An Exploration of Critical Incidents Impacting Female Students' Attitude Towards STEM Subjects

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Abstract: Science, Technology, Engineering and Math (STEM) subjects are extremely important to any nation's economy. For society to flourish sustainably there should be equal involvement of men and women in these professions. Even though the number of women in STEM areas has increased over the past several decades, there is still a sizable underrepresentation of women overall and in key positions. In the winter term 2020/21, among all the 1,090,804 students in STEM subjects at German universities, only 347,197 were female students (31,8%) (Statistisches Bundesamt, 2022). According to research by Corbett and Hill (2015), the following factors limit girls and women from majoring, for example, in computer science: Cultural prejudices, gender biases, and microinequities (subtle discriminatory actions) all contribute to a lack of sense of belonging in these sectors. Overall, this study aims to better understand the key situations that affect girls' and young women's decision for or against a career in STEM. In particular, the research is interested in finding out about subtle or obvious discriminatory but also facilitating actions which influence attitude towards STEM subjects. An online questionnaire was distributed to a student panel via a market research institute, which was answered by 777 German female students aged 16-20 years in May 2022. The questionnaire collected female students' memorable positive and negative critical incidents which had an impact on their attitude towards STEM subjects. On the one hand, female students reported a learning environment in school leading to fear, frustration or anxiety which result into them questioning their math or science competence. On the other hand, female students also reported very positive, memorable experiences and appraisal situations in and offsite the classroom which increase their positive attitude about STEM subjects and might lead to a future career choice in a STEM subject. The authors hope to spark a conversation about how institutions might better tailor their offers to a female audience.

Keywords: Women in STEM, STEM career, Female students, Education, Critical incidents

1. Introduction

The significance of educating women and girls in science, technology, engineering, and mathematics (STEM) originates from two main aspects. First, a person should not face any unjust obstacles and barriers based on gender and other discriminatory factors to gain access to STEM education. Secondly, the contribution of women in the STEM sector is considered highly significant for the economic and welfare development of a country. The STEM subjects form important fields of action of the German government's high-tech strategy due to their research, economic and prosperity potential (BMBF 2020). An equal gender-based participation within these fields is a prerequisite for the sustainable and future-oriented development of our society. However, the pattern of underrepresentation of women especially in the STEM disciplines persists in many European countries including Germany (BMBF 2020).

The lack of girls choosing and participating in STEM-related education contributes to the shortage of the STEM-skilled workforce (González-Pérez et al. 2020). This results in the exclusion of female perspectives in developing solutions as well as the scarcity of female candidates prepared to access leadership positions or high management positions such as board of directors which require an educational background in technological subjects (González-Pérez et al. 2020). Ample research has therefore been devoted within various countries from different perspectives and disciplines, including sociology, psychology, and biology, to understand barriers and factors that influence women's and girl's education and career choices (van Tuijl and van der Molen 2016).

This paper attempts to further explore these barriers that girls face in choosing STEM subjects for further education and career choices by examining girls' positive and negative experiences related to STEM subjects at school or in their free time.

2. Literature Review: Attitudes and Determinants Influencing Female Students' Career Choices in STEM

Girls and women face a prevalent inequality in STEM education worldwide, which is exacerbated in higher education and in certain subjects (Chavatzia 2017). Globally, a positive overall trend can be observed in girls' access to education. However, gender differences exist, especially in STEM subject enrollments. Girls seem to lose interest in STEM subjects as they get older, and more so than boys, especially in upper secondary education and this increases as the education level rises (Spearman and Watt 2013). As significant differences continue to exist across regions, countries and within countries, this situation invites reflection on the causes of gender segregation in STEM fields. The low participation and interest of female students is a complex problem with many influencing factors contributing to the choice and enrolment in STEM education and career. These determinants are derived from a range of disciplines and theories, including sociological, psychological, socio-cultural and socio-historical factors. A substantial body of literature is available in the domain of STEM (van Tuijl and van der Molen 2016).

