The Impact of Invention Education Participation on Students' Confidence and Anxiety in STEM

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Current research focus areas: Invention Education, Equity, Identity, OST, SEL

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Abstract

Invention education plays a crucial role in the K-12 setting as it creates a culture of innovation and critical thinking from an early age. It provides a platform for students to identify real-world challenges and devise innovative solutions, fostering a sense of self-efficacy. Students' sense of belonging, psychological safety, and decision-making processes about their future often align with their interests and curiosity, but anxiety can negatively influence these perceptions. Anxiety can affect children's strategic behavior by discouraging them from choosing advanced strategies and methods or even considering such options in the first place. Prior research efforts in invention education have focused on intent to persist in STEM, attitudes towards STEM, inventor identity, teamwork, and collaboration skills, but further research is needed to explore how to cultivate confidence and minimize anxiety through the practice of invention education.

This research aims to study a well-established, scaled invention education summer program and examine its overall program impact on participants' outcomes: science and math interest, science and math anxiety, and problem-solving and inventing skills. The study also examines the potential associations of gender and geographical locations with participants' outcomes. Data were gathered through both qualitative and quantitative methods for over 900 children who participated in Camp Invention during the summer of 2023. Student outcomes were assessed using a pre- and post-survey design. Focus groups were conducted to investigate students' perspectives regarding activities and content included in the program. Findings indicate that students' interest increased and anxiety decreased over the course of the week. Additionally, students' problem-solving and inventing skills increased. By reducing anxiety factors and increasing confidence, educators can create a supportive atmosphere that enhances students' engagement with STEM subjects and promotes a healthy mindset toward problem-solving, innovation, and future career paths.

Introduction

Invention education is vital to creating the next generation of innovators and problem-solvers who will tackle global challenges. It encompasses a diverse set of teaching methods in which students actively learn through the invention process: empathy, problem identification, ideation, design, prototyping, testing, and effectively communicating ideas to an audience. Invention education provides a platform for students to identify real-world challenges and devise novel and innovative solutions, fostering a sense of self-efficacy. Encouraging invention, innovation, and an entrepreneurial mindset helps students become more self-determined and contributes to students' acquiring the skills needed to shape their own future [1].

Students' sense of belonging, psychological safety, and decision-making processes about their future often align with their interests and curiosity, but anxiety can negatively influence these perceptions. The aim of this study is to examine the constructs of interest and anxiety, with respect to science and math and specifically to inventing. Prior research efforts in invention education have focused on intent to persist in STEM, attitudes towards STEM, inventor identity, and teamwork and collaboration skills, but further research is needed on anxiety [2], [3], which includes worrisome thoughts such as failure, avoidance of healthy risk-taking, and nervousness in STEM and invention-related situations.

Previous studies on STEM anxiety examined math and science anxiety in middle school-aged children. Alemdar et al. show that math and science anxiety decreased when students participated in integrated STEM courses with engineering design, allowing students to practice these skills in relaxed, real-world contexts. In addition, as anxiety decreased, science and math interest increased over time [4]. The findings of this study are consistent with the idea that providing students the opportunity to apply their science and math knowledge and skills to use within the framework of interesting and engaging middle school engineering classes can have a significant positive impact on both academic achievement and STEM engagement. Additionally, similar studies highlight anxiety as a contributing factor to poor self-efficacy in math and science [5], [6]. Anxiety can affect children's strategic behavior by discouraging them from choosing advanced strategies and methods or even considering such options in the first place [6].

Evaluation studies have reported significant short-term gains in creativity, problem-solving, and STEM interest among children participating in Camp Invention [7], [8], [9]. A 2017 study by the Institute for Learning Innovation (ILI) supported these findings, revealing lasting effects measuring up to four years post-program [10]. Repeated STEM challenges contribute to children's problem-solving skills development and foster confidence in children's ability to analyze and solve these challenges. Recent findings show that children's favored Camp Invention activities were associated with higher ratings in perceived confidence, task utility, and task novelty, while less preferred activities received lower scores in perceived autonomy and psychological safety [3]. In general, interest in STEM disciplines is more about perception than ability [11], and we hypothesize that alleviating anxiety will allow students to feel more confident and make better decisions about their future in STEM and invention.

