Chen et al.
International Journal of STEM Education (2023) 10:56
https://doi.org/10.1186/s40594-023-00448-1

International Journal of STEM Education

RESEARCH

Open Access

The role of media in influencing students' STEM career interest

Chen Chen[1,3*], Stephanie Hardjo[2], Gerhard Sonnert[3], Jiaojiao Hui[1] and Philip M. Sadler[3]

Abstract

Background Digital media are pervasive in the lives of young people and provide opportunities for them to learn about STEM. Multiple theories argue that the STEM media environment may shape how youth see a STEM career in their future. Yet, little is known about how pre-college digital media consumption may be related to students' STEM career interest at the beginning of college. The wide variety of STEM media also raises the question of potentially different effects and pathways by media type. In this study, we collected a nationally representative sample of more than 15,000 students in their first year in U.S. colleges and universities. We asked about their career interests at the beginning of college and also asked them to retrospectively report their STEM media consumption during high school.

Results We found that watching STEM-related TV and online videos, as well as playing STEM-related video games during high school, were positively associated with students' STEM career interests at the beginning of college. However, we also found that STEM media consumption did not impact directly on STEM career interest, but acted through two intermediaries: STEM identity (I and others see me as a STEM person) and three personal career outcome expectations: a high interest in self-development (enhancement and use of talents), and low interests in material status (money, fame, power) and in interpersonal relationships (helping, and working with, other people).

Conclusions This study finds that STEM media have a significant effect in fostering STEM career interest, with most of the effect coming from STEM TV, STEM video viewing, and STEM video games. The effect is mediated mainly through students' identity and, to a lesser extent, through personal values, such as self-development, material, and interpersonal relationship values. This study suggests that media communication should be mindful of how different platforms may deliver nuanced and varied messages of what STEM careers may afford and who can succeed in STEM.

Keywords Media, STEM education, Career interest, Motivation, Identity

Introduction

Media are the images, sounds, and words delivered through print (e.g., books), broadcast (e.g., television), and internet (e.g., smartphones) (Dijkstra et al., 2005). As of 2019, American teens aged 13–18 years consumed an average of 9 h and 49 min of media daily (for school-unrelated purposes) (Rideout & Robb, 2019). There is a rich and varied landscape of the common forms of media that youths consume–some are considered passive such as television and some more active such as Apps on smart devices. Whereas some scholars have worried about a negative impact of passive media consumption

*Correspondence:
Chen Chen
logancc@hku.hk
[1] Faculty of Education, The University of Hong Kong, 523 Meng Wah Complex, Hong Kong, Hong Kong
[2] Harvard Graduate School of Education, Cambridge, USA
[3] Science Education Department, Harvard-Smithsonian Center for Astrophysics, Cambridge, USA

on youths' psychological wellbeing (e.g., fostering materialism, social stereotypes) and academic engagement (e.g., depressing learning interest, career interest) (Dubow et al., 2007; Sampassa-Kanyinga, et al., 2019), others have emphasized the opportunities provided by media, especially new media platforms combined with (inter)active science content, to cultivate interest in science, technology, engineering and mathematics (STEM) careers (Bell et al., 2009; Storksdieck, 2016). Attracting a large cadre of capable and innovative young people to these careers is essential for a nation to compete in the global economy (Beede et al., 2011; Briggs, 2016; Chen & Weko, 2009; Melguizo & Wolniak, 2012). These debates implied the assumption that different types of media may have different effects and pathways to influence how youth see (STEM) careers in their future (Carli et al., 2016; Cheryan et al., 2013; Steinke et al., 2009). Another assumption is the time-lagged effect of media that are consumed at a younger age (e.g., pre-college) on career interests observed at an older age (e.g., college) (Dou et al., 2019; Sadler et al., 2012). For example, Dou et al., (2019, 2021) showed that informal STEM experiences in early childhood such as storytelling may have a long-term effect on STEM identity measured in young adults. Shah et al. (2023) showed that the duration of computer game play and social media usage during high school had different effects on beginning college students' career interests in computer science.

This study examines these assumptions. Specifically, we looked into the relationship between students' exposure to different types of STEM-related media during the high school years and their STEM career interest at the beginning of college, including the specific pathways and mechanisms of how media may influence students' career interest. A connection between adolescent media use and STEM interest of young adults has been suggested by prior literature, as exampled above (Dou et al., 2019, 2021; Shah et al., 2023). We focused on STEM career interest at the beginning of college because college-level career intention has a stronger fidelity to suggest future career choices than do the intentions reported in earlier ages (Lent et al., 2002; Wang et al., 2006). We focused on media consumption during the high school period because high school was found to be a critical time when students start to seriously consider their future careers and are susceptible to pro-STEM and anti-STEM influences as their career intentions become more concrete (Chen et al., 2020a; Potvin & Hasni, 2014). Unlike middle and elementary school sciences that are closely contextualized to everyday experience, high school science becomes increasingly decontextualized and aims toward abstract scientific purposes, such as the norms, values, and actions being recognized and rewarded by the science community and society (Anderhag et al., 2016). STEM media may not only bring everyday experiences back to the conversation in science learning, but may also help anchor abstract scientific purposes to real-life examples and behavior modeling (Sevin & Decamp, 2016; Shaw et al., 2019).

Literature review

Theoretical framework

Three theories provide possible ways to explain the relationship between youth STEM media consumption and STEM career interests. They are Cultivation Theory, Social Cognitive Theory, and (Situated) Expectancy-Value Theory. Traditionally, Cultivation Theory emphasized a uniform media effect, Social Cognitive Theory focused on the formation of identity, and Expectancy-Value Theory focused on the appraisal of value, opportunities, and cost. Nevertheless, all of the three theories have evolved to be increasingly compatible and complementary with each other (Eccles & Wigfield, 2020; Gerbner et al., 2002), and together they imply intricate media effects that are channeled through the individual's motivation system. This evolution of the theories is timely, given the rapid development of images, narratives, and methods of interaction in new media forms (Pajares et al., 2009; Shrum, 2017). In the following, we first introduce the foci of each theory, followed by relevant empirical evidence, and then discuss the coherence among the theories.

Cultivation theory

According to the Cultivation Theory, media exposure can directly alter individuals' beliefs about, and perception of, science through both (1) "message system analysis," defined as how certain characters are depicted in the media (e.g., scientists in the movies always wear a white coat (Chambers, 1983; Buldu, 2006; Pansegrau, 2008)); and (2) "cultivation analysis," defined as how strongly viewers' conceptions of the world tend to converge toward what is usually depicted in the media (Gerbner & Gross, 1976; Gerbner, et al., 1994, 2002) [e.g., more STEM figures in the media making students think STEM careers to be attainable (Dou et al., 2019)]. Both imply the existence of a direct effect of mass media, where media impose certain conceptions or images on, or intrinsically motivate, their viewers, with the viewers passively receiving the information and being influenced by the dominating narrative–such as a scientist's stereotypical body image (Capobianco et al., 2011; Holmegaard et al., 2014; Moreno, 2014, p. 1), social problems related to science (Lai et al., 2015), and the nature of scientific evidence (Brewer & Ley, 2010; Lee & Niederdeppe, 2011).

In the context of STEM education, empirical support of the direct effect of media on STEM career interest is mixed. Some studies have found a positive correlation between media exposure (including paper-based reading, television viewing, and internet using) and affinity to STEM careers (Dabney et al., 2012; Dudo et al., 2011; Lantz, 2015). Experimental studies also saw an increased engagement and interest in learning STEM among students as a result of incorporating mobile technology (Gilliam et al., 2016; Metcalf et al., 2008) and social networking sites (Evans & Drape, 2014) in students' learning experience. Without examining indirect effects, such evidence of the positive effects of STEM media was often interpreted as media setting the normative image (or representation) of the STEM profession (Aladé et al., 2020; Wyss et al., 2012). Viewers who are frequently exposed to these images, would model STEM professionals or aspire to STEM careers (Elliot & Risebbergm 1987; Gehrau et al., 2016; Hoag et al., 2017; Hwang & Southwell, 2009; Sheehan et al., 2018; Wyss et al., 2012). However, not all direct effects reported in the literature were positive. For example, Shah et al. (2023) found that the duration of social media use had a negative effect on computing career interests, and that the positive effect of computer gameplay on computing career interests attenuated as the game hours went beyond 5 h per day.