Two psychological theories - Social Cognitive Career Theory (SCCT) and Expectancy-Value Model of Motivation (EVMM) - played a significant role in explaining the education and career choice behavior of students (van Tuijl and van der Molen 2016). Both theories suggest that career interest and choice form a complex human agency process. Some of the core influencing concepts include performance, self-efficacy (perceived capabilities or ability beliefs (EVMM)), subjective value, outcome expectations, goals as well as well-being and satisfaction. EVMM further describes four types of values: intrinsic values (expected enjoyment/interest in an activity or task), attainment value (perceived importance be competent at a task), utility values (perceived usefulness of a task in obtaining rewards/facilitating the achievement of goals) and perceived cost (in terms of effort and evoked emotions, such as fear of failure) (van Tuijl and van der Molen 2016). These values along with the ability beliefs may predict the educational and occupational preferences and choices. These psychological factors have many inter-relations. For instance, ability belief tends to predict a child's task values, and the subjective task values are closely linked to educational and career choices (Durik 2006).

The self-efficacy and task values are largely shaped by individual characteristics (e.g., abilities, experiences, goals, interests etc.) to environmental influences (cultural, peer beliefs and behaviors) (González-Pérez et al. 2020). Different obstacles in the form of environmental influences (school's learning environment, media, parents, peers) are witnessed in three developmental periods, childhood and adolescence, emerging adulthood and young to middle adulthood (Kaleva et al. 2019). In childhood and adolescence, gender stereotypes about STEM, parents' expectations of daughters, peer norms, and its lack of fit with personal goals repel girls from STEM fields (Kaleva et al. 2019). Parents', teachers' and peers' beliefs, behavior, perception, and attitude towards STEM can be passed on, implicitly or explicitly, shaping the girls own attitude towards STEM (Eccles 2015, Raabe 2009). Parents also shape their children's self-image through their feedback, both positively and negatively (Eccles 2009). The learning environment and the socialization process at school influence girls' interest and engagement in STEM, for instance, teachers' own STEM self-efficacy and gender stereotyping behavior could hinder their performance and intrinsic value of STEM subjects (Francis et al. 2017). Gender stereotyping has also shown to influence girls' ability beliefs, task values and STEM identity (Nix et al. 2015, Makarova 2019). From an early age, males are thought to have greater intellectual abilities than females, for example interest in math/physics is associated with males (Bian et al. 2017). Parents supporting traditional gender role stereotypes evaluate their children's competencies differently: In male-related activities, girls' abilities are underestimated and boys' are overestimated (Eccles 2009). In emerging adulthood, feeling like a misfit in STEM classes, being outnumbered by male peers, and lack of female role models make women avoid STEM majors or leave prematurely (Kaleva et al. 2019). Even women who selected math intensive majors find it difficult to associate with math compared to male gender (Nosek 2002).

Media as well plays a very important role in portraying characteristics of individuals working in STEM (i.e., people lacking social abilities, unattractive appearance etc.) (Steinke 2017). Despite their negative impact on girls STEM choice, there is evidence that the right interventions can allow the environmental influencers to create positive impact, fostering girls interests in STEM (van den Hurk et al. 2019, Rozek et al. 2015). In addition, increasing the female STEM role-models in class (female teachers), at home, and outside, can positively influence girls' attitudes toward STEM, boosts their STEM identity and sense of belonging (González-

Pérez et al. 2020). In addition, gender-responsive curricula and connecting it to real-world situations, as well as hands-on teaching approaches, such as labs, can promote girls' interest in STEM.

The spectrum of research in STEM over the world shows that cross-culturally, cross-nationally these factors can function and affect female student's STEM choice differently, making it important to understand each factor country and culture wise, and tailor the interventions and policies accordingly (Gebauer, M.M., 2021, Miralles-Cardona 2021). This paper supports this with a study of critical incidents reported by German school girls.