Background

Camp Invention, the National Inventors Hall of Fame's flagship summer program, is a weeklong summer program promoting invention, entrepreneurship, intellectual property (IP) literacy, and STEM interest and participation while building 21st-century skills such as creativity and problem-solving. Designed for children entering grades K-6, the camp offers an engaging and educational summer experience focused on innovation and problem-solving. It provides an experience that revolves around the core themes promoted in the program, as stated above, as well as promoting an I Can Invent® Mindset. Camp Invention partners with educators, schools, districts, and community organizations to extend the program to different communities across the nation. As a result, the program has become widely recognized as a leading summer enrichment program emphasizing STEM with over 389,000 students participating in 2023. Of those, over 289,000 were from underserved communities and over 2,000 summer camps were available with locations in all 50 states. The program continually designs new curriculum and activities to align with current educational trends and advancements in innovation, STEM, and best practices.

Each year, Camp Invention introduces a brand-new series of curricular modules to keep participants engaged and excited about learning. For example, MimicBot, is a module where students explore nature, genetics, and adaptive innovation. The students apply mimicry tactics found in nature which involves creative thinking to make the bot distinct and one-of-a-kind. Students also learned about reverse engineering by taking apart the bot's inner components. In Pop-Up Venture, participants design their own business and are tasked with making financial decisions, navigating unexpected challenges, and discovering opportunities that may arise while building entrepreneurship skills. Another module, Catching Air, focuses on students exploring the physics of skateboarding and designing their own skate park. In the last module, Invention Celebration, participants discover the importance of celebrating. They use their creativity and STEM skills to design the lighting, sounds, and mood for the celebration. The hands-on experience includes engineering a light-up party hat, building a musical instrument, and investigating the science of color. With these activities in mind, an evaluation of Camp Invention was designed to understand student outcomes associated with science and math interest, science and math anxiety, and problem-solving and inventing skills.

Methods

Research Design

This research study utilizes a mixed-methods approach, incorporating both quantitative data through paper surveys and qualitative data through focus groups and interviews. The research was guided by the following questions:

1. What is the overall program impact on participants' confidence towards STEM?
2. To what extent is gender and socioeconomic status associated with participants' confidence towards STEM?

All research personnel involved, including the camp facilitators, were required to complete the Collaborative Institutional Training Initiative (CITI) certification to assist with data collection.

Participants

This study was conducted at 20 locations throughout Georgia and Ohio including rural and urban areas. Participants consisted of lower and upper elementary school-aged students, 3rd – 6th grade, who were enrolled in the week-long invention education camp, Camp Invention, offered in the summer of 2023. An email with details about the research study and a link to complete the informed consent form was sent to parents and guardians whose children had been enrolled. In all, 940 children participated in the pre-survey data collection. The post-survey data collection resulted in a slightly smaller matched sample size (n = 875). Of the pre-post matched participants who provided self-reported demographic information, 51.3% reported that they were male, 46.5% reported that they were female, and 2.2% chose to prefer not to say/other. The majority of participants indicated that their race was White (63.7%) or Black or African American (6.1%). 8.3% are considered underrepresented in this context based on race and/or ethnicity. 54.1% of participants were from a suburban area while 45.9% were from a rural area.

Data Sources

Student pre-and post-surveys

Quantitative data were gathered employing a pre- and post-survey methodology. Elements of this survey include demographic information, such as gender, race/ethnicity, and grade level, and questions related to the constructs: science interest, science anxiety, mathematics interest, mathematics anxiety, and problem-solving and inventing. Students completed a pre-survey at the beginning of their five-day Camp Invention summer program, prior to any instructional lessons. Subsequently, on the program's final day, a post-survey was administered. Each survey took approximately 15 minutes to complete. The instrument comprised of 27 Likert-type questions where students were asked to express their level of agreement. The response options range from "Strongly Disagree" (1) to "Strongly Agree" (4). Cronbach's alpha is a measure assessing the internal consistency of a construct and ranges from 0 to 1.00. A value of 0.80 or above indicates very good measurement reliability, while an alpha of 0.65 is considered acceptable [12]. Cronbach's alpha was analyzed for the constructs, each of which shows good reliability, with all constructs at or above 0.75 (Table 1).

