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An Analysis of Effective Secondary STEM Learning and Teaching Methods that Encourage Student Participation and Success in Secondary School and Beyond

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ABSTRACT

Student participation and success in Science, Technology, Engineering, and Mathematics (STEM) subjects at secondary school and college are critical to the advancement and growth of STEM-based industries and organizations that are vitally important to the economy of the United States. This study explored the prevalent interest level and attitudes among high school students at the local school district towards STEM subjects such as the Sciences and Mathematics, and conducted a digital survey on study methods that high school students employ to support their success in these STEM subjects. The survey also gathered insights from the students about obstacles in their path to success in STEM subjects and about changes and improvements that will help them succeed. This study included in-person interviews of the district's middle and high school Science and Mathematics teachers regarding their instruction methods, student engagement, and their ability to provide different perspectives to students through their teaching methodologies. While this study does not offer a comprehensive conclusion of effective STEM teaching and learning methods due to limitations in collecting data about actual student performance and grade trends, it presents useful insights about effective steps that both students and teachers can take to improve the students' understanding of complex STEM topics and help them succeed in future STEM pathways in high school and beyond.

Literature Review

Although the United States is known to be one of the world's greatest superpowers at the forefront of science and technology, success in math and science education in middle and high schools, or lack of success thereof, has not been addressed uniformly throughout the country.

The Growing STEM Industry

According to the US Department of Education (2022), only 37% of middle school students and 67% of high school students passed science in 2022. It is concerning that if the current number of students majoring in Science, Mathematics, Engineering, and Technology (STEM) fields continues at the current rate, there will still be 3.5 million vacant STEM jobs in the next 10 years according to the predictions of iDTech (2023), a website that tracks tech-related news within the United States and globally. It is therefore important to increase the number of STEM graduates in the US to boost STEM industry growth. To encourage students to pursue STEM majors in college and beyond, they must be nurtured in STEM subjects from middle and high school.

Students Moving Away from STEM Subjects

Over the years, many have studied why students stray away from science, especially higher-level math-intensive science. In a study by Crawley, F. E., & Black, C. B. (1992), 8th to 12th graders' attitude towards science were observed as per gender, race, career goals, and other factors. As students progressed from physical sciences, to biology, to chemistry, to physics, attitudes towards the sciences shifted from positive to negative due to fear of failure and doubts about whether their science education was necessary for their career. With colleges getting more selective, students are worried about their GPA and grade trends. Many students are not comfortable risking a negative GPA trend while applying for college. The lack of mentoring or the lack of awareness about support for struggling students are reasons why many students would rather drop the subject than continue to struggle through and truly understand the subject. Although colleges wish to see that a student is taking rigorous classes in high school, they would prefer that a student not only takes these classes but also succeeds. That is why students would rather move to another subject that they can succeed in, especially when the stakes are high.

Lack of Family Support

Another factor the fear of failure is attributed to is a lack of support at home. Especially for women in science and math, an academic study by Young, D. J., & Fraser, B. J. (1994) found that generational attitudes towards girls entering STEM can either hinder or accelerate a girl's journey in science and mathematics. As children grow up, they often channel the views of the community around them. Subtle messaging, including role models in their life, media, social groups, etc., send hints and often will encourage a person to think and act in certain ways. In another study by Tyler-Wood, T., Ellison, A., Lim, O., & Periathiruvadi, S. (2012), it was found that women often rejected STEM if they were not exposed to the subjects and the possible careers from a young age. Families are the starting points in a child's journey, and they can expose a child to STEM at an early age and encourage them throughout their educational career and beyond. Because society is constantly sending messages directly or indirectly, women and people who are not considered "STEM people" are often discouraged from further pursuing STEM when they start to struggle. In the study, the lack of support and encouragement was not limited to women. African American children were observed to have the least support at home either from parents or siblings. The lack of support can discourage a student because without close family members giving them advice on a subject, they must search harder for support systems that are most accessible to them.

Underqualified STEM Teachers

Even for students with family support in science studies, a teacher's expertise can make a difference in their attitude toward the subject. Unfortunately, according to Hechinger Report by Yonder (2023), 32% of middle school science teachers at schools where 75% of the students have free or reduced priced lunch do not have a degree in science or a certification to teach science. Although the 32% percent may seem low, its impact is long lasting. If a teacher does not have the skills to teach their students, then students lose interest in the subject and shift focus to another. This is because the very person who the students look upon as the subject "expert", the teacher, is unable to help them deepen their understanding and to clear doubts they may have. And even if the student navigates middle school successfully, science concepts will only grow more complex in high school. Without a steady foundation built by a teacher who understands not only the subject but also how to teach the subject to a child, a student might end up failing the subject and eventually losing interest. According to a study done by Furner, J. M., & Kumar, D. D. (2007) that observes teachers, "It really is [teachers'] obligation as an educational community to make the difference for the future of our students in an ever-growing competitive global environment, which depends so heavily on mathematics, technology, and the science. If schools do more in terms of integrating mathematics and the sciences, they may impact the lives of

their students forever." When teachers teach science or mathematics well as individual subjects but cannot integrate the two in their teaching, a student will not be able to grasp advanced concepts that combine the two.

