demographic categories with a complex (e.g., boys vs. girls for STEM+Athletic+Artistic), statistically significant differences are denoted with different letters (**a** for the categories within the statistically smaller quantity and **b** for all the cells with the statistically larger quantity). **a**, **b** Use for cases that are in-between and not statistically different from the higher quantity or the lower quantity

highest probabilities in being in one of the two STEM-related identity complexes. But the only significant difference was for the STEM+Athletic+Artistic identity complex suggesting maybe an access issue on the possibility of experiencing many different activities with limited resources. There is a medium size difference between White and Latinx students, where Latinx students were more likely to be in the STEM+Athletic+Artistic identity complex ($d = 0.25$ $p = 0.01$). The rest of the differences were not statistically significant.

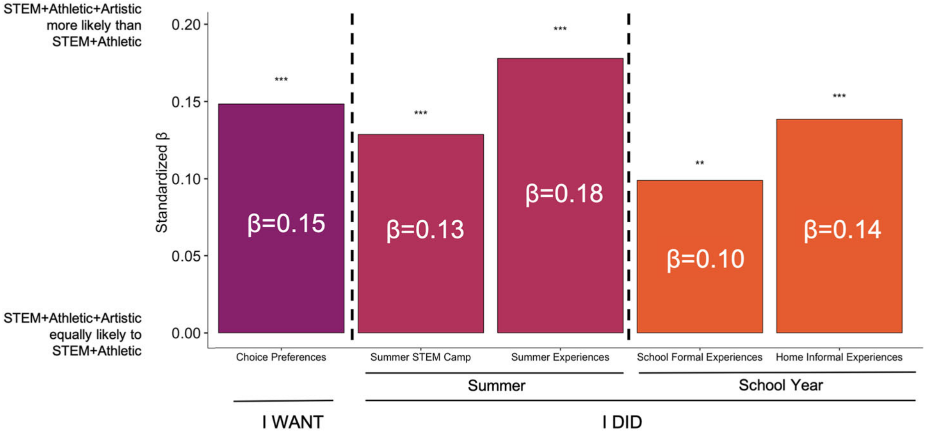

Fig. 4 Multiple linear regressions for comparing the increasing levels of participation of STEM+Athletic+Artistic students vs. STEM+Athletic. Standardized betas are reported using STEM+Athletic as a reference group for choice preferences and optional science experiences. Controlling for grade, race/ethnicity, and gender effects. $^{***}p < 0.001$; $^{**}p < 0.01$

Research Question 3: Topical Complexes and Students' Participation in Out-of-School Science Experiences

Using artistic as the reference category, regressions controlling for demographic variables revealed significant associations between identity complexes and optional science learning choices, whether measured by choice preferences or each actual science experience as outcomes. Not surprisingly, in all cases, students in both complexes with higher science identity were significantly more likely to want to and actually participate in optional science experiences than students in the complexes with lower science identity (Table 5). For example, when compared with the artistic complex, students in high science identity complexes were more likely to actively prefer these optional experiences and to later have actually experience them. Some of these effects were large: individuals in the STEM+Athletic+Artistic identity complex were much more likely to have informal science experiences in the summer.

More interesting from a topical complexes' perspective is the contrast comparing the STEM+Athletic+Artistic and STEM+Athletic identity complexes: does the all identity involve lower levels of participation in science due to a conflict in time, in available resources, or in commitment? In fact, rather than showing a conflict effect, the reverse pattern was found. As Fig. 3 shows, across all optional science experiences, students in the STEM+Athletic+Artistic identity complex were more likely than the STEM+Athletic to want to and to actually participate in them. Interestingly, the effect is equally large in preferences as in actual experiences, suggesting the difference is not just one of students being forced by parents to participate in many forms of activities. The contrast also suggests students are not just falsely listing an unrealistically broad identity because they actually do participate in many activities. However, it is also important to note that these differences were moderate to small—both of these complexes were generally high in optional science participation levels.

Discussion

Identity has long been considered important to understanding participation or lack there of in science (Archer et al. 2010; Aschbacher et al. 2010; Barton et al. 2013). This paper explores science identity from a new perspective—science identity as part of a topical identity complex—to provide new insights into who is more likely to endorse a science identity and

Table 5 Multiple linear regressions of identity complexes predicting choice preferences and optional science experiences, with artistic as the baseline group and controlling for grade, race/ethnicity, and gender effects

Predictors	Choice preferences		STEM camp		Informal summer experiences		Formal school experiences		Informal home experiences	
	Std. beta	*p*	Std. beta	*p*	Std. beta	*p*	Std. beta	*p*	Std. beta	*p*
STEM+Athletic+Artistic	0.22	*< 0.001*	0.18	*< 0.001*	0.28	*< 0.001*	0.17	*< 0.001*	0.21	*< 0.001*
STEM+Athletic	0.09	*0.012*	0.07	0.051	0.13	*< 0.001*	0.10	*0.012*	0.09	*0.015*
Athletic	− 0.11	*0.003*	− 0.04	0.243	− 0.19	*< 0.001*	− 0.03	0.495	− 0.12	*0.002*
Adjusted R^2	0.090		0.046		0.169		0.033		0.090	

Italics means statistical significant effects how science identity is related to choices within a co-occurring, competing or synergistic topic identity. Such new insight can support new understandings of how those historically minoritized in science might be more frequently included. We will now revisit each of our primary research questions to discuss the theoretical and practical implications of our findings.