It is noteworthy that the cultivation theory was developed in a media era when television provided by a few national networks was the mainstream (Gerbner et al., 1980; Shrum, 2017). The original theory was concerned with how TV assimilated the general population toward consensus (e.g., Gerbner et al., 1986; Hawkins & Pingree, 1981). However, with the mainstream media breaking into multiple side-streams and passive broadcasting exposure transitioning into user self-selection processes (William, 2006; Fletcher et al., 2021), new developments in the cultivation theory have moved away from a direct and uniform media effect to an indirect and individual one. For example, Shrum () conceptualized how media may influence viewers' personal values and beliefs and how such intermediary beliefs may further influence viewers' life choices and satisfaction. Recent scholarship also showed that genre-specific media may present different messages of social reality that influence different sub-populations' beliefs differently (Cohen & Weimann, 2000, Lee & Neiderdeppe, 2011). This is pertinent to the media effect on the cultivation of STEM career interest, because (1) different forms of media may propagate different and even conflicting images and messages about STEM (Aladé et al., 2020; Cheryan et al., 2013; Levine et al., 2021; Steinke, 2017), and (2) the youth's media preferences and STEM career interests are highly individualized (Solberg et al., 2021; Wang et al., 2017).

Social cognitive theory

According to Social Cognitive Theory, human behavior should not be regarded as a reaction to passive information reception, but as proactive decision and sense making by the socially constructed self, also known as one's identity (Bandura, 1977; Hazari et al., 2010; Steinke, 2017; Trujillo & Tanner, 2014). Identity is the way people "make sense of themselves and are made sense of by others" (Kane, 2012, p. 458). Further, STEM identity determines how one perceives one's participation in science by triangulating it from the perspectives of others (Brickhouse & Potter, 2001). According to Hazari et al., (2007, 2015), STEM identity not only positions oneself relative to others but also internalizes the script and actions associated with their performance of STEM tasks. Applying Social Cognition Theory to the context of STEM media, STEM identity is constructed in two steps: (1) identify with a figure or an archetype ("people who are like me") on media, particularly those STEM professionals who are seen as attractive or similar to the viewer (Hazari et al., 2010; Steinke, 2017), and (2) pay attention to how behaviors of this figure are positively or negatively reinforced by others ("how are they perceived by others?") or by consequences ("are they successful?"). Through this constructed identity, one internalizes a whole system of expected behaviors, such as who is supposed to enter and persist in STEM (Brickhouse et al., 2000).

Several empirical studies have supported this notion of an indirect effect of media through identity. For instance, Roux (2012) found that about 80% of adolescents in her sample searched and watched YouTube videos that were meaningful to them and that they could relate to. These adolescents reported that watching such videos helped them think about their identity and the specific roles that they could play within society. Jeremiassen (2018) found a significant relationship between game play motivations and preferences on the one hand and STEM identity and future career interest on the other. Students tended to select games that offered relevant types of thinking and challenges that matched their identity. In turn, the games offered possible selves and future technical realities that further motivated students' engagement in gaming and STEM. Foster (2008) also suggested that games can be used to develop student interest in science, leveraging their affordances for personal identity development and their relevance to scientific practices and ideas. Furthermore, based on a sample of over 15,800 college students, Dou et al. (2019) found that having a stronger STEM identity increased students' likelihood of pursuing a STEM career. This STEM identity, according to Dou et al. (2019), was in turn predicted by consuming science and science-fiction books or television programs during childhood.

Situated expectancy-value theory

From the perspective of Expectancy-Value Theory (Wigfield & Eccles, 2000), media consumption leads to an internalization process in one's personal value system, consisting of (a) attainment value (importance for sense of self); (b) utility value (usefulness of STEM); and (c) cost (opportunity cost against other alternatives) (Anderson & Ward, 2013; Atkinson, 1957; Bandura, 1997; Betz & Hackett, 1997; Eccles et al., 1983; Lent et al., 1994; Wigfield, 1994; Wigfield & Eccles, 1992, 2000). Not only are viewers influenced by the values disseminated through media content, but they also assess the alignment between their own value preferences and the values that are perceived to be afforded by certain career paths.

Recently, Eccles and Wigfield (2020) updated the EVT theory to the Situated EVT (SEVT), which is particularly useful in analyzing the media effect on career choices. SEVT considers the processes underlying the traditional EVT model (Wigfield & Eccles, 2000) to be situated in the immediate and personal experiences (in our case, the media environment). The new development of SEVT emphasized a dynamic, not static, formation of an individual's motivation, and such a dynamic view argued for a developmental growth perspective and more intricate intermediary pathways in the self-assessment mechanism (Chen et al., 2021; Eccles & Wigfield, 2020; Gladstone et al, 2022). Most importantly, SEVT "discuss(ed) the often-neglected middle part of the model focused on how individuals understand and interpret their own performance as well as the many messages they receive from different socializers regarding their activity participation and performance" (Eccles & Wigfield, 2020, p. 1). In the context of our discussion, the different socializers are the different forms of media. They may deliver various messages of the nature of a STEM career, such as what STEM jobs and activities entail, who succeeds in STEM, and what values a STEM career may afford. Individuals compare these messages to their own experiences and personal value system to interpret (1) if there exists a good match and (2) what the expectancy is that "people like me can be successful in this field." Taken together, SEVT strongly suggested an indirect mechanism for media influence on young people's STEM career interests via the personal value system and identity.

This theory has been supported by a long list of qualitative and quantitative empirical studies (see examples in Anderson & Ward, 2013, Caspi, 2019, and Wigfield & Eccles, 2000). Most notably, Anderson and Ward (2013) showed that college students' interest and persistence in STEM can be traced back to their attainment value and utility value that they had held during high school. Based on Expectancy-Value Theory, scholars have proposed media product designs that may promote the perceived value of STEM activities, such as introducing the real-life-relevancy of science through sports games (Metcalf et al., 2008) or introducing personal values through role-playing in an alternative reality (Gilliam et al., 2016). Ball et al. (2017) further argued that STEM disparity is closely linked to digital disparity, in that inequality in students' access to digital media has led not only to an underexposure to STEM information for underrepresented students, but has also intensified emotional stress vis-à-vis computer technology, which can be conceptualized as another form of "cost" in the Expectancy-Value Theory framework.

Combining the three theories into one framework

The three theories mentioned above are not mutually exclusive. Both Social Cognitive Theory and SEVT argue that the viewers need to actively internalize the media content into their self-motivational system to commit to a potential career path. SEVT explicitly incorporated the identity formation from the Social Cognitive Theory by specifying it as a key influence on one's expectancies for success ("is that person on TV representing me, can people like me succeed?"). Although the Cultivation Theory originally emphasized direct social programming, its recent evolution has considered media to first cultivate individuals' values and beliefs before influencing people's decisions and preferences (Gehrau et al., 2016; Shrum, 2011, 2012). Taken together, these theories imply a holistic mechanism for media to influence STEM career interests: a direct effect explained by Cultivation Theory, an indirect path via STEM identity implied by both Social Cognitive Theory and SEVT, and an indirect path via the personal value systems implied by SEVT and Cultivation Theory (as shown in Fig. 1). Yet, no empirical study has put these direct and indirect paths under test simultaneously.