Student Mentoring

As much as teaching style, social attitudes, and fear of failure cause students to give up science, little is known about how tutoring for students who are struggling with math and science in middle and high school encourages them to pursue these subjects. In a study conducted by Stoeger, H., Debatin, T., Heilemann, M., Schirner, S., & Ziegler, A. (2023) on high school girls who were mentored in STEM, 51.2% of the mentees went on to pursue STEM majors in college as compared to just 23.9% girls in a German school who did not receive mentoring observed in the same study. What was not clear is whether the girls were struggling in STEM or were just mentored in order to increase the number of girls in STEM. Often, people begin helping a student only when they struggle in high school, due to the upcoming college applications. But college STEM courses require a solid foundation in the sciences and mathematics, so guidance and extra help must start in early secondary education, when math and science merge.

The Gap and the Research Question

Overall, the literature in this review contained peer-reviewed studies that either specifically focused on students or on teachers. Studies related to students often only focused either on a student population that succeeded in specific mentoring programs or on why students gave up on STEM in secondary school. The studies which focused on teachers either gave suggestions for teachers to incorporate mathematics and science in their curriculum or focused on the implications of having underqualified teachers. There is a gap in available research about the convergence of effective teaching methods for students learning STEM and effective learning techniques that students use to grasp concepts presented in STEM. This led to the research question in this study: *What are effective STEM learning and teaching methods that encourage student participation and success in secondary school and beyond?*

Methods

Many of the studies, including Stoeger (2023), Crawley, F. E., & Black, C. B. (1992), etc., used methods such as a case study or a survey conducted before and after the study. All these methods required several months and even years to have elapsed before a correlation could be made. In this study, due to privacy constraints and limited time available, it was best to choose another type of method that would observe an existing population to find a connection between teaching and learning methods. Since a population of both students and teachers was needed to find the connection in the time span of two months, it was best to use interviews and surveys to get quick results.

To find the connection between science and math teaching methods in secondary schools and the success of secondary students in STEM subjects, the perspectives of both the students and the teachers need to be collected. The "Convergent Designs" method best suited this aim. This method, as Leedy (2016) describes in the textbook *Practical Research*, has the researcher collect "both quantitative and qualitative data in parallel" with the researcher giving "similar and equal weight to the two types of data and striv[ing] for triangulation, with the hope that analyses of both data sets lead to similar conclusions".

Mixed-Method Approach

Using a mixed-method approach, this study was conducted in two stages:

1. A researcher-created digital survey sent to students in the senior class in the local high school, and
2. An in-person or video interview conducted by the researcher with middle and high school science and mathematics teachers.

All the faculty members and students who participated were in the local school district.

Surveys were chosen for the student-centric part of the method because they gave the researcher the ability to reach more participants in different schools than conducting one-on-one interviews would have. Another reason for choosing surveys was that students can stay anonymous and would not feel pressured by the researcher to choose a "correct" option. The Information Form sent to the students and teachers about the research project can be found in Appendix A. A copy of the student Consent Form can be found in Appendix B, and a copy of the Senior Survey Questions can be found in Appendix C.

Interviews were chosen for the teacher-centric part of the method because they gave the participants the ability to give detailed and in-depth answers by listing various examples and expressing their views on the topic without the limitation of having to choose from pre-supplied options. A copy of the Teacher Interview Questions can be found in Appendix D.

Digital Survey of High School Students

In the high school class of 2024, many seniors were transitioning to their next step of life, college. A digital survey was emailed to the students in the local high school, and 41 students finally agreed to participate in it.

The first section of the survey had the participant answer a "Yes" or "No" question about whether the participant planned to enter college in the next school year. The question was crucial to prevent the participant from giving hypothetical data if they were not a college-bound senior, by giving them the option to say "No" and ending the survey.

The second section of the survey had the participant choose the reason(s), or write in a reason, for why they chose the college major that they listed. When applying for a specific college and major, a student typically chose an area of study that either interested them or they had an affinity for. This section would help this study gain insights about such possible reasons for major choice.

The final section of the survey asked about the grade trend the student experienced in their STEM courses and about what teaching methods were helpful for the student. Through the provided options of "Upwards, "Flat", "Downwards", and "Other" for the grade trend, this section helped gather a new dimension of knowledge on whether the student was successful in STEM subjects. Finally, the helpful teaching methods listed by the participants were used later in the research study.

Interviews of Secondary School Teachers

The next step was to interview middle and high school math and science teachers. The list of teachers was found in the staff directory of the local middle and high schools in the local school district. Out of the list, 19 teachers agreed to be interviewed. In each five-to-ten-minute interview, the teacher was asked about the following points:

- How they involved their students in the learning process,
- What teaching methods they used,
- Which methods did the students tend to enjoy,
- How teachers kept their students engaged,
- What methods did they recommend to students to use when a concept was hard to grasp, and
- Would they choose to change their teaching methods or advise the student to get extra help, if a student fell behind in the course.

Combining the teachers' perspectives of student success through certain teaching methods with the student-survey results about which teaching methods were most effective, this study attempted to sift out good, effective teaching methods and to compare the teachers' interview feedback with the students' data produced by the digital survey.

Results

Student Digital Survey Results

The digital survey data reveals a slight bias towards seniors who are not going to enroll in STEM majors versus seniors who are going to choose STEM majors in college, as seen in Chart 1 below.