Table 1: Cronbach's alphas for each construct

Construct category	Construct	Cronbach's alpha
Interest	Science Interest	0.79
	Mathematics Interest	0.87
Anxiety	Science Anxiety	0.75
	Mathematics Anxiety	0.84
Problem-Solving and Inventing	Problem-Solving and Inventing	0.81

Interest

This factor emphasizes both the students' interest and their sense of personal relevance, which is the relevance of learning to one's goals. Mathematics items were adapted from the Mathematics Anxiety Scale-Revised [13]. Science items were adapted from the Science Motivation Questionnaire [14]. Certain item statements were modified when necessary to align with lower-

grade students' reading level. Example items include "I enjoy learning about science" and "Math is one of my favorite subjects".

Anxiety

Anxiety includes feeling nervous, such as when students take exams, and worrying, which manifests as a fear of not performing well. This study's anxiety measures encompass both positive aspects, such as a sense of ease and absence of fear, and negative elements, including feelings of discomfort and uneasiness, associated with science and mathematics. The intention was to comprehensively capture the experiences students may have in relation to these subjects. These items were adapted from the Science Motivation Questionnaire [14], and the Mathematics Anxiety Scale-Revised [13]. Certain item statements were modified when necessary to align with lower-grade students' reading level. Examples include "I worry about learning science" and "Math makes me feel confused".

Problem-Solving and Inventing

This factor emphasizes students' problem-solving and inventing skills that are crucial in navigating challenges, critical thinking, finding effective solutions, and their capacity to generate innovative products and solutions. Four of the eight items were adapted from the validated Student Attitudes toward STEM Survey-Upper Elementary School Students [15]. The four remaining items were developed by the research team. Example items include "I think of several ways to solve a problem and choose the best one" and "I want to improve things that people use every day."

Focus Group Discussion Protocols

Six 30-minute focus groups, three in Georgia and three in Ohio, were conducted on the final day of the summer camps to gather qualitative data on the students' Camp Invention experience. The focus group participants were asked about their perception of the camp activities they participated in during the week and how it relates to math and science, what it means to them to be inventive, and what they would like to work on as a career when they grow up. The discussions within the focus groups were recorded audibly and served as the basis for analyzing the findings.

Data analysis

IBM SPSS was used to calculate descriptive statistics and significance testing of means when appropriate from quantitative survey data. Specifically, an analysis involving frequencies, means, standard deviations, and paired-samples t-tests was carried out to examine the difference in student responses from pre-survey to post-survey. Qualitative data were analyzed and used as a supplement for quantitative data.

Results and Discussion

An analysis of the pre-survey scores revealed that, on average, the participants were already at the higher end of the scale, which is not surprising given that students and families self-select into this programming. This suggests that the absence of significant changes in outcomes could be attributed to a ceiling effect. Due to the observed ceiling effect, we opted to focus on student

responses positioned at the lower end of the scale. Specifically, we restricted our analysis to pre-survey responses with scores of 1, 2, and 3, replacing instances of 4 with "missing" to exclude them from the analysis. The tables below display outcomes after eliminating the ceiling effect. Findings from the paired t-test showed a statistically significant difference between the pre-post means for each item for all constructs, science interest (Table 2), math interest (Table 2), science anxiety (Table 3), math anxiety (Table 3), and problem-solving and inventing (Table 4).

Science and Math Interest

Qualitative and quantitative data indicate that students' science interest and math interest increased over the course of Camp Invention (Table 2).

Table 2: Participants' science interest and math interest before and after the summer camp

		Pre			Post			
#	Items	N	Mean	SD	N	Mean	SD	Mean difference
1	I enjoy learning about science.	525	2.79	0.49	525	3.04	0.75	0.25***
2	I find learning science interesting.	521	2.78	0.50	521	3.04	0.76	0.26***
3	The science I learn is relevant to my life.	656	2.47	0.67	656	2.67	0.89	0.20***
4	Doing science makes me proud.	566	2.48	0.64	566	2.83	0.90	0.35***
5	I like science that challenges me.	512	2.38	0.77	512	2.70	0.97	0.32***
6	I find math interesting.	492	2.39	0.78	492	2.61	0.96	0.22***
7	Math is one of my favorite subjects.	447	2.11	0.84	447	2.33	1.02	0.22***
8	I enjoy learning math.	487	2.38	0.79	487	2.60	0.96	0.22***
9	Math relates to my life.	536	2.33	0.79	536	2.59	1.00	0.26***