3. Methodology

An online questionnaire was used in May 2022 to gain data for this study. A reputable market research panel collected the data in Germany and 777 female students between 16-20 years from all German federal states finalized the questionnaire. Although the questionnaire consisted primarily of quantitative questions, it also included qualitative components. The critical incident technique which was originally proposed by Flanagan (1954) has been used to collect subtle or obvious discriminatory but also facilitating actions which influence girls' attitude towards STEM subjects.

23,4% of the participants are 16 years or younger, 15% are 17 years old, 29,3% 18 years old, 14,6% 19 years old and 17,8% are 20 years or older. The majority of girls (83%) are seeking to get A-Levels, 7,6% are seeking to get an advanced technical college entrance qualification and 9,3% are seeking to get a secondary school certificate. From the overall sample, 70% of all girls reported to have a general interest in STEM subjects.

The female students answered questions concerning their values, their attitude towards STEM, role models in STEM and described positive and negative critical incidents. In the acquired 777 questionnaires, a total number of 524 critical incidents were reported and collected. Some girls reported several incidents which were counted separately. The reported incidents were grouped into trigger categories in an inductive approach. Categories were built in several rounds. Once a final set of categories was developed by three researchers, another researcher categorized the incidents. Deviations between the category groupings were assessed by a further researcher who decided on the categorization. The percentage of agreement for the placement into categories was 96,6%. According to Gremler (2004), Perreault and Leigh's (1989) reliability index I_r, is more precise than the percentage of agreement because it also considers the number of categories. Perreault and Leigh's (1989) inter-rater reliability was 88,9% whereas Muñoz-Leiva et al. (2006) note that values above 75% are considered acceptable.

4. Analysis

Through the analysis of incidents seven different trigger categories were extracted. Table 1 shows the trigger categories and their descriptions. The following analysis of the trigger categories is based on the number of incidents classified into the categories.

Table 1: Incident Trigger Categories

Incident trigger category	Trigger category description	No. positive	No. negative	Total No (%)
Teacher personality and motivation	Incidents related to teacher influence e.g., personality and motivation (own enthusiasm for the subject taught and the way the students are encouraged or discouraged e.g., by derogatory comments), learning atmosphere	57	137	194 (30,0%)
School lesson design	Incidents related to school lesson's design (e.g., methodology, didactics, explanation of content in an easily comprehensible way, individual support, how subject is positioned in school)	63	49	112 (21,4%)
Student experience	Incidents related to specific students' experiences (e.g., good or bad grades, pride about success, embarrassment, having fun)	53	39	92 (17,6%)
Student perception of own ability	Incidents related to student's ability or perceived ability in STEM subjects (e.g., the ability to resolve complex tasks or to explain the subject, having difficulties to	30	28	58 (11,1%)

Incident trigger category	Trigger category description	No. positive	No. negative	Total No (%)
	understand STEM subjects, limitations such as dyscalculia)			
Personal perception of STEM	Incidents related to the girls' perception of STEM, i.e., whether they perceive STEM topics as interesting and relevant (e.g., as relevant for everyday life) or as boring or even irrelevant	29	15	44 (8,4%)
Influence of personal environment	Incidents related to student's personal environment (private and out-of-school context, e.g., parents, friends, offerings by companies or universities)	13	6	19 (3,6%)
Influence of (social) media	Incidents related to the portrayal of STEM in media (e.g., in films, social media, series)	5	0	5 (1%)
Total (percentage)		250 (47,7%)	274 (52,3%)	524 (100%)

Table 1 shows that students reported more negative (52,3%) than positive (47,7%) incidents overall. The majority of incidents relate to the teacher's personality and motivation (30,0%), followed by the school lesson design (21,4%) and the students' general experience (17,6%). The trigger categories and the respective incidents are described in more detail in the following paragraphs.

4.1 Teacher Personality and Motivation

The majority of negative incidents were reported in this trigger category and revolved around a negative atmosphere because of the teacher's personality and motivation in class. The mind map in Figure 1 summarizes the issues reported by students.