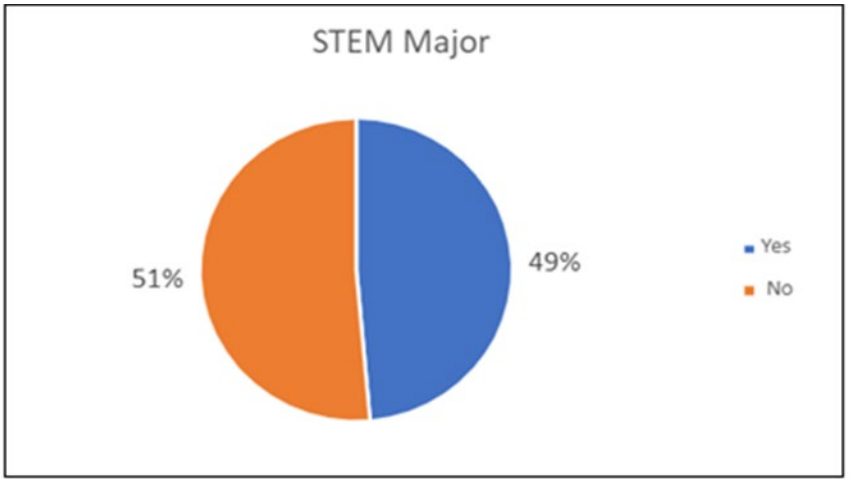


Chart 1. Chosen majors in students' college applications.

When the seniors were asked to list the factors that led them to pursue their chosen major, as seen in Chart 2 below, the most common factor chosen was "Passion for the Subject" while there was no senior that chose "Peer Pressure" or "Tutoring options were available and I made use of them".

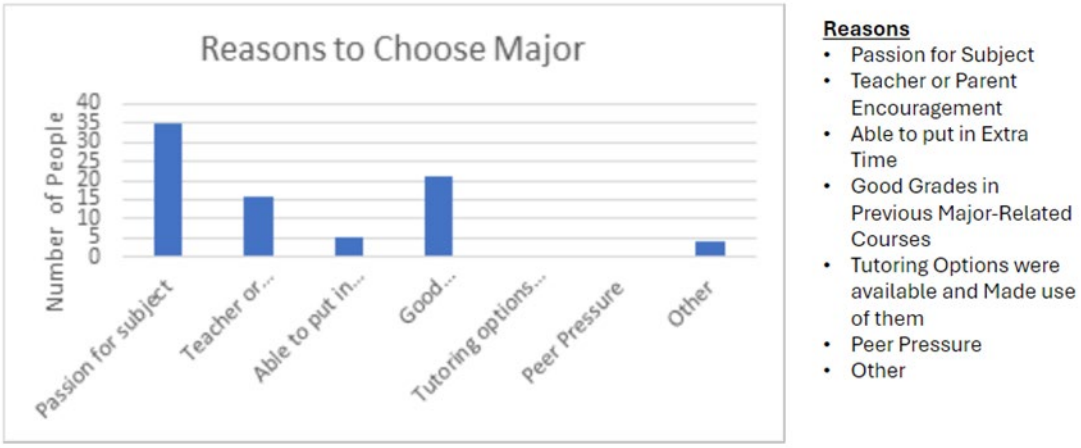


Chart 2. Students' reasons for choosing their college major.

Although the results in Chart 2 did not strictly apply to seniors who wished to major in STEM, they reflect the most common motivations for major choice, such as "Passion for Subject" and "Good Grades in Previous Major-

Related Courses". Since it was possible in the survey for a participant to choose multiple factors, a bar graph was chosen to present this data.

One piece of the data from the survey that turned out inconclusive was the student's grade trend in STEM-related classes, as showcased in Chart 3 below.

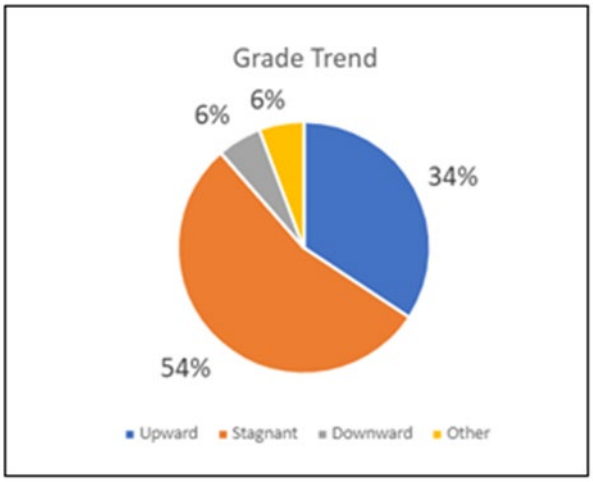


Chart 3. Students' grade trends in science and math courses in high school.

Most participants had "Stagnant" grade trends, with some reporting an "Upward" grade trend, a few reporting a "Downward" grade trend, and a few using the "Other" option to specify fluctuations in their grades over specific years. Unfortunately, due to privacy concerns, the participants could not be asked for their actual grade letter or percentage to quantify their grade trend claims. Therefore, these results only offered a limited conclusion about the seniors' performance in STEM. The pie chart was chosen as the best visual representation of the percentages in each category.

However, the data gathered about the students' most effective STEM learning methods, and the reasons they were effective, provided more insight, as shown in Chart 4 below.