Note. Difference = post-survey mean – pre-survey mean. Thus, a positive difference indicates an increase in degree of agreement from pre-survey to post-survey.
#1-5: Science interest items, #6-9: Math interest items
**p < .05, **p < .01, *** p < .001*

The pre-survey data indicated that students, on average, exhibited lower interest in science and math at the beginning of Camp Invention. Throughout the course of the camp, students' average responses increased indicating a positive change in their outcomes. The greatest shift in mean difference from pre to post for science interest was noted in the item "Doing science makes me proud", which increased from 2.48 (SD = 0.64) at the start of the camp to 2.83 (SD = 0.90) at its conclusion. Similarly, the greatest change in mean difference for math interest from pre to post was observed in the item "Math relates to my life," increasing from 2.33 (SD = 0.79) to 2.59 (SD = 1).

During the focus group, students were asked what their favorite activity was and why. Most participants agreed that they liked science and math and could relate the subjects with everyday

tasks. One participant stated, "*my favorite part was probably going to be Adventure Celebration. When we were doing the light-up party hats, we learned how to make electricity to get the light going and on. And we also did some fun things like make our own instruments. So I think that was cool. It was very interactive*." Another participant stated (in relation to the Pop-Up module), "*We got a hundred dollars in that to spend in our businesses and we have to loan that back so we have to pay the hundred dollars back. That was the math part about it. I thought that was really cool*."

Science and Math Anxiety

Qualitative and quantitative data indicate that students' science anxiety and math anxiety decreased over the course of Camp Invention (Table 3).

Table 3: Participants' science anxiety and math anxiety before and after the summer camp

		Pre			Post			
#	Items	N	Mean	SD	N	Mean	SD	Mean difference
1	I worry about learning science. (r)	384	2.69	0.59	384	3.13	0.76	0.44***
2	Science makes me feel nervous. (r)	403	2.70	0.54	403	3.09	0.81	0.39***
3	Science makes me feel confused. (r)	509	2.45	0.68	509	2.83	0.89	0.38***
4	I feel good about myself when I explore science.	498	2.61	0.67	498	2.85	0.86	0.24***
5	I know I can do well in science.	521	2.66	0.64	521	3.01	0.73	0.35***
6	I worry about solving math problems. (r)	431	2.42	0.70	431	2.84	0.87	0.42***
7	Math makes me feel nervous. (r)	427	2.48	0.72	427	2.84	0.92	0.36***
8	Math makes me feel confused. (r)	485	2.33	0.70	485	2.66	0.93	0.33***
9	I feel good about myself when I do math.	497	2.49	0.75	497	2.73	0.93	0.24***
10	I am the type of person to do well in math.	429	2.42	0.75	429	2.73	0.93	0.31***

Note. Difference = post-survey mean – pre-survey mean. Thus, a positive difference indicates an increase in degree of agreement from pre-survey to post-survey.
(r): reverse coded items
#1-5: Science anxiety items, #6-10: Math anxiety items
**p < .05, **p < .01, *** p < .001*

Items noted with (r) were reverse coded, so a higher score means less anxiety. The pre survey data showed that students started with higher anxiety in science and math at the beginning of Camp Invention. However, as the camp progressed, students' average responses increased, suggesting a positive improvement in their overall experiences. The greatest change in average

scores from pre to post for science anxiety was seen in the statement "I worry about learning science", which increased from 2.69 (SD = 0.59) initially to 3.13 (SD = 0.76) by the end of the camp. Likewise, the greatest change in average scores for math anxiety from pre to post was observed in the statement “I worry about solving math problems,” increasing from 2.42 (SD = 0.70) to 2.84 (SD = 0.87).

Notably, students’ lowest pre survey averages were for the items about science and math making them feel confused, “Science makes me feel confused”, M = 2.45 (SD = 0.68) and “Math makes me feel confused”, M = 2.33 (SD = 0.70). Both items showed an increase in the mean difference, 0.38 for the science item and 0.33 for the math item, suggesting that the invention education activities students participated in throughout the week helped alleviate some of the confusion they felt around science and math.

Problem-Solving and Inventing

Qualitative and quantitative data indicate that students’ problem-solving and inventing skills increased over the course of Camp Invention (Table 4).