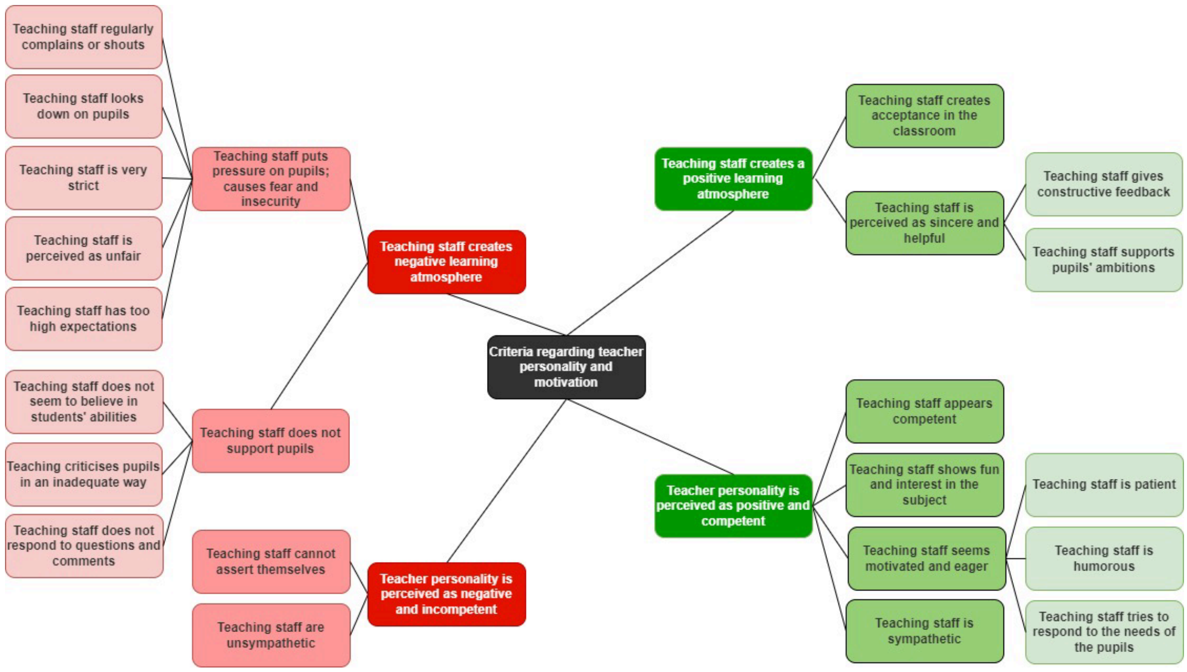

Figure 1: Critical Incidents Related to Teacher Personality and Motivation

The girls perceive the teachers as not sympathetic, cannot assert themselves, do not appear to be competent. They feel that teachers put students under pressure which results in student fear and insecurity.

> *"Even though most teachers pretend this isn't true, teachers make up the entire class and your relationship with it! If a teacher can't explain well or is not passionate about their job, the subject sucks. Also, you shouldn't have to be afraid of the teacher. It is mentally very stressful" (negative, 1170).*

Students also reported that teachers do not believe in student's abilities. Moreover, teachers sometimes encourage boys while at the same time they deny girls' competencies in STEM subjects.

> *"I was told by a male teacher that science was only for males and that people with female associations had no chance in the same field. That was humiliating and discouraging at the same time" (negative, 1098).*

> *"In further education, my math teachers often told me I was stupid or something similar. In technology class, I was the only girl and often got excluded. In both situations, I felt very hurt" (negative, 201).*

However, some students also report positive incidents and that teachers are sympathetic, create a positive atmosphere in class and are very helpful and encourage students.