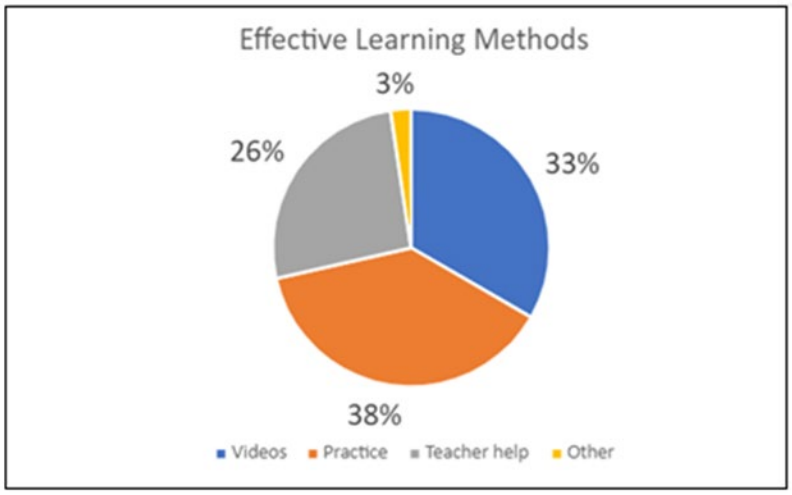
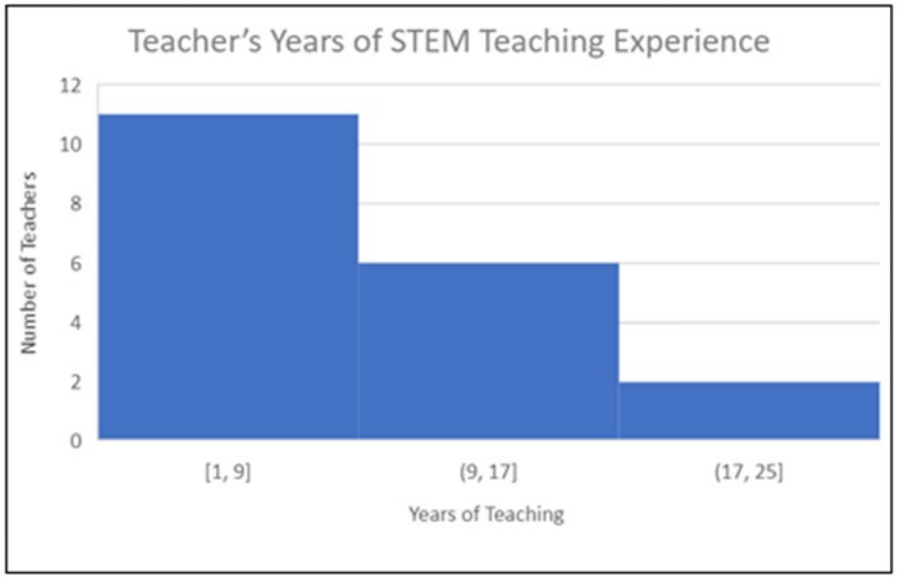


Chart 4. Effective STEM learning methods most preferred by the high school students.

The responses about STEM learning methods consisted of one or more of the four categories listed in Chart 4: “Practice”, “Videos”, “Teacher help” or “Other”. These categories were formed by filtering out the most common recurring methods in the free-response section.

Teacher Interview Results

Totally, 19 interviews were conducted with secondary teachers from around the local school district.



Histogram 1. Teachers’ number of years of STEM teaching experience.

Histogram 1 showcases the distribution of the teachers’ years of experience in teaching. Overall, the data is skewed right, with most teachers starting their teaching career less than a decade ago. The mean number of years of teaching experience is 8.526 years.

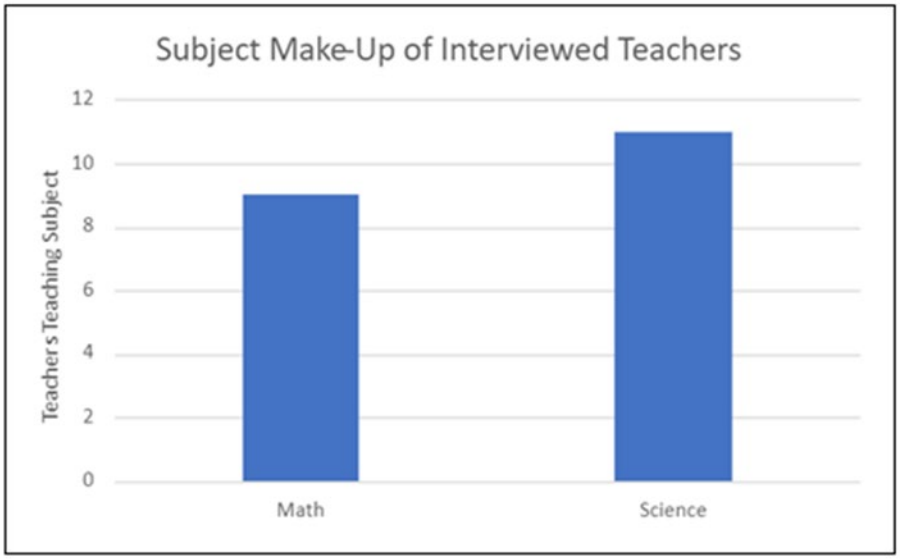


Chart 5. STEM subjects taught by middle and high school teachers.

Although science uses mathematics to model and explain concepts, teaching each subject by itself requires different skill sets. Therefore, Chart 5 displays the subject make-up of the interviewed teachers. More science teachers than math teachers were willing to participate in this study, thus science teachers are more represented.