Content in STEM media

The above mentioned framework may suggest different directions (positive or negative) of the media effects on STEM career interest, because the effects are highly dependent on the actual portrayal of STEM roles, the values conveyed, and the kind of reinforcement (reward or punishment) on STEM-related behaviors. Viewers may passively take in stereotypes of STEM persons from media and be motivated to opt in or out of STEM ("biology is about raising animals, I want to do science," or "scientists always wear a white coat, I don't like it.") (Baker & Leary, 1995; Buday et al., 2012; Cheryan et al., 2011; Flouri & Buchanan, 2002; Ruiz-Mallén & Escalas, 2012). In the meantime, these stereotypical messages about science are usually coupled with signals of (1) identity–for example, it is usually women who take care of

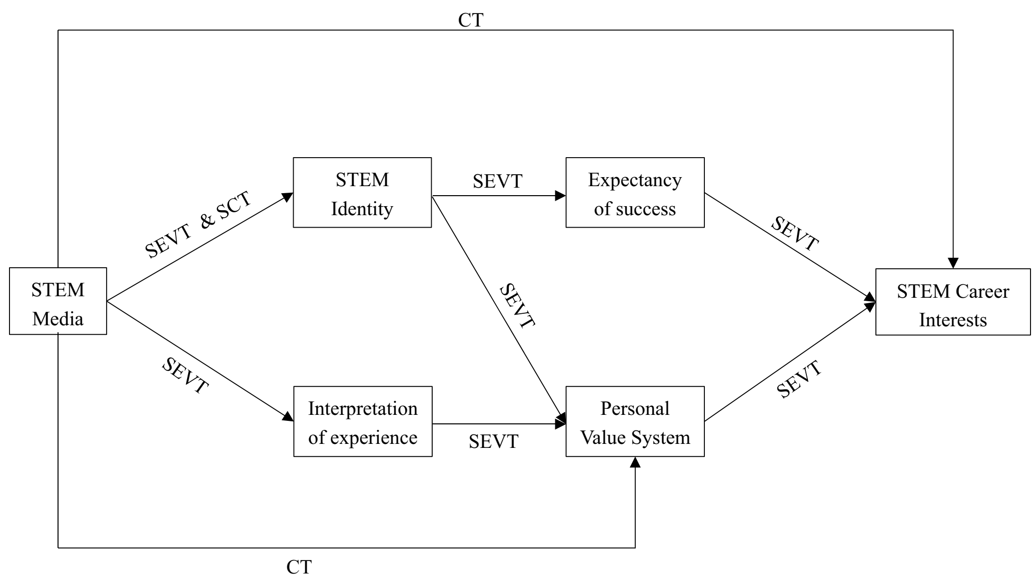

Fig. 1 A theoretical framework synthesizing the cultivation theory (CT), social cognition theory (SCT), and situated expectancy value theory (SEVT) to explain how STEM media consumption may influence STEM career interest through different pathways

the animals (even in the lab) (Dawson, 2000; Jones et al., 2000), and (2) personal value appraisal–for example, the myth that scientists do not care about money or being social (Cooper, 2018; Eagly & Diekman, 2003). These stereotypes entangled with identity and value may activate the intermediary pathways in the abovementioned framework.

If we look into the literature of content analysis in STEM media, we often see favorable images of STEM persons or STEM matters (Bissonnette, 2014; Chandler, 2012; Demirbas, 2009; Potter, 2008; Warren et al., 2016; Yang, 2023). The scientists often solve the mysteries and save the day (Allen, 2009; Kirby, 2017; Nisbet & Dudo, 2013), they are often morally innocent and respectable (usually before they become rich and powerful) (Dudo et al., 2011; Pansegrau, 2008), and they are being admired and positively reinforced by others because of their intelligence (Chambers, 1983; Pansegrau, 2008). STEM matters are usually presented in artistically pleasing ways. For example, science documentaries tend to show the marvelous universe, beautiful nature, striking phenomena, and serene microscopic images (Bissonnette, 2014; Kahle et al., 2016, Stepanova et al., 2019; Yang, 2023). Such awe-inspiring images may create a sense of wonder and intellectual aspirations among the viewers (Anderson et al., 2020; Hadzigeorgiou et al., 2012; Kang et al., 2009; Urban, 2023). Educational STEM shows nearly always show successful demonstrations of scientific investigations or experiments (Hickey et al., 2003; Hofstein & Lunetta, 2004), augmenting viewers' expectancy of success. Not all such rosy images of science are authentic, but they are positive messages.

Nevertheless, a large body of content analysis also documents the tenacious narrow and unfavorable portrayal of STEM-related professions in contemporary media that heavily emphasize scientists' personal behaviors and shortcomings or offer a distorted view of their job (Barman, 1999; Bianchini et al., 2000; Finson, 2002; Funk, 2003; LaFollette, 1992; McDuffie, 2001; Schibeci, 2006; Terzian & Grunzke, 2007). Scientists in the movies are usually portrayed to be White or Asian and male (Brooks & Hébert, 2006; Long et al., 2001), alienating the traditionally minoritized groups. Some studies showed that scientist characters scarcely appear in television programs (Dudo et al., 2011) and that, even when they are incorporated in the storyline, their character is often dramatized in a dichotomous fashion, either as "good," "humanitarian idealist" or as "bad" or "strange" (Gebner, 1985; Nisbet et al., 2002; Robinson, 1976). Other studies suggested that scientists are often portrayed in the media as "fumbling and quirky or arrogant and egotistical" (Moreno, 2014, p. 1), or are heavily stereotyped, accentuating the gender, racial, and age stereotypes of STEM-related professions (Archer et al., 2010; Capobianco et al., 2011; Fralick et al., 2009; Fung, 2002; Lachapelle et al., 2012; Odell et al., 1993). All of these may foster youth's common perceptions of STEM professionals as a privileged socially-awkward individuals who tend to work alone (Barman, 1996, 1999a, 1999b; Buck et al., 2008; Christidou et al., 2016; Cheryan et al., 2013; Fort & Varney, 1989; Google-Gallup, 2015; Huber & Burton, 1995; Knight & Cunningham, 2004; Laubach et al., 2012; Maoldomhnaigh & Mhaolain, 1990; Mercier et al., 2006; Parsons, 1997; Scherz & Oren, 2006; Steinke et al., 2007; Steinke et al., 2017). Empirical studies have found these negative images of STEM to adversely affect individuals' perceptions, values, and interest towards STEM professions (Chory-Assad & Tamborini, 2003; Dudo et al., 2011; Krumboltz et al., 1976; Pfau et al., 1995).

Implications of media types

As suggested by the varied results from prior empirical studies, it is unreasonable to assume that the effects of media on STEM career interest are all the same across different media types (i.e., Dou, et al., 2019). This is consistent with Nisbet et al.'s (2002) study, which provides evidence that different media types, i.e., paper-based reading, general television, and science television, affect perceptions about science differently due to differing mechanisms being active in the background. For instance, only science reading had an indirect effect, boosting positive perceptions about science through increased factual and procedural knowledge in science; general television watching, however, adversely affects science interest, because the often negative images of science on television appear to depress objective levels of science knowledge and cultivate reservations about science.

Interestingly, the development of new media—such as apps, social media, and YouTube channels—has steered STEM out-of-school learning from the lecture mode (such as in television) to peer conversation and hands-on experience. For instance, Pollara and Zhu (2011) showed that a high school science-mentoring program was more effective when it was delivered via Facebook, rather than in a traditional school setting, because (1) students could communicate instantly and informally with mentors or peers on Facebook, and (2) seeing others' posts and replies made students think about science ideas and issues deeply and constantly. The most popular STEM influencers are no longer teacher or scientist figures from the older generation, but are peers with whom youths can identify (Nouri, 2018). Hands-on exercises and experiments also shifted from TV demonstrations that often require special gadgets and materials to self-made video productions, app development, or programming that can be done with computers or tablets (Chen et al., 2016). More importantly, the new media were built on a culture of sharing and entrepreneurship, which may bring about a new perspective on STEM that counteracts the traditional stereotypes (Chesky & Goldstein, 2016).