> *"Good teachers who are enthusiastic about the subject that they teach, automatically convey enjoyment of what students are learning" (positive, 345).*

> *My teacher has seen my "potential" in math and has told me this several times and has awakened my ambition and interest with the first good grades" (positive, 238).*

4.2 School Lesson Design

The second most often reported trigger category is school lesson design. In this category, the girls reported more positive (56,3%) than negative (43,8%) incidents. School lessons are perceived as positive, if teachers explain the topics in a comprehensible way, use everyday examples as well as different teaching methods. Figure 2 summarizes the issues reported by students regarding school lesson design.

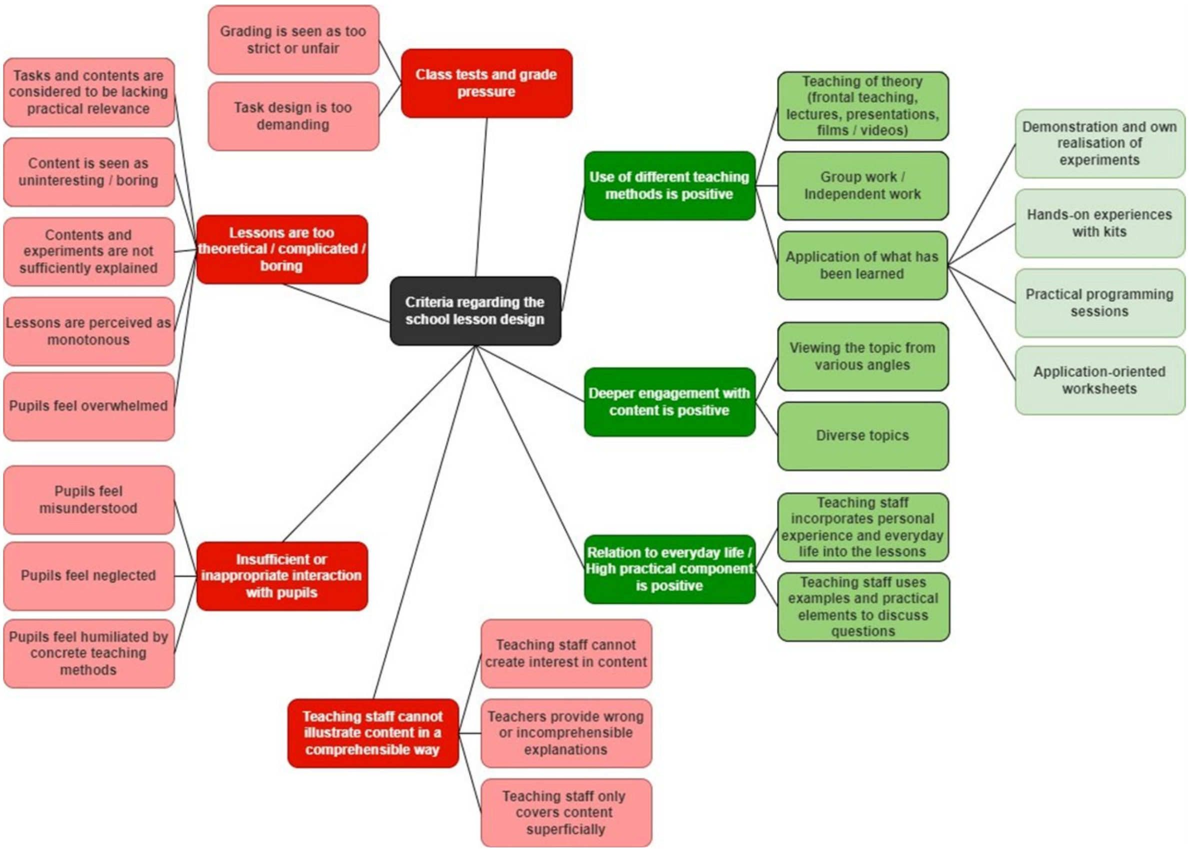

Figure 2: Critical Incidents Related to School Lesson Design

The girls also appreciate experiments they can do by themselves (e.g., microscopy, use of construction kits, programming).