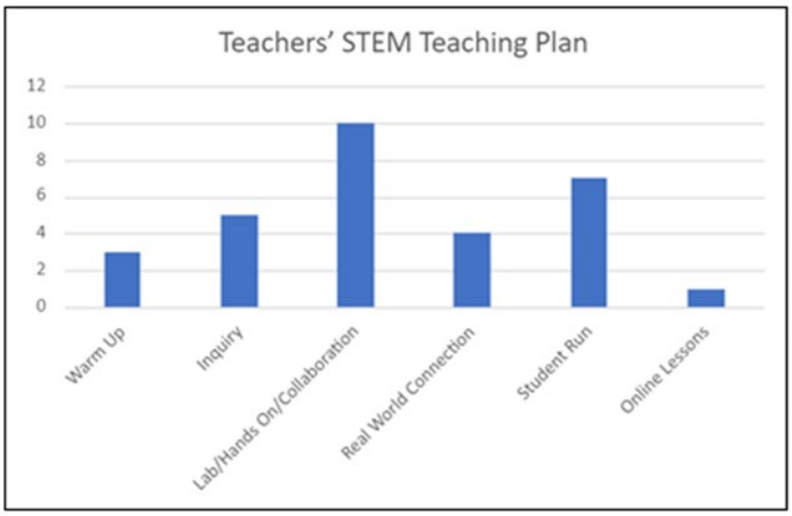


Chart 6. Teachers' STEM subject teaching plans.

Chart 6 represents the teachers' usual or default teaching style. Most teachers said they rely on student collaboration, labs, and other hands-on activities to explain concepts taught in class. The next common teaching style was to use student-run lesson plans, that are composed of students monitoring what they are learning throughout the unit, students choosing how they show their understanding of the topic, and/or students leading the conversation in group discussions about the concept. The third most common teaching style was inquiry-based, where, throughout the unit, the teacher would choose or let the students choose what questions to explore and through the answers to those questions, the students would learn the concepts. The remaining three styles include showing real life applications of the learned concepts, warm up questions, and usage of online lessons. These last three were often mentioned in tandem with the other teaching methods.

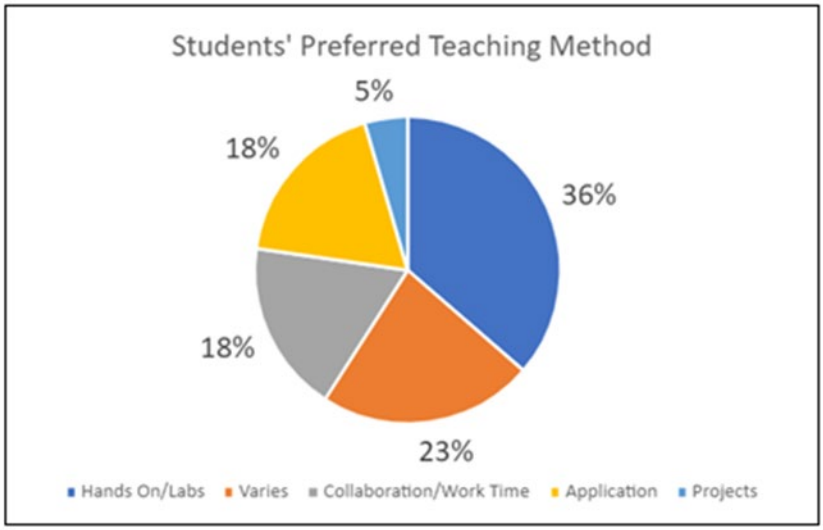


Chart 7. Teaching methods that teachers consider as preferred by students.

Next, teachers were prompted to talk about which teaching methods their students enjoyed. Chart 7 shows the distribution of teaching methods that were appreciated by the students. The largest percentage of teachers claimed that students appreciated hands-on learning, and the next most liked methods were collaboration and discussing applications of the concept. However, about a fifth of the teachers mentioned that the success of any method varied per class and even per student.

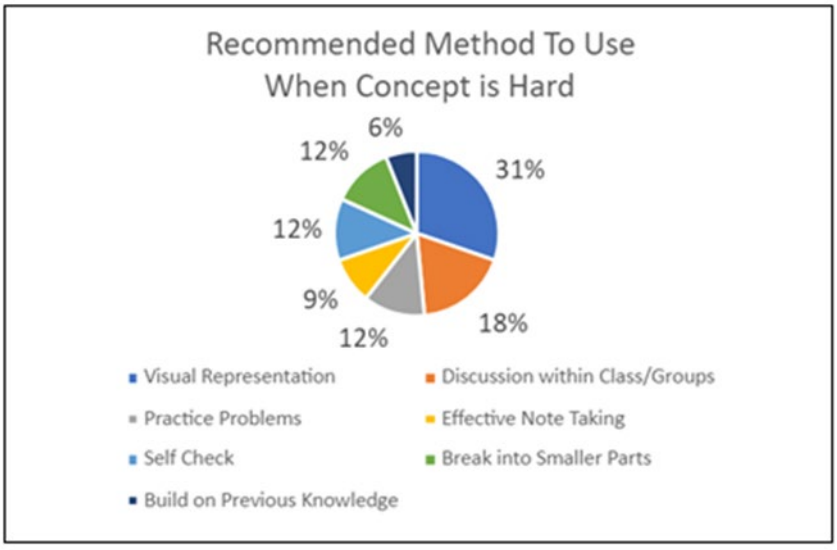


Chart 8. Secondary teachers' recommended methods for teaching hard STEM concepts.

When asked about teaching challenging concepts, most teachers recommended the usage of visual representation for understanding. This theme encompassed labs, models, videos, etc. The next highest theme was collaborating with the class or peers. Thus, the tactile and collaborative theme continued. However, when it came to presenting harder concepts, teachers advised employing a variety of methods such as practice problems, breaking the problem into smaller parts, note-taking, self-checks, and building on previous knowledge.