Missing pieces and rationale

Despite this extensive literature and synthesis of different theories to describe the dynamic relationships between media and STEM career interest, as shown in Fig. 1, most of past research did not discern the direct effects, indirect effects, and different paths simultaneously within one framework. Thus, we do not know to what extent STEM media may exert a direct influence on youths' STEM career interest, and to what extent their influence is mediated through an internalization mechanism. Only by specifying multiple indirect pathways can we observe both positive and negative influences of STEM media consumption taking place simultaneously through different mechanisms. Besides, most of the prior literature focused on one media product or platform; seldom did any one study investigate and compare different types of media in terms of their effects on students' STEM career interest. Lastly, few studies looked into the time-lagged effect of STEM media usage during the high school years on college-level STEM career interests (Sadler et al., 2012).

To address these challenges, we need to have a large sample, collect participants' pre-college media consumption and in-college STEM career interests, and measure participants' STEM identity and personal value system, before we can build mediation models to discern the effects of different pathways. We also need to collect and control for background variables such as gender, race, and parental education because an extensive literature shows that these variables may influence how learners self-select into informal STEM experiences (Alexander et al., 2012; Hazari et al., 2013; Riegle-Crumb et al., 2011). Thus, they may potentially confound our estimation of the media effects.

Research questions

This study is intended to address this gap by digging deeper into these mechanisms and asking the following two research questions:

RQ1: Is there a direct effect of STEM media consumption during high school on STEM career interests in college? Specifically, for each type of high school STEM-related media consumption defined in the study, what is its effect on STEM career interest in college, after controlling for covariates?

RQ2: Are there indirect effects of STEM media consumption during high school on STEM career interests in college? Specifically, to what extent is the effect of each type of STEM-related media on students' STEM career interest mediated by students' STEM identity and their personal value system?

It is noteworthy that, in this correlational study, we use "effect" to indicate an associational effect, not a causal effect.

Data and methods

Survey

The data used for this research are taken from a survey—*Collaborative Research: A study of How Informal Activities Influence Female Participation in STEM*—administered in 2017 to a national sample of first-year college students in the United States. The survey was administered in freshman year introductory English classes. Sampling compulsory English classes is advisable in STEM education research conducted in higher education institutions (Chen et al., 2020b; Kitchen et al., 2022) because it covers the full range from students interested in STEM to those who are uninterested. If we only sampled within STEM tracks or courses, we would encounter the problem of restricted range (Wiberg & Sundström, 2009) and could retrieve only the prior experiences of those who already have strong STEM affinity and would not be able to build models to use prior experiences predicting STEM affinity. For sampling purposes, we used two stratification criteria: first, we drew a distinction between 2-year and 4-year institutions; second, each of these two institutional types was further stratified by the size of the institution (small, medium and large). From a total of 5,189 institutions registered in the Integrated Postsecondary Education Data System (IPEDS) website (3024 4-year schools and 2165 2-year schools), we obtained 2012 enrollment numbers for American 2-year and 4-year institutions. Lastly, we excluded all institutions with fewer than 1000 students enrolled and ended up with a total of 1476 4-year institutions and 900 2-year institutions, from which we could recruit First Year students. The sample included a total of 15,752 respondents, 44.7% of whom identified as male, 54.6% as female, and 0.7% as others. Table 1 presents descriptive statistics for our sample.

The participants responded to questions about their demographic background, career interests at the beginning of high school and at the beginning of college, endorsement of personal values that contribute to future career satisfaction, STEM identity, experiences with STEM media, and other possible factors influencing their interest in STEM careers. From these questions, we extracted and operationalized several variables that are relevant to our research questions, as outlined below.

Table 1 Descriptive statistics of variables

	Mean or percentage	S.D
STEM Career Interest – Beg. of College (0 = non-STEM; 1 = STEM)	Non-STEM: 69.1% STEM: 30.9%	
STEM Learning Interest (Likert scale, 0 = No, not at all to 5 = Yes, very much)	2.60	1.62
Readings (0 = Blank/Never engaged, 1 = Sometimes, 2 = Often)	0.94	0.71
Watching TV and Games (0 = Blank/Never engaged, 1 = Sometimes, 2 = Often)	0.78	0.68
Using STEM Apps (0 = Blank/Never engaged, 1 = Sometimes, 2 = Often)	0.40	0.54
Overall Media Exposure (0 = Blank/Never engaged, 1 = Sometimes, 2 = Often)	0.65	0.53
Gender	Male: 45.0% Female: 55.0%	
Race	White: 66.1% Asian: 14.7% Black: 12.2% Hispanic: 4.1% Indian Native: 1.3% Other: 1.7%	
Parents' Education (Average of parents' highest level of education; 0 = Less than High School Diploma, 1 = High School Diploma/GED, 2 = Some College/Associate Degree, 3 = Bachelor's Degree, 4 = Master's Degree or Higher)	0.62	0.26
STEM Career Interest – Beg. of High School (0 = non-STEM; 1 = STEM)	Non-STEM: 66.5% STEM: 33.5%	

Outcome of interest: STEM career interest at the beginning of college

The outcome of interest in this study is STEM career interest (a binary variable) at the beginning of college. Participants were asked to choose the career they were most interested in pursuing from a list of 23 possible careers. STEM career interest in this context is defined as any responses indicating Astronomer, Biologist, Chemist, Earth/Environmental Scientist, Physicist, Other Scientist, Computer Scientist/Programmer, Engineer, and Mathematician/Statistician as occupation of interest. Similarly, the survey captured participants' STEM career interest at the beginning of high school. We used students' career interest at the beginning of college as our dependent variable, while including students' career interest at the beginning of high school as a control variable for prior STEM interest.

Key predictor: STEM media exposure

Our main predictor variable is STEM media exposure. Respondents answered how often (0 = have never engaged with that particular media type, 1 = sometimes, and 2 = often) they engaged with different kinds of STEM-related media between 9 and 12th grade (self-assessed, see its limitation discussed in "Limitations and future work"). We first ran a factor analysis to identify underlying latent variables that might suggest possible groupings of these various STEM media exposure items. Our factor analysis yielded a 3-factor solution with moderate separation between factors (see Table 2): (a) STEM reading (including non-fiction science and science fiction); (b) STEM related TV or video (including watching STEM-related TV programs, movies, online videos, and playing video games); and (c) STEM apps (including following STEM on social media, using STEM apps, creating online STEM content, and writing or designing programs/apps). This factor analysis used Weighted Least Square Mean and Variance (WLSMV) estimator that treated the observed indicators as ordered categorical variables and estimated probit coefficients. The model had an adequate model fit: $\chi^2 = 2755.63$, df = 24, $p < 0.001$; RMSEA = 0.08; CFI = 0.99; SRMR = 0.03.

Table 2 Measurement model for STEM media consumption

	β	SE	Sig
TV/GAME			
TV	1.000	0.000	***
Video	1.063	0.007	***
Games	1.061	0.008	***
READ			
Non-fiction	1.000	0.000	***
Fiction	1.026	0.012	***
APP			
Social media	1.000	0.000	***
Apps	0.989	0.005	***
Blog	1.018	0.005	***
Coding	0.901	0.006	***
Covariation			
TV			
READ	0.505	0.006	***
APP	0.630	0.006	***
READ			
APP	0.480	0.007	***

The observed items are categorical variables. Therefore, probit coefficients are calculated using WLSMV estimator. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$ after Bonferroni p value adjustment due to multiple comparisons

Mediators: STEM identity and personal values

STEM Identity was constructed from five items that probed STEM identity, namely "I see myself as a STEM person," "My family sees me as a STEM person," "My Friends/classmates see me as a STEM person," "My classroom STEM teachers see me as a STEM person," and "My out-of-school teachers see me as a STEM person." The response to each of this item was on a Likert scale, taking values of 0–5, where 0 indicated "No, not at all," and 5, "Yes, very much."