Table 4: Participants’ problem-solving/inventing skills before and after the summer camp

		Pre			Post			
#	Items	N	Mean	SD	N	Mean	SD	Mean difference
1	I have ideas for creating new products.	498	2.60	0.63	498	2.84	0.81	0.24***
2	I want to improve things that people use every day.	507	2.64	0.60	507	2.90	0.82	0.26***
3	I am good at building and fixing things.	518	2.58	0.63	518	2.91	0.80	0.33***
4	I can figure out how things work.	523	2.72	0.54	523	3.01	0.73	0.29***
5	I think of several ways to solve a problem and choose the best one.	543	2.62	0.62	543	2.92	0.82	0.30***
6	When something doesn’t work, I want to fix it.	456	2.69	0.59	456	3.01	0.75	0.32***
7	I know how to test my ideas to see if they work.	509	2.67	0.57	509	2.94	0.76	0.27***
8	I can figure out how much my product should cost.	534	2.46	0.72	534	2.73	0.88	0.27***

Note. Difference = post-survey mean – pre-survey mean. Thus, a positive difference indicates an increase in degree of agreement from pre-survey to post-survey.
**p < .05, **p < .01, *** p < .001*

The pre survey data indicated that, at the start of Camp Invention, students began with lower problem-solving and invention-related skills. As the student's participated in the camp activities, their perspective on problem-solving and inventing shifted, showing an improvement in their overall outcomes. The greatest increase in agreement for the problem-solving and inventing construct was observed for the item "I am good at building and fixing things". Interestingly, this item received one of the lowest mean scores when the camp started (M = 2.58, SD = 0.63) and one of the highest scores by the end of the camp (M = 2.92, SD = 0.80). The smallest change was for the item "I have ideas for creating new products". The pre survey average was 2.60 (SD = 0.63) and increased to 2.84 (SD = 0.82) for the post survey average, with a difference of 0.24. Although students' outcomes for having ideas for creating new products increased slightly, there is still a need for invention-related material that can help students generate ideas which, in turn, will help foster innovation and motivate students to become problem-solvers.

Focus group participants explained what it means to be inventive to them. Students expressed creativity, using their imagination, fixing things, and solving problems. One student described being inventive as, "*creating something new that can change the future*.", and another student indicated the best part of inventing is "*actually succeeding because it makes you think about all like the trial and error and how long it took you that you finally made something and the hope that you can make it even better.*"

Gender Differences

Survey items for each construct were combined to create an average construct measuring students' science interest, math interest, science anxiety, math anxiety, and problem-solving and inventing skills. Table 5 provides insights into the changes in science and math interests, anxiety levels, and problem-solving and inventing skills among boys and girls before (pre) and after (post) attending the camp.

Table 5: Gender differences in grouped constructs

		Boy			Girl			
Construct average		N	Mean	SD	N	Mean	SD	p-value
Science interest	Pre	413	2.58	0.47	371	2.65	0.42	0.028*
	Post	445	3.11	0.71	404	3.16	0.65	0.383
Math interest	Pre	318	2.33	0.70	331	2.44	0.64	0.045*
	Post	437	3.13	0.94	395	2.99	0.87	0.027*
Science anxiety	Pre	379	2.63	0.50	355	2.65	0.50	0.65
	Post	445	3.28	0.62	403	3.30	0.57	0.676
Math anxiety	Pre	331	2.48	0.63	333	2.44	0.58	0.364
	Post	438	3.26	0.77	395	3.12	0.71	0.007**
Problem solving/inventing	Pre	393	2.60	0.45	368	2.65	0.43	0.076
	Post	444	3.19	0.59	397	3.20	0.56	0.679

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

For science interest, both boys and girls exhibited an increase from pre to post, with boys showing a mean difference of 0.53 and girls with a mean difference of 0.51. Similarly, math

interest saw an increase in mean difference of 0.80 for boys and 0.55 for girls. Math interest saw a statistical significance between boys and girls for both the pre survey and post survey (p = 0.045 ad P = 0.027), respectively. Regarding anxiety levels, there was a decrease in anxiety for both boys and girls for science anxiety and math anxiety. However, the data did not show a statistically significance change between boys and girls except for the math anxiety post survey (P = 0.007). For problem-solving and inventing skills, both boys and girls demonstrated an increase in scores from pre to post, but the differences were not statistically significant (P = 0.076 for pre and P = 0.679 for post). The findings highlight the importance of considering gender differences in educational settings and emphasize the need to address potential gender-related needs.