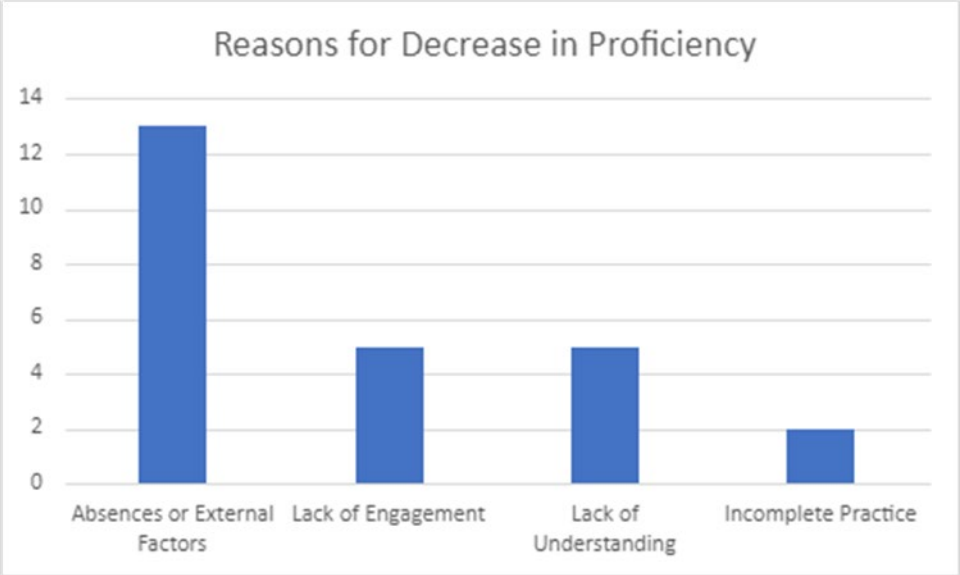


Chart 9. Teachers' reasons for decrease in the students' STEM subject proficiency.

Throughout the year, students can see fluctuations in their proficiency in a STEM subject. However, teachers can notice when certain students are consistently not meeting set standards or have a sudden drop in proficiency. In this study, absences and external factors that led to absences were the main causes of a student's proficiency decreasing, as seen in Chart 9. Both "Lack of Engagement" and "Lack of Understanding" had an equal number of mentions, while "Incomplete Practice", or incomplete work, was only mentioned twice.

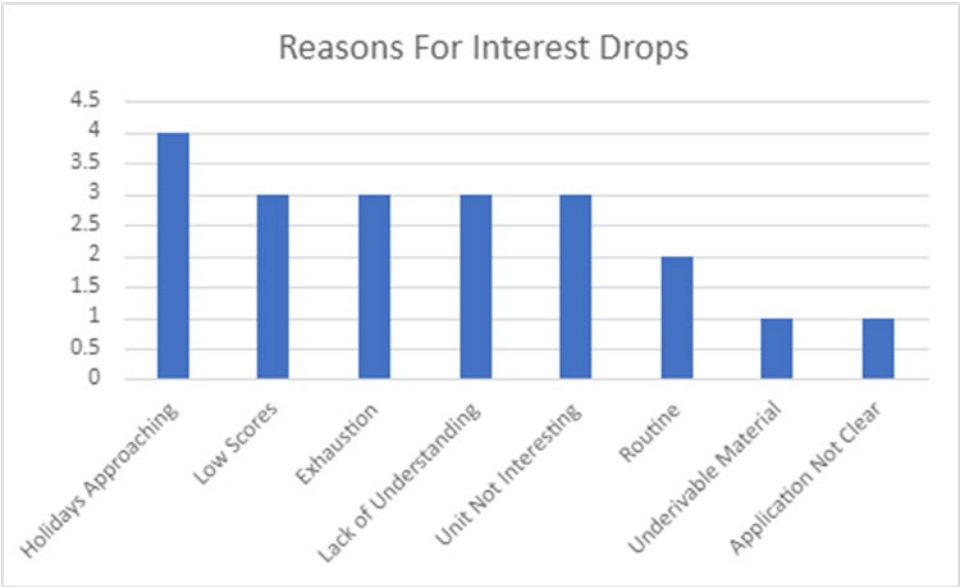


Chart 10. Teachers' reasons for drops in students' interest in class.

Since absences and external factors cannot be controlled, it made sense to focus on factors one can control to improve proficiency. For example, incomplete work can be solved by extra effort or encouragement, and a lack of

understanding can be fixed with additional support. However, the unknown factor for a drop in proficiency that was harder to pinpoint or quantify was a "Lack of Engagement" in class, as seen in Chart 9. Teachers explained that students got quite distracted by upcoming holidays. However, low test scores, a lack of understanding of the concept, the unit not being interesting to a particular student, and exhaustion were all equal contributors to engagement drops, as seen in Chart 10. Set routines were mentioned two times, while underivable or memorization-based subject material and the lack of clarity on real-world applications of the learned concepts were mentioned once.