The "type of person" is a common phrase used by youth to describe (STEM) identity (Shanahan, 2008). Combining the ratings on "see me as a STEM person" from multiple viewpoints is a common approach to measure STEM identity in survey studies (Carlone, 2004; Dou et al., 2019; Kang et al., 2019; Pugh, 2004; Rahm, 2007; Rahm & Ash, 2008). Although this approach cannot capture the nuanced sub-dimensions in the definition of STEM identity, research has shown this measurement correlates strongly with other sub-dimensions (Hazari et al., 2007, 2010, 2015; Shanahan, 2007, 2008).

Personal Values were constructed from a list of ten items that asked the importance of an attribute to the respondents' future career satisfaction. Each item was on a Likert scale, taking values of 0–5, where 0 indicated "Not at all important," and 5, "Extremely Important."

Based on a factor analysis, we grouped the items into four categories of Personal Values: Self Development ("Invent new things," "Develop new knowledge and skills," "Making my own decisions," "Have an exciting job," "Make use of my talent," "Have a lot of job opportunities," "Have a creative job"), Work Life Balance ("Have lots of family time," "Have lots of time for myself"), Material Status ("Make money," "Become well known," "Have others working under my supervision"), and Interpersonal ("Help other people," "Work with people rather than objects").

The measurement model for all the mediator variables (5 latent factors) used the WLSMV estimator that treated all observed items as ordered categorical variables. This model had adequate model fit ($\chi^2 =$ 12,804.99, df = 142, $p < 0.001$; RMSEA = 0.07; CFI = 0.99; SRMR = 0.05).

Control variables

To control for other variables that may affect STEM career interest, we included the following covariates, namely Career Interest at the beginning of High School, Gender (male vs. female), Race/Ethnicity (Hispanic, non-Hispanic White, non-Hispanic Black, non-Hispanic Asian, or non-Hispanic Other), and Parents' Education (0 = Less than High School Diploma, 1 = High School Diploma, 2 = Some College/Associate Degree, 3 = Bachelor's Degree, and 4 = Master's Degree or Higher").

Analysis

We constructed a Structural Equation Model (SEM) with the following specification: (a) the outcome of interest—STEM Career Interest (at the beginning of college) was predicted by both STEM Media Exposure latent variables (Reading, Video Viewing and Gaming, and Apps) and the mediator latent variables (Identity, Self-Development, Work-Life Balance, Material Status, and Interpersonal), while controlling for the covariates; (b) all mediator variables covaried with each other and were predicted by STEM Media Exposure, while controlling for the covariates. In other words, STEM Media Exposure potentially has direct paths to STEM Career Interest, as well as indirect paths via the mediator variables.

It is noteworthy that participants were nested in English classes. Typically, a hierarchical modeling approach is necessary to account for the two-level nature of the data structure. However, the key predictors (media exposure) occurred before the nesting event. In other words, the nesting is a post-treatment event, which should not be adjusted for according to established literature in statistics (Montgomery et al., 2018; Rosenbaum, 1984), cautioning that adjusting for post-treatment information may increase bias in estimation, instead of decreasing the bias. Nonetheless, we estimated a base hierarchical model for the outcome variable without predictors and found that the ICC was very small (0.03), indicating that only a very tiny amount of the variation in the outcome variable was explained by classroom clustering. For these reasons, we did not adopt a hierarchical modeling approach.

Table 3 Measurement model for STEM identity and personal value system

	β	SE	Sig
IDENTITY			
I [see me as a STEM person]	1.000	0.001	***
Family …	1.023	0.001	***
Friends …	1.032	0.001	***
School teachers …	1.028	0.001	***
Other teachers …	1.003	0.001	***
Personal value system:			
SELF-DEVELOPMENT			
Invent new things	1.000	0.008	***
Develop new knowledge and skills	1.136	0.008	***
Making my own decisions	1.165	0.008	***
Have an exciting job	1.300	0.007	***
Make use of my talent	1.363	0.007	***
Have a lot of job opportunities	1.152	0.008	***
Have a creative job	1.192	0.007	***
WORK-LIFE BALANCE			
Have lots of family time	1.000	0.009	***
Have lots of time for myself	0.906	0.009	***
MATERIAL STATUS			
Make money	1.000	0.011	***
Become well known	1.661	0.009	***
Have others working under my supervision	1.608	0.009	***
INTERPERSONAL			
Help other people	1.000	0.01	***
Work with people rather than objects	0.956	0.01	***
Covariation			
IDENTITY			
SELFDEV	0.067	0.012	***
WORKLIFE	− 0.044	0.012	**
MATERIAL	− 0.008	0.013	**
INTERPER	− 0.033	0.014	
SELFDEV			
WORKLIFE	0.220	0.01	***
MATERIAL	0.131	0.01	***
INTERPER	0.201	0.012	***
WORKLIFE			
MATERIAL	0.138	0.012	***
INTERPER	0.237	0.013	***
MATERIAL			
INTERPER	0.104	0.014	***

The observed items are categorical variables. Therefore, probit coefficients are calculated using WLSMV estimator. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$ after Bonferroni p value adjustment due to multiple comparisons

Results

Model fit

The SEM model yielded a good model fit with χ^2 (434) = 13,708.68, $p < 0.001$, RMSEA = 0.05, SRMR = 0.06, and CFI = 0.99. Table 4 shows the coefficients for the

Table 4 Coefficients for the structural components of the model

	β	SE	Sig
STEM career interest ON			
READ	– 0.042	0.015	
TV/GAME	0.030	0.017	
APP	0.006	0.016	
IDENTITY	0.519	0.013	***
SELFDEV	0.526	0.026	***
WORKLIFE	0.116	0.018	***
MATERIAL	– 0.399	0.024	***
INTERPERSO	– 0.709	0.022	***
Male	0.122	0.013	***
Parent edu	– 0.017	0.013	
Beginning of HS STEM career interest	0.618	0.012	***
IDENTITY ON			
READ	0.031	0.012	**
TV/GAME	0.221	0.013	***
APP	0.069	0.012	***
Male	0.111	0.01	***
Parent edu	0.081	0.01	***
Beginning of HS STEM career interest	0.522	0.01	***
SELFDEV ON			
READ	0.001	0.012	
TV/GAME	0.024	0.015	***
APP	0.067	0.014	***
Male	– 0.029	0.011	***
Parent edu	– 0.035	0.011	***
Beginning of HS STEM career interest	0.016	0.011	
WORKLIFE ON			
READ	– 0.046	0.013	***
TV/GAME	– 0.022	0.015	
APP	0.048	0.014	***
Male	– 0.049	0.011	***
Parent edu	– 0.067	0.011	***
Beginning of HS STEM career interest	– 0.063	0.011	***
MATERIAL ON			
READ	– 0.052	0.014	***
TV/GAME	– 0.024	0.016	***
APP	0.084	0.015	***
Male	0.083	0.012	***
Parent edu	– 0.041	0.012	***
Beginning of HS STEM career interest	– 0.040	0.012	***
INTERPER ON			
READ	0.028	0.014	**
TV/GAME	– 0.026	0.017	*
APP	0.050	0.016	***
Male	– 0.256	0.012	***
Parent edu	– 0.033	0.012	***
Beginning of HS STEM career interest	– 0.274	0.012	***

When the outcome of the prediction is STEM career interest (a binary variable), the coefficients are probit coefficients. Other coefficients are linear regression coefficients. The measurement components of the model are not shown in this model, they are nearly identical to the coefficients shown in Tables 2 and 3. Capitalized variables are latent variables. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$ after Bonferroni p value adjustment due to multiple comparisons

structural paths of the model. The measurement components of the model are not shown in Table 4 because they were very similar to the coefficients reported in Tables 2 and 3. Because we had both categorical (i.e., STEM Career Interest and indicator items for latent variables) and continuous (i.e., latent variables) endogenous variables in the model, we used the WLSMV estimator. In Table 4, when the outcome of a path was STEM Career Interest, the paths coefficients are probit coefficients. A probit coefficient represents the change in the z-score of the latent scale underlying the observed binary (outcome) variable that is associated with a one-unit change in the predictor. In predictions of latent mediator factors (e.g., Identity), which are already on a continuous z-score scale, the path coefficients are the linear regression coefficients. Table 2 reports the unstandardized path coefficients. The standardized coefficients are displayed in the path diagram shown in Fig. 2. In the Tables and in the following text, we will use capitalized variable names for latent variables.