Science Identity Within Topical Identity Complexes

Across a large, diverse sample of learners in urban US early secondary schools, students could be classified into four different topical identity complexes. There were two salient patterns in these results. First, some of these identity complexes matched traditional school cliques with little connection to science that have been previously studied in the literature like jocks (athletes with few other interests) and artists (Barber et al. 2001). Collectively, these low science topical identity complexes represented almost two-third of the students, with even higher percentages in under-represented minorities and in girls. Furthermore, these two most common complexes were mono-topical, consistent with the notion that traditional cliques have a lower risk perception (Bagwell et al. 2000; Kahan et al. 2007; Nichols and White 2014). By lower-risk perception, we mean that traditional cliques conform with social norms constructed in secondary school, and students at this age are aware that non-conformity has social consequences like exclusion and isolation (Thornberg 2011). Interestingly, math was relatively high in both of these identity complexes (close to the 50% threshold), even though science was not. This could be explained by the gatekeeper role mathematics has for most educational and economic opportunities (Gresalfi and Cobb 2006; Moses and Cobb 2001). That is, it is possible students perceive the need to become members of mathematical communities if they want to have access to future opportunities like college.

Second, despite clear representation as a stereotype in popular media (Kendall 2011), the latent class analysis did not reveal any kind of pure science or STEM identity complex. Its conspicuous absence may have a number of causes. A very small number of students did endorse only STEM topical identities, but in various unique combinations. That is, even though STEM is usually packaged as a goal for students (Hughes et al. 2013; Zeidler 2016), students' topical identities may only align with certain components of STEM. Some students may have career goals that aspire towards traditional science research (Russell et al. 2007), while others may be interested in more practical applications of science into technology (Diekman et al. 2011) and therefore, that will influence their learning choices and in turn their identities. Furthermore, since latent class analysis is sensitive to sample size (Collins and Lanza 2009), these STEM subgroupings may have been too small to be captured. Finally, it may be that some students do not feel comfortable endorsing science identities or STEM-related identities without endorsing, at the same time, something consistent with social expectations. This pressure may be especially true for girls and racially/ethnic under-represented groups in science (Bucholtz 1999).

Demographic Variation in Science-Related Topical Identity Complexes

Overall, the observed relative frequencies of topical complexes were consistent with common cultural expectations for both gender and ethnicity (i.e., science-related topic complexes were highest among white males and lowest for females) (Carlone and Johnson 2007; Chang et al. 2011). But this study also revealed new patterns regarding the differential ways in which subgroups included science in their identities (e.g., as part of a STEM+Athletic complex for boys) (Kahan et al. 2007; Kendall 2011). The analyses also revealed the common complexes for each subgroup that did not include science (e.g., athletics for boys and artistic girls), perhaps suggesting topic contexts that are especially likely to support the addition of science (e.g., sports science or STEAM).

Furthermore, this study provided important insights into what additional information is obtained by looking at identity complexes rather than topical identities in isolation. For grade, the decline in the STEM+Athletic complex matched the increase in the athletic complex as students progressed through early secondary school. This change is consistent with the increasing time commitment that athletics requires of students as they move into late secondary school (Guest and Schneider 2003; Veliz et al. 2017). And in the USA specifically, this time commitment is connected to students' access to athletic scholarships for college (Biddulph 1954; Harrison et al. 2011).

In terms of gender, the biggest difference was related to athletic-related complexes. More importantly, there was an overall difference of boys being more likely to be classified in a science-related complex (Archer et al. 2013; Osborne et al. 2003). However, there was no statistically significant difference in the STEM+Athletic+Artistic complex (with a tendency of girls being higher) while there was a medium-sized difference. The fact that there was such a large difference in the frequency of the artistic complex suggests that STEAM opportunities could offer a pathway for girls to shift from that complex to the STEM+Athletic+Artistic one (Liao et al. 2016) rather than athletic-related opportunities.

Finally, there was an overall tendency of White students to be more likely to be classified into STEM-related identity complexes. The only statistically significant difference was within the STEM+Athletic+Artistic complex, suggesting possibly an access issue for students from less advantaged backgrounds (Akiva and Horner 2016). These results across ethnicity and gender highlight systems of disadvantage in science across gender (Adams et al. 2014; Archer et al. 2013; Barton et al. 2013; Bucholtz 1999; Crowley et al. 2001), where gender at this age (in the early seondary years) is the main driver of differences in identity complexes beyond race and grade.