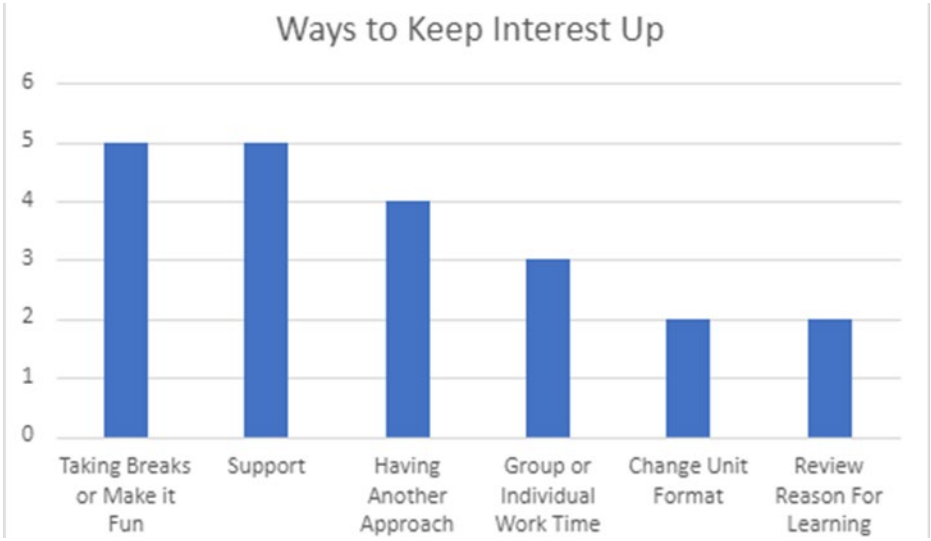


Chart 11. How secondary teachers keep student engagement high in STEM courses.

To keep the class engagement high, the interviewed teachers gave a variety of tactics that they use. Taking breaks or making learning fun, as well as giving support to students were the most common responses. Having another approach to a concept was mentioned four times. Changing the unit format and reviewing the reason for learning a concept were mentioned along with the other methods, while group or individual work time received three mentions. This is the first time that collaboration is not one of the highest employed methods.

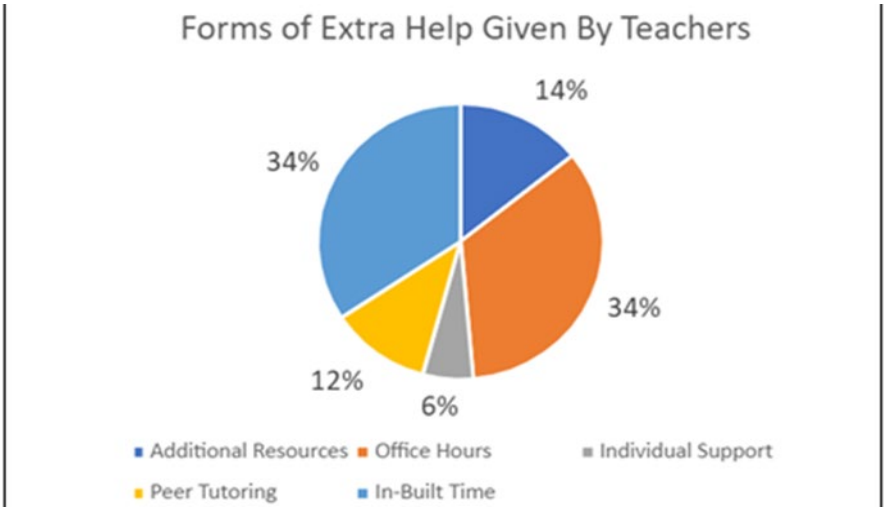


Chart 12. Additional support provided by secondary teachers to students.

As mentioned earlier, a lack of understanding of a concept often requires a student to receive extra support within and outside the classroom. Chart 12 displays the various ways that the teachers gave additional support to their students if the students wanted or needed it. Two-thirds of the teachers had some form of support during the school day and/or had office hours before and after school. When a teacher said that they pointed their students to additional materials, they often meant extra videos or notes. One-sixth of the teachers had this form of help as their support method, while one-sixth recommended their students to peer tutoring or booked time individually with a student to best support them.

Discussion, Observations, and Conclusion

Different Perspectives for Effective Learning

High school students seek out different perspectives about a concept in math or science to better understand the topic areas. These perspectives could come from peers, online videos from a reputed source, clarifying with their teacher, tactile methods, or practicing additional problems to find new patterns of solving problems.

Throughout the interviews, this study shows that hands-on learning and labs were the students' most preferred choices of learning. Although these choices were more commonly used in science classrooms, mathematics teachers also pointed out that using hand-on learning helped solidify concepts for students, especially where proof of a concept was involved.

Whenever a student participant would mention additional educational videos (Khan Academy and The Organic Chemistry Tutor were mentioned predominantly), they would explain that watching a concept being explained with a new perspective or a problem being solved using a different method would often clear up doubts they had on the topic.

Another category of student responses involved getting help from a teacher. This included asking the teacher for clarification on certain concepts or going over homework with them. Participants pointed out that their teachers would go into more detail about the concept or explain it in a different way that would help the student understand the material better than just from the classroom lecture.

Practicing putting the concepts learned into use, either in the form of doing extra problems/tests or working on the subject with a study group, was the last major category. Students who fell under this category often mentioned that additional practice solidified the understanding of the concept. Practicing extra problems helped a student encounter different problems they may have not solved in class or on a test before.

All the above categories follow the "different perspective" theme because, if a student solves new problems that are similar to the ones they have already solved, then they gain a new perspective on how different problems can be framed about the same concept that they learned, and how they can recognize the underlying concept and solve these problems.

The participants who did not fall under any of these categories, landed in the "Other" section only because their effective learning method did not fit into the three main categories. These students answered as "I make detailed notes to use at a later time", etc.