Path coefficients

We observed that none of the three kinds of STEM media exposure, i.e., reading STEM books, STEM video viewing and gaming, and using STEM applications, had any statistically significant direct effect on STEM Career Interest (READ: β=-0.042, se = 0.015, $p > 0.05$; TV/GAME: $\beta = 0.030$, se = 0.017, $p > 0.05$; APP: $\beta = -0.006$, se = 0.016, $p > 0.05$).

Looking at STEM media exposure and the mediator variables, we observed that different kinds of media had different effects on different mediator variables.

- All three media types had significant positive effects on IDENTITY (READ: $\beta = 0.031$, se = 0.012, $p < 0.001$; TV/GAME: $\beta = 0.221$, se = 0.013, $p < 0.001$; APP: $\beta = 0.069$, se = 0.012, $p < 0.001$), with TV/GAME having the largest effect.
- With respect to SELF-DEVELOPMENT, TV/GAME and APP had significant positive effects (TV/GAME: $\beta = 0.024$, se = 0.015, $p < 0.001$; APP: $\beta = 0.067$, se = 0.014, $p < 0.001$), but READ did not.
- Regarding WORK-LIFE BALANCE, READ had a negative effect ($\beta = -0.046$, se = 0.013, $p < 0.001$), APP had a positive effect ($\beta = 0.048$, se = 0.014, $p < 0.001$), and TV/GAME had no significant effect.
- Regarding to MATERIAL STATUS, READ and TV/GAME had negative effects (READ: $\beta = -0.052$, se = 0.014, $p < 0.001$; TV/GAME: $\beta = -0.024$, se = 0.016, $p < 0.001$), and APP had a positive effect ($\beta = 0.084$, se = 0.015, $p < 0.001$).
- Lastly, with respect to INTERPERSON value, we observed that READ and APP had positive

effects (READ: β = 0.028, se = 0.014, $p < 0.001$; APP: β = 0.050, se = 0.016, $p < 0.001$), whereas TV/GAME had a negative effect (β = − 0.026, se = 0.017, $p < 0.05$).

Considering how mediator variables predicted STEM Career Interest, we observed that IDENTITY (β = 0.519, se = 0.013, $p < 0.001$), SELF-DEVELOPMENT (β = 0.526, se = 0.026, $p < 0.001$), and WORK-LIFE BALANCE (β = 0.116, se = 0.018, $p < 0.001$) had positive effects on STEM Career Interest, whereas MATERIAL STATUS (β = 0.339, se = 0.024, $p < 0.001$) and INTERPERSONAL (β = 0.709, se = 0.022, $p < 0.001$) values had negative effects.

Figure 2 displays the significant paths in the structural part of the model. The path coefficients are standardized coefficients. The items for the latent variables, control variables, and covariances among independent variables are not shown in Fig. 2, but are included in the model.

Total effects and indirect effects

For each type of media exposure, Table 5 shows its direct effect, indirect effect via each mediator, and total effect on STEM Career Interest. Among all three types of STEM media exposure, only TV/GAME had significant total effect on STEM Career Interest (β = 0.028, se = 0.014, b = 0.153, $p < 0.001$). Because the direct effect of TV/GAME was not significant, its indirect effect contributed to nearly all (84%) of its total effect. In other words, the effect of TV/GAME was almost completely mediated via the internalization mechanism. Among the sum of indirect effects of TV/GAME, the positive path via IDENTIY contributed 75%, which was the largest effect among all indirect (or direct) pathways. In addition, TV/GAME had a positive indirect effect due to the product of the two positive paths via SELF-DEVELOPMENT (double positive, β = 0.013, se = 0.004, b = 0.011, $p < 0.001$). It also had a positive indirect effect due to the product of the two negative paths via MATERIAL STATUS (double negative, β = 0.009, se = 0.008, b = 0.008, $p < 0.001$).

The total effects of READ and APP were not statistically significant. Neither of their direct effects were significant. For each of the two types of media exposure, its indirect effects on STEM Career Interest canceled each other out via different pathways, because they had mixed signs. READ had a positive indirect effect on STEM Career Interest via IDENTITY (double positive, β = 0.016, se = 0.006, b = 0.013, $p < 0.01$) and MATERIAL STATUS (double negative, β = 0.021, se = 0.004, b = 0.017, $p < 0.01$). In the meantime, READ had a negative indirect effect via WORK-LIFE BALANCE (negative positive, β = 0.016, se = 0.006, b = 0.013, $p < 0.01$)

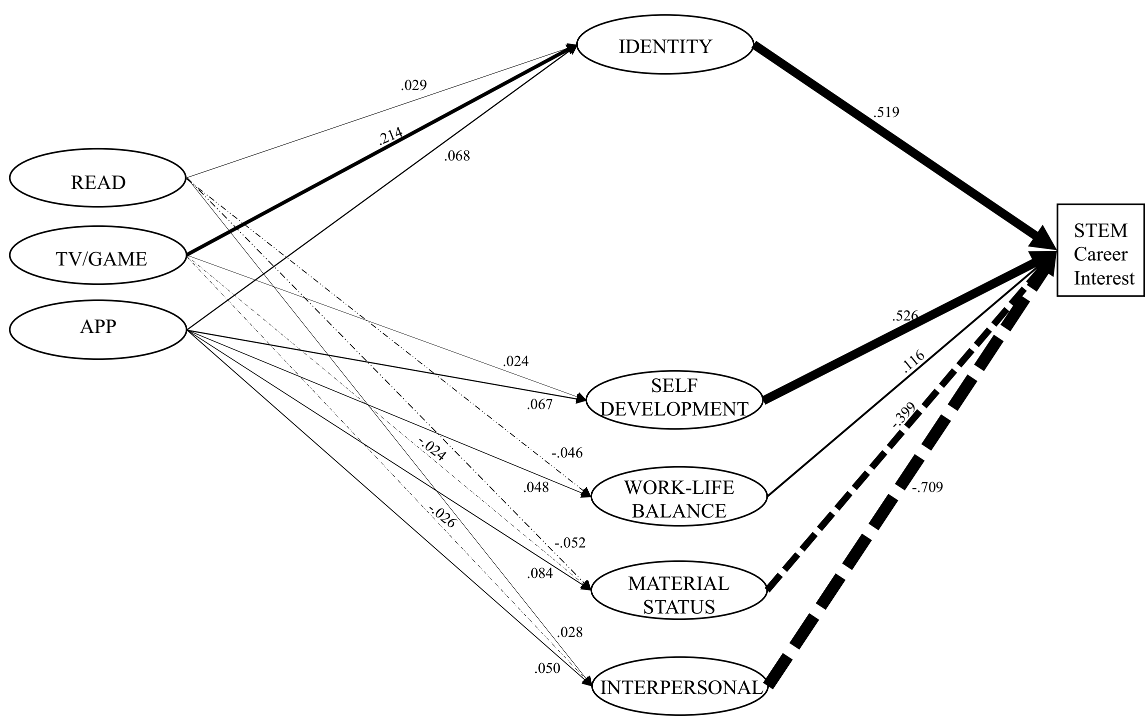

Fig. 2 Structural equation model result showing the significant paths and their standardized coefficients. The widths of the paths are proportional to their coefficients. The solid lines indicate positive effects, hashed lines indicate negative effects. For display purpose, the controlled variables and the items for latent variables are not shown in this graph