Identity Complexes and Participation in Optional Science

Replicating previous identity research, students with higher science identities were to seen to have optional science learning experiences (Feldman and Matjasko 2005; Guest and Schneider 2003); the current study showed that this relationship is very strong. Turning to the level of topical complexes and participation, it appeared that having multiple topical identities did not create conflict in which experiences students chose to participate (Knifsend and Graham 2012). In fact, the opposite pattern occurred: students in the STEM+Athletic+Artistic identity complex were more likely to do science than the STEM+Athletic. It may be that these results, which are suggestive of non-competition for participation time, occurred because students at this age could still juggle multiple activities. Requirements for many activities may increase with older ages (e.g., sports become more competitive in later high school and therefore more time consuming), and school time becomes more important for their future (e.g., SAT prep, college application processes). Therefore, it is likely that some competition effects will emerge at later ages.

The high participation of the STEM+Athletic+Artistic complex students is a validation of the importance at looking at the relationship of multiple identities. It could have been argued that students falsely endorsed multiple topical identities simply to give responses expected by society or by the researchers. However, if this were the case, there should not have seen a significant relationship between complexes including STEM identities and participation in optional science experiences.

Limitations and Future Directions

This study purposely sampled students from diverse public urban schools in the USA to be representative on the dimensions that mattered the most for science identity endorsement (gender, ethnicity). However, a much larger sample is required to produce truly representative data for non-urban students, other regions within and outside the USA, as well as including private, charter, and home-schooled students. For example, the large emphasis on athletics within the identity complexes maybe particularly salient within public schools in the USA, given the regular inclusion of competitive sport teams within the schools.

A larger sample might also support uncovering relatively rare STEM identities, such as those with and without mathematics, or with and without technology. Such different identity complexes would likely be differentially connected to science-related outcomes (e.g., in medicine, in computer science). Larger cross-national samples might also reveal the role of cultural expectations in shaping the types of complexes which include science; athletics may be less central in other countries where competitive athletics is not so strongly represented within the schools themselves.

It might be that the high endorsement of athletic identities is a reflection of the emphasis US culture puts in it in education. In other countries, there could be another identity the is more salient. However, the purpose of this study is not to define the unique or definite set of identity complexes possible at this age, but rather to show that students in early secondary school have complex identities, which can be important for interventions and research. The current findings should be analyzed further through qualitative studies that build upon the framework developed here.

Implications for Practice

The theoretical contribution of this study is in introducing the concept of identity complexes. This concept directly represents the many identities individuals hold, including the possibility of multiple topical identities. It also builds on the theory that an individual's topical identities are a constant negotiation with their goals, cultural expectations, and the different social identities they chose to endorse, which then shape the combinations of topical identities that are observed and their association with demographic-based identities. The main practical application of this study is regarding STEM stereotypes. Our results show that students in this sample did not match typical stereotypes of kids interested in STEM. A possible application of this research is to provide information to students about what their own stereotypes, of what kind of person a scientist or science person is, and that there is nothing wrong with endorsing non-related science identities.

The Identity complexes with multiple topical identities of different kinds raises the question about what experiences best serve students' identity development. It is still an open question whether these complexes mean students prefer combination experiences like STEAM or whether they simply want a diversity of experiences. So, we caution against immediately creating combination experiences.

In this study, we found results consistent with general identity theorists' perceptions of identity as a multicomponent construct (Crenshaw 1991; Stets and Burke 2000). However, even though researchers studying science identity have indeed included an understanding of learners' characteristics, like gender and ethnicity, they have not studied how science identity may compete with other topical identities. Thus, our contribution to the science identity field not only highlights the ways in which students endorse other non-STEM identities at the same time, but it also reveals the ways in which these other identities are not detrimental to participation in science. Furthermore, science identities research often uses gender and ethnicity variables as controls and in isolation, whereas this current study systematically explored both. We found that students with STEM-related identities tended to be White and male, consistent with societal expectations. We also found that students' complex classification tended to be along very gendered lines. However, girls' high endorsement of art identities may serve as a possible introduction to science. STEAM experiences and Maker spaces could introduce girls to the idea of a STEM pathway within a space in which they already feel safe and part of a community (Carlone and Johnson 2007). This psychological safety aspect can also explain why science identity was found paired with identities that are more socially acceptable in the USA, like artistic and athletic. The fact that we did not find students endorsing only STEM identities in isolation as an identity complex reflects the limitations and simplicity STEM/non-STEM dichotomy.

Finally, we hypothesized that the combination of multiple "unlike" topics maybe a way for students to cope with perceived social expectations particularly if they have demographic identities that are otherwise marginalized in science.

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