Additional Time Spent on Learning

The next observation is that students, whether they were passionate about STEM or not, often spent extra time on improving their knowledge in STEM. Although only 5 participants mentioned, as in Chart 2, that they wished to pursue their chosen major because they were able to spend extra time on the subject, the most prominent effective study methods chosen were additional practice and videos, as shown in Chart 4. Even if a teacher gave class time to

practice problems or showed educational videos in class, some students may not have been able to grasp the concept well enough to apply their understanding in tests or in the real world. Therefore, students used extra time, outside of the time given in class and spent in completing any homework, to either practice more problems or watch videos to improve their understanding.

Since science and math concepts build on top of each other, students will need a firm understanding of each concept before moving to the next. Thus, taking the additional time to increase one's understanding improves the student's knowledge of the subject.

Positive Feedback Loop

Another phenomenon that can be observed in the results is that students redoubled their efforts in a subject/topic they were passionate about when they received positive reinforcement while learning it. Positive reinforcement in this context can be good performance in subject-related courses, teacher and/or parent encouragement, etc. In Chart 2, "Passion for the subject" was the most chosen option for reasons why a student chose to pursue their listed major. But since the question allowed multiple selections per person, the other options were also crucial factors. The next two highest selected options were "Good performance in other subject-related courses" and "Parent and/or teacher encouragement".

When a student sees their efforts reaping good results or a respected person in their life believing in them, their self-esteem gets boosted and thus the student puts more effort into the subject.

Teacher Interview Results

In a study by Hedges (2011), it was said that collaborating with peers "enable[s] children to demonstrate knowledge of how they themselves had experienced being encouraged to learn something new." This goes back to providing different perspectives. Students who learned together in the same class still had different experiences with a subject and different levels of understanding. By allowing students to collaborate on sharing their knowledge, teachers not only gave students a space for a low-stakes test of knowledge, but also a chance to see how other students in a class thought of and understood the topic. In this study, overall, the interviewed teachers strived to provide students with multiple perspectives to understand concepts. In Chart 6, many of the teachers stated that their default lesson plans included labs, discussions, hands-on work, inquiry, or student-chosen focus and application of knowledge. In this way, teachers provided their students with many perspectives throughout their lesson plans. This solidifies that students and teachers are working together to provide and make use of multiple perspectives available.

Even if teachers did provide the additional perspectives that students want, there were many cases where a student needed extra help. In Chart 12, when the teachers were prompted to state how they provided extra help to students in need, many listed multiple options. The two most common options were additional resources, such as notes, videos, etc., and availability outside of school hours (office hours). This is similar to students referring to additional videos and clarifying the concept with their teacher to gain extra perspectives.

Finally, teachers helped students learn by trying to keep the class engaged. In Chart 9, other than external factors, the main reason for a student's decrease in proficiency was their "Lack of Engagement" (or loss of interest) in the class. Chart 10 explains that students mostly lost interest in class due to an upcoming scheduled school break, and the next set of equal contributors to engagement drops included low scores, fatigue, or the unit not being interesting to them. So, as seen in Chart 11, teachers tried to keep the class engaged by making it fun, taking breaks, and offering support in many ways.

Conclusion

The overarching conclusion that can be drawn from this study is that methods such as getting one-on-one time with the teacher to clarify doubts, watching additional educational videos, and practicing problems other than just those given in homework, all helped the student to think over the concept and study it from different perspectives to properly understand it. The additional time spent gaining these different perspectives helped students thoroughly understand the concept and prepared them to learn further topics that rely on a solid understanding of foundational concepts. Additionally, receiving positive results and positive feedback for their efforts increased the students' drive to continue pursuing the STEM subject. Finally, students' and teachers' efforts to have consistent engagement in class led to a lower likelihood of student proficiency and interest in the subject dropping.

Limitations and Implications

Although students were asked for their grade trend in their STEM courses, students' actual GPAs and current grades could not be collected due to privacy concerns. If this study had been able to collect GPA and grade data, the correlation between the students' listed effective study method(s) and the change in their proficiency in STEM could have been made.

A similar situation was present in the teacher interviews. Although the teachers did provide their various teaching methods, their insight on which methods were popular among the students, and their reasons for a drop in a student's proficiency in their class, questions about improved grades and current classroom success were avoided due to the concern that teachers would have felt "graded" on their teaching methods. If teachers were to answer such questions, along with the data they did provide, a correlation could have been drawn between a specific teaching method and the corresponding change it caused in class performance.

Another limitation of this study is that the opinions heard were limited to the seniors of only the local high school and the secondary STEM teaching faculty of only the local school district. Therefore, these opinions do not represent the views of all high school students or secondary teachers.

Future Steps

Further research can be conducted on students' responses to how the delivery of a school district's science and math curriculum changes when they transition from elementary to secondary school. These changes can include the introduction of formulas and numbers in science in secondary school, and students designing a lab from scratch instead of having a prepared lab set up.

Another area of future research is the effectiveness of peer tutoring in a student population that is struggling with STEM. In the interviews, teachers have stated that sometimes they refer students who need extra help in the subject to peer tutors. Further research in this area could prove the recurring theme that students want, need, or require different perspectives on a concept to properly understand it.

Finally, future research can include a student's performance in the AP and/or IB exams of an AP/IB STEM course, in addition to the data already collected in the study, to gauge the effectiveness of the teachers' teaching methods in the course as well as the effectiveness of the students' own learning methods.

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