Table 5 Direct effect, indirect effect and total effect of each of the three types of STEM media on STEM career interest

	β	SE	b	Sig
READ				
Direct effect	− 0.042	0.018	− 0.034	
Indirect effect via				
IDENTITY	0.016	0.006	0.013	**
SELFDEV	0.001	0.004	0.001	
WORKLIFE	− 0.005	0.002	− 0.004	**
MATERIAL	0.021	0.004	0.017	***
INTERPER	− 0.020	0.007	− 0.017	**
Total effect	− 0.030	0.018	− 0.024	
TV/GAME				
Direct effect	0.030	0.020	0.025	
Indirect effect via				
IDENTITY	0.115	0.008	0.096	***
SELFDEV	0.013	0.004	0.011	***
WORKLIFE	− 0.003	0.002	− 0.002	
MATERIAL	0.009	0.008	0.008	*
INTERPER	0.030	0.020	0.016	
Total effect	0.183	0.020	0.153	***
APP				
Direct effect	0.006	0.018	0.005	
Indirect effect via				
IDENTITY	0.036	0.007	0.031	***
SELFDEV	0.035	0.006	0.030	***
WORKLIFE	0.006	0.002	0.005	***
MATERIAL	− 0.033	0.006	− 0.028	***
INTERPER	− 0.035	0.008	− 0.030	***
Total effect	0.014	0.019	0.012	

β is the unstandardized probit coefficient, b is the standardized coefficient, se is standard error for β. *p < 0.05; **p < 0.01; ***p < 0.001 after Bonferroni p value adjustment due to multiple comparisons

and INTERPERSONAL (negative positive, $\beta = 0.020$, $se = 0.007$, $b = 0.017$, $p < 0.01$). APP had positive indirect effects via IDENTITY (double positive, $\beta = 0.016$, $se = 0.006$, $b = 0.013$, $p < 0.01$), SELF-DEVELOPMENT (double positive, $\beta = 0.016$, $se = 0.006$, $b = 0.013$, $p < 0.01$) and WORK-LIFE BALANCE (double positive, $\beta = 0.016$, $se = 0.006$, $b = 0.013$, $p < 0.01$). APP also had a negative indirect effect via MATERIAL (positive negative, $\beta = -0.033$, $se = 0.006$, $b = -0.028$, $p < 0.01$) and INTERPERSONAL (positive negative, $\beta = -0.035$, $se = 0.008$, $b = -0.030$, $p < 0.01$).

Discussion

Looking back at our research questions, we can summarize our primary findings as follows: With respect to RQ1, we found that no type of media usage had a direct effect on STEM career interest. With respect to RQ2, only STEM video viewing and gaming had a significant total—positive-effect on STEM career interest at the beginning of college, after controlling for a list of covariates, but the effect of STEM video viewing and gaming was completely mediated via STEM identity and personal value system, among which the paths via STEM identity contributed the majority of the effect. STEM reading and STEM app using had a positive indirect effect via STEM identity and a mixed indirect effect via the personal value system, but the total effect was not significantly different from zero because the mixed indirect effects canceled each other out.

The main message of this study is that (1) STEM media exposure in high school is not directly related to STEM career interest at the beginning of college; (2) STEM identity is the key mediator between STEM media exposure and STEM career interest; and (3) different types of STEM media affect students' career interest differently via the personal value system. It is noteworthy that this study examined the long-term or delayed effects of STEM media, where we observed the connection of media exposure during high school with STEM career interest at the beginning of college. It is not clear how the delayed effects would compare to immediate effects, but we speculate that the time delay in the data structure may have led us to observe smaller effects of STEM media, as compared with prior studies that examined the short-term effects (e.g., Gilliam et al., 2016; Metcalf et al., 2008).

Reflection on the theoretical frameworks

Reflecting back on our synthesized theoretical framework (Fig. 1) that conceptualized the dynamic relationships between media and STEM interest, we specified a direct effect (primarily motivated by the Cultivation Theory) and two mediating pathways via personal value system and STEM identity (motivated by a convergence of SEVT, Social Cognition Theory, and Cultivation Theory). Our findings did not find support for the direct effect that claimed youths' career interests might be directly influenced by their media exposure. This was not surprising, given that the recent development in Cultivation Theory itself has moved away from positing direct and uniform effects to specifying indirect and individual effects via more fine-grained personality and value pathways (Shrum et al.,). Our findings strongly support the overlapping part of the three theories that emphasizes the central role of identity development (with relatively stronger indirect effects) and personal value system (with relatively smaller indirect effects).

STEM video viewing and STEM video games

Because our models show that, among all examined types of STEM media, STEM TV, STEM video watching, and STEM-themed video games were the only contributors to the total effect of STEM media on STEM career interest, and that most of the mediation effects were channeled through STEM identity, we infer that video or games are especially able to provide positive role models that adolescents can easily relate to and identify with (believing that "I am a science person"), compared with reading STEM books or using/developing STEM applications. Applying the lenses of the aforementioned theories, the particularly strong effect of STEM TV and Video Games might be attributed to these activities allowing more varied, more frequent, and more immersive modeling or experience, possibly through the use of storylines and role-plays, such that STEM becomes a more relatable and inviting path for adolescents (Akbar et al., 2018; Madani et al., 2017).

Large volumes of literature have shown that STEM interests are positively associated with intellectual-development and actualization goals and negatively associated with material or interpersonal goals (Diekman, et al., 2011; Spencer et al., 2016). Our findings are consistent with the literature—that STEM TV or video games consumption is positively associated with the endorsement of self-development values, and negatively associated with material and interpersonal values. Because material and interpersonal values had negative effects on STEM career interest, the indirect effect of STEM video viewing and gaming on STEM career interest via each of the two mediators were positive (the product of two negative paths is positive). Our findings suggest that STEM TV or gaming content may frequently portray the STEM professions as solely interested in intellectual development and uninterested in material or interpersonal goals, which might further "fit" the students into a stereotypically defined STEM-person category.

STEM book reading

Our results show that reading science-fiction and science non-fiction did not have a significant total effect on STEM career interest, but had an indirect positive effect on STEM career interest via identity and material values. All of these effects were weak, ranging from 0.3% to 11% of the total effect of STEM video viewing and gaming exposure on STEM career interest. This finding is surprising because it contradicts some of the prior literature that showed a moderate positive association between STEM book reading and STEM career interests (e.g., Dou et al., 2019). One possible explanation is that, in the same model, we tested multiple types of media exposure that competed in explaining the variation in the outcome.

The negative effect of STEM reading on material and work-life balance values and positive effect on interpersonal value suggests a scenario in which STEM books highlighted and praised how scientists endured hardship (i.e., lack of financial reward and deprivation of leisure) in their scientific practice to serve the greater good (e.g., cure diseases), which might influence young readers to think lightly of material rewards (a personal value that encourages a reader to persist in STEM) and to think highly of interpersonal rewards (a personal value that discourages a reader to persist in STEM). This implication raises a question about the different storytelling about, or portrayal of, scientists or science activities in books and on television (or in video games). Do STEM books portray more of the social aspect of STEM than TV or video games do? Do both types of media glorify scientists' unswerving determination under financial hardship? Detailed content analysis in STEM media will be needed to answer these questions.