> *"At school, we were allowed to dissect a lung in biology while we discussed the respiratory system. Everyone had a lot of fun in the lesson, and we could remember the processes much better. This class was one of the best biology lessons, and I would like to see more practical work in this subject" (positive, 380).*

"My computer science teacher had us write codes on our own. We had a goal to reach, but we had to solve every little thing ourselves. It was great!" (positive, 929).

In contrast, regarding the negative incidents, girls report about tests and gradings that they perceive as too strict or even unfair, school lessons that are only theoretical, topics that are not well explained and presented in a manner that the girls perceive as not having any practical relevance. Also, the way teachers interact in their lessons with the students makes a difference.

"Experiments are not properly explained and are boring. Mostly only frontal teaching" (negative, 161).

"Having to go to the front of the blackboard even though you don't know the solution. Just embarrassing and very humiliating feeling" (negative, 617).

"Physics, on the other hand, I find very horrible. Our teacher writes everything on the blackboard, and I just sit through 3 hours a week. It's boring and made incomprehensible" (negative, 612).

4.3 Student Experience

Incidents concerning specific students' experiences are often related to obtaining good or bad grades, but also to experiences about being proud of e.g., solving a complex math problem or feeling embarrassed about making mistakes. In this category, positive incidents (57.6 %) outweigh negative incidents (42.4 %).

"Success in the subjects, especially good grades" (positive, 101).

"Whenever you have the chance to show the others how to do something in math, you feel proud of yourself" (positive, 834).

"Bad grades in some of these subjects, made me feel more negative about these subjects" (negative, 950).

4.4 Student Perception of own Ability

Incidents related to the students' ability or their perceived ability in STEM subjects, often address the perception of being or not being able to understand certain topics or complex interrelationships, being or not being talented, but also describe personal limitations such as dyscalculia and dyslexia. The proportion of positive incidents (51.7%) versus negative incidents (48.3%) in this category is almost balanced.

"It makes me feel good to raise my hand when we discuss complex interrelationships in the classroom, or to explain such relationships in exams, this is fun. Since I started to dive deeper and understand complex things, I am much more interested in this field" (positive, 1181).

"Maths overwhelms me, that's why I often feel frustrated and disoriented in Math lessons" (negative, 942).

"[…] Also, I have dyscalculia as well as dyslexia. The teachers considered my dyscalculia irrelevant, which made my experience with math hell on earth" (negative, 791).

4.5 Personal Perception of STEM

Incidents concerning the girls' perception of STEM subjects and topics relate to perceiving the subjects as interesting, relevant, challenging, or boring, irrelevant, difficult on the negative side. The introduction of interesting topics seems to raise sustained interest in the field in general. Also, the practical relevance or irrelevance for everyday life frequently represents a trigger for the positive or negative perception of STEM subjects.

"I have been positively influenced by natural sciences, especially chemistry and biology, from a young age. I never liked boring stuff like office or sales work where everything is very monotonous. So, I started to inquire about and do internships to get involved. Consequently, I decided to do my "Fachabitur" in chemistry and biology, which was the best decision of my life. I am more than satisfied" (positive, 230)

"[…] for example, I have dropped Chemistry and Physics, because these subjects are so far from reality and appear complicated to me. Also, in Maths, I often question myself 'What is the relation/ the benefit of this method (e.g. vector analysis) for my life? Why should there ever be a situation when I need this kind of knowledge?" (negative, 942).

"Computer Science: only excel tables, boring, unnecessary" (negative, 1121).

4.6 Influence of Personal Environment

Incidents in this category show the influence of the students' personal environment towards their perception of STEM subjects. In this category, the positive incidents (68,4%) clearly outweigh the negative ones (31,6%). However, this category is very small (only 3.6% of all incidents), especially in comparison to the number of incidents reported from school. The incidents involve for example their friends or parents. Also, private, out-of-school activities such as offerings by companies (e.g., German Girls' Day) or universities influence the students' interest in STEM. In all cases in which students reported about such offerings, they did it in a positive way.