Socioeconomic Status Differences

Survey items for each construct were combined to create an average construct measuring students' science interest, math interest, science anxiety, math anxiety, and problem-solving and inventing skills. Table 6 provides insights into the changes in science and math interests, anxiety levels, and problem-solving and inventing skills among suburban and rural setting students before (pre) and after (post) attending the camp.

Table 6: Socioeconomic status differences in grouped constructs

		Suburb			Rural			
Construct average		N	Mean	SD	N	Mean	SD	p-value
Science interest	Pre	440	2.59	0.47	359	2.64	0.42	0.137
	Post	472	3.10	0.71	396	3.18	0.64	0.046*
Math interest	Pre	357	2.35	0.69	309	2.41	0.66	0.259
	Post	461	3.05	0.93	390	3.06	0.90	0.894
Science anxiety	Pre	400	2.64	0.50	349	2.63	0.50	0.775
	Post	471	3.32	0.58	396	3.26	0.62	0.146
Math anxiety	Pre	364	2.48	0.58	317	2.43	0.64	0.301
	Post	461	3.23	0.71	391	3.13	0.78	0.05*
Problem solving/inventing	Pre	426	2.63	0.44	350	2.62	0.44	0.896
	Post	466	3.22	0.59	394	3.17	0.56	0.187

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

For science interest, there was an increase in both suburban and rural areas, with suburban students showing a mean difference of 0.51 and rural students showing a mean difference of 0.54. Math interest also showed an increase in mean difference's for both suburban and rural students, 0.70 and 0.65, respectively. The data showed that post survey data for science interest was statistically significant between suburb and rural students (P = 0.046). Anxiety levels decreased throughout the week as shown in Table 6, but there was no statistically significant change except for post survey data for math anxiety (P = 0.05). Problem-solving and inventing skills demonstrated a positive shift from pre to post for both areas, although the changes were not statistically significant.

Conclusion

According to the data, students initially had lower interest and higher anxiety in science and math and a lower outlook on their abilities in problem-solving and inventing. However, as the camp progressed, there was a positive shift in their outcomes. These results are reinforced in comparing gender and geographical locations. Overall, the findings highlight the effectiveness of invention education programs in cultivating positive changes in students' confidence in science, math, problem-solving, and inventing skills. This confidence is transferable to their approach to STEM subjects, encouraging them to tackle challenging problems with a positive mindset.

Despite the positive outcomes revealed in this study, there are limitations that should be considered. The self-selected sample of participants, such as those that attended Camp Invention, may not fully represent the wider student population. This is because students who chose to participate in the camp likely already had a pre-existing interest in invention, science, and math. Additionally, the utilization of a pre-post design may not sufficiently capture the effectiveness of intervention programs, especially when students enter with a high level of pre-existing STEM knowledge and interest.

Invention education programs play a crucial role in shaping students' experiences and outcomes in STEM subjects. To gain a more comprehensive understanding of these programs, future work should focus on extending beyond student perspectives and incorporating input from program instructors. This multi-perspective approach will provide a more detailed representation of the outcomes for students participating in invention education, as well as insights into the challenges and successes faced by instructors in implementing the curriculum. Future research should also include older participants, middle and high school, to understand how their experiences and outcomes change across different stages of education.

As educators strive to enhance STEM engagement, ongoing research is vital to document the lasting impact of invention education programs. Identifying specific components that support student success will guide the development of effective strategies, helping educators tailor interventions to maximize confidence, reduce anxiety, and foster problem-solving skills among students in science and math.

By engaging in invention-based learning, students develop critical thinking, problem-solving, leadership, communication, creativity and gain hands-on experience in applying these skills and knowledge to real-life situations and challenges. This approach encourages a deeper understanding of STEM preparing them for future careers in innovation driven fields. Moreover, invention education builds confidence, adaptability, and an entrepreneurial spirit which are essential for addressing global challenges. By developing and supporting an environment of curiosity and exploration, it empowers students to become lifelong learners, who can solve the challenging issues of the future.

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