STEM apps

The effects of STEM applications on STEM career interests are very different from the effects of STEM reading, video viewing or gaming, because STEM applications had a positive effect on all of the mediator variables. This suggests that STEM applications may have provided a wholesome experience or personal growth to the users—that every life goal is valuable and worth pursuing—and avoided reinforcing a biased stereotype about STEM. The innovative, collaborative, and social media nature of STEM apps (i.e., programming one's own apps, developing and reading YouTube videos) may at the same time encourage more peer interaction (interpersonal values), creativity (self-development values), entrepreneurship (material values), and playful learning (work-life balance) (Heljakka & Ihamäki, 2019; Larkin & Lowrie, 2022; Miller, 2018). It is noteworthy that the largest effect of STEM app on mediator variables was on the material value, suggesting a culture of entrepreneurship shared by the new media, which may have expanded on the success stories of the contemporary businessmen who started off as STEM persons (e.g., Elon Musk).

Unfortunately, the interests in material and interpersonal values, as enhanced by STEM apps, were then negatively associated with STEM career or learning interests. This might imply a scenario in which, for instance, a STEM app development course that celebrates the business success of Elon Musk may make students more interested in making money, which in turn actually reduces their interest in a STEM career (perhaps in the context of students' ideas about easier ways to make money). More worrisome is the indirect effect via interpersonal values. While the STEM education field is adopting new media to push for a portrayal of STEM careers as fulfilling communal goals, the STEM apps that enhance students' interpersonal or communal values appear to diminish STEM interests, according to our findings.

Practical implications

The findings of this study carry several implications for multiple stakeholders involved in intervention designs that aim to foster students' STEM learning and/or career interest. For media producers and content creators, it is worth noting that, because the effect on STEM career interest is mostly mediated through identity, the structure of programs that seek to foster STEM career interest should be preferably of the "first-person shooter" kind, which may give students opportunities to solve problems or experience a professional role from the perspective of a STEM person. This can be achieved, for example, by creating interactive programming where students can explore and experience a wide range of STEM-related roles and projects by themselves. Supported by our finding about STEM apps and borrowing the example from immersive marketing, having TV shows that are supported by an ecosystem of its own online videos (e.g., YouTube channel), social media, and even video games or interactive apps for a more intensive user engagement, might be a promising strategy to not only boost identity development, but also promote a more balanced growth among adolescents.

Furthermore, STEM media producers or providers should put greater emphasis on building an aspirational, yet relatable storyline about STEM-related roles or projects. Here, a dilemma is posed by the findings of this study. Should STEM media conform to the traditional stereotypical images of scientists—intelligent, non-social, and uninterested in making money—which may more effectively enhance students' STEM learning or career interest? Or, should STEM media take the challenge to portray a fuller image of scientists—enjoying career and life satisfaction from multiple aspects—which may be less effective in attracting students into science? We offer a reflection from two perspectives. First, it is not, and should not be, the sole purpose of STEM media to recruit students into STEM. If a STEM app (or any other media) introduces a student to a non-STEM career, it still offers educational value. Second, our study suggests that, as some STEM media (i.e., STEM apps) were trying to counteract the traditional stereotypes of STEM, other STEM media (i.e., STEM TV or game) were reinforcing such stereotypes. Success in transforming the tenacious STEM stereotypes not only relies on introducing a balanced image of science in new media using cutting-edge platforms and technology, but also depends on revisiting the legacy portrait of science in the old media.

In addition to results interesting to media producers and content creators, this study also offers several important takeaways for teachers and educators who wish to foster students' STEM career interest, either in the classroom or in an out-of-school setting. From the perspective of STEM identity development, one should incorporate the principles of autonomy, competence, and relatedness in the instructional design (Ryan & Deci, 2000, 2001). This can be achieved, again, by creating a program or a space that gives students the agency to explore and be personally involved in a wide range of STEM-related roles and projects, such that they develop their own sense of ownership towards the projects (autonomy) (Annetta et al., 2014; Nino & Evans, 2015; Pivec et al., 2003); incorporating the "right" sense of fulfillment where students can both gain new mastery as well as capitalize on existing knowledge to cope with new challenges as they arise (competence) (Papastergiou, 2009; Whitton, 2015); and portraying STEM occupations as relatable and in congruence with students' interests, goals, values, and behaviors (relatedness) (Cain et al., 2022; Hidi & Renninger, 2006). In the context of instructional design, this means leveraging media to create more interactive, possibly game-based programs, where students can both experience and get rewarded for their achievement in the STEM-related roles of their choosing.

Limitations and future work

Because this study was conducted using nationally-representative survey data from the United States, its generalizability outside the United States remains to be demonstrated. We also add the standard caution that this is a correlational study that cannot unequivocally establish causality. The chicken-and-egg dilemma often encountered in studies of this kind (in our case, does media use cause career interest, or does career interest cause media use?) was somewhat alleviated by including STEM career interest at the *beginning* of high-school as a control variable. Yet we still cannot entirely rule out the possibility of a self-selection bias. Along with other external factors, e.g., students' family environment, classroom pedagogy, informal learning experiences, et cetera, this can potentially influence the results in ways unaccounted for. Another potential limitation is measuring career interest with dummies rather than with rating scales, which would reveal a more nuanced view of levels of commitment. However, we decided to use the dummy approach because questions of the type "what do you want to be?" have real-life validity. Young persons are probably used to deal with them frequently as they grow up.

Future work should closely examine and compare more specific types of media effects on both STEM learning and career interest, for instance, specific types of books, applications, coding programs, et cetera. This could provide more robust explanations of the weak and negative effects found in this study. In future studies, it would also be interesting to examine the content, such as the gender and racial stereotypes, in different types of STEM media and how it interacts with the viewers' gender and racial identity.

Furthermore, it is important to note that the media exposure variables used in this study are self-reported and also limited only to STEM-related media. In light of the latest media developments, it would also be worthwhile to look at media in a more general sense, covering mainstream TV, online videos, social media, and so forth, to see whether exposure to non-STEM-related media has any effect on STEM learning and/or career interest.

Lastly, because this study considers only a very specific time frame, i.e., media exposure during high school on STEM career interest at the beginning of college, future studies should also look at media exposure at multiple time points and compare its effect overtime. This would be valuable in shedding light on the optimal timing for conducting interventions that are geared toward cultivating STEM career interests. From an experimental standpoint, one could also consider a longitudinal study to evaluate an even longer-term effect of media, i.e., not just impacts on STEM career interests, but whether or not these interests are translated into real STEM majors or actual STEM careers.

Conclusion

Digital media offer a lot of fascinating applications in the field of education, including cultivating students' interest in STEM. This study finds that STEM media have a significant effect in fostering STEM career interest, with most of the effect coming from STEM TV, STEM video viewing, and STEM video games. The effect is mediated mainly through students' identity and, to a lesser extent, through personal values, such as self-development, material, and interpersonal relationship values.

Acknowledgements
This work was supported by the National Science Foundation (grant numbers 1612375 and 1611985). Any opinions, findings, conclusions, or recommendations expressed in this material are the authors' and do not necessarily reflect the views of the National Science Foundation. The authors would like to thank all members of the research team for their dedicated work. We also thank all the participating English professors and their students for making this study possible.

Author contributions
CC: writing manuscript, data analysis, literature review. SH: initial literature review, and exploratory data analysis. GS: data collection, manuscript editing. JH: literature review, manuscript editing. PMS: data collection, manuscript editing.

Availability of data and materials
Data is available upon request.

Declarations

Ethical approval and consent to participate
This research project has received IRB approval from Harvard University Committee on the Use of Human Subjects.

Consent for publication
Participation in the survey implied consent.

Competing interests
None of the authors have any competing interests in the manuscript.

Received: 26 January 2023 Accepted: 29 August 2023
Published online: 11 September 2023

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