"A man at Girls Day talked so enthusiastically about technology that he inspired me." (positive, 638)

"I used to hate math; there was no particular reason for it, but all my friends hated math, and I found no reason NOT to feel the same" (negative, 497).

4.7 Influence of (Social) Media

Only a small number of students described a critical incident in this category (1,0%). They relate to the portrayal of STEM in the media. All incidents in this category are positive. Students report especially on films, videos in social media and series.

"When I discovered the YouTube channel MaiLab, I found out that chemistry can also be fun. That was about 4 years ago" (positive, 138).

"When I watched The Big Bang Theory a few years ago, I developed a great interest in science or even chemistry from watching Breaking Bad" (positive, 864).

5. Discussion and Conclusion

The overall results of experiences amongst girls show a small disparity in the number of positive and negative incidents (47.7% positive incidents).

The study identified seven different trigger categories for the critical incidents. The environmental influencers mainly consisted of the school learning environment (i.e., the teachers and experience of curriculum lesson design), peers, out-of-school STEM activities and media. Teachers form the largest part of the barrier group (30%), with more negative incidents reported. Both negative and positive experiences seem to be mainly shaped by teachers own self-efficacy, enthusiasm, beliefs, and perception of STEM. There is also a concerning evidence of unfair and abusive treatment that persist in classrooms in form of gender stereotyping, unfair grading, shouting, sarcasm and more. This hampers the intrinsic value of the STEM subject and increases its perceived cost for the girls. The second barrier group consists of the teaching methods and curriculum design (21.4%). Both the positive and negative experiences here indicate the need for practical hands-on over dominantly theoretical learning. A perceived relationship of class material and enjoyment of subject to the teacher's abilities is also reported. The influence of peers in form of friends and out-of-school STEM activities towards STEM choice forms a small number of incidents (3.6%). While forming only 1% of the incidents, media shaped the interest towards STEM choice.

The categories, students' experiences, students' perception of own ability and students' perception of STEM highlights the significance of students' self-efficacy, self-concept, math-efficacy/identity, and subjective task value in STEM choice, as observed in previous research. The grades, ability to solve a task or making a mistake affects the ability beliefs of the students. The self-efficacy is also affected by underlying conditions such as dyslexia. Students' STEM identity is also affected by their subjective task value in terms of subjects' relevance in real world. Subjects are also expected to be interesting, challenging, and enjoyable.

In conclusion, despite a small disparity between overall negative and positive incidents, there persists significant barriers for the girls during STEM enrolments. Having both positive and negative incidents within the same trigger category indicates that with right interventions, the negative influencers can turn to positive ones. In contrast to prominent role of parents and peers in research, their part was smaller in this study. However, teachers had the strongest influence and considering their negative and positive effects, teachers' behavior and teaching methods should be investigated from a pedagogical and didactical point of view. Their own beliefs and perceptions related to STEM talent development should be known before recruiting them. A teacher's expected role forms a mix of learner yet expert curriculum designer, negotiator and asker, collaborator yet a teacher and motivator. Appropriate training should be provided, for example incremental-based support intervention training to encourage students to develop a growth mindset and see their intelligence as malleable. The learning environment should be non-judgmental, safe, inclusive, and interactive, wherein students are not stigmatized for having learning difficulties (ex. dyslexia), are encouraged to ask questions, can display their abilities by answering or explaining subjects, have hand-on practical experience, understand the practical relevance of the subject and nurture math efficacy/identity. It plays an important role in increasing their self-esteem and resulting STEM self-efficacy. Even with lower number of incidents, social media as well as peer support plays an important role in fostering STEM choice and can be used as positive influencers. Media can boost much lacking representation of female role models to increase female STEM identity and belonging. Out-of-school STEM activities show a great potential, too and should be considered as a right intervention in building STEM efficacy and identity.

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