Student-Centered Math Instruction

In High Schools

District Leadership Forum

District Leadership Forum

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1) Executive Overview

Key Observations

Student-centered instructional techniques improve student engagement with math according to all profiled studies that investigate the relationship. Across profiled studies, students more frequently report that they enjoy math in student-centered classrooms, report more interest in their work, and report more confidence in their mathematical abilities.

Though multiple profiled studies suggest that student-centered instructional techniques improve student math achievement, associated evidence is weak. For example, though one profiled study found that students in student-centered math courses demonstrated higher SAT scores, the difference was statistically significant only at one high school. That said, no profiled studies report deficits in student achievement in math courses due to student-centered classroom strategies. In addition, EAB researchers were unable to identify studies that demonstrated negative impacts of student-centered math instruction on high school student engagement with math or achievement in math.

Teachers may find student-centered strategies difficult to implement in STEM courses. One profiled study interviewed 13 STEM teachers, seven of whom reported easy transitions to student-centered instruction. However, five teachers reported difficult transitions, and one teacher was unable to transition. Moreover, teachers in the study relied on student teaching assistants to mitigate common barriers to student-centered instruction such as difficulties managing classrooms and disengaged students.

Some student-centered high schools in profiled studies show impressive student graduation rates, student achievement on standardized tests, and persistence in college relative to other similar schools. Specifically, these student-centered high schools show promise in supporting students from diverse, low-income areas. Schools with achievement gains incorporate inquiry-based learning strategies and collaborative learning structures.

Teachers at student-centered high schools in profiled studies report that student-centered instructional practices take more time to prepare for and implement. These teachers report that student-centered practices may slow the rate of instruction (i.e., teachers can cover less content over the course of the year). However, teachers report that student-centered practices increase student engagement.

Teachers and administrators at student-centered high schools in profiled studies report frustration with competency-based learning and differentiated instruction. Teachers at these high schools respond more positively to student-centered strategies that focus on student ownership and student choice over more intensive student-centered practices that impact lesson pacing and grading practices.

Research supports the use of specific student-centered instructional strategies in math. Though the studies profiled in this review highlight mixed student achievement outcomes related to student-centered approaches to math, research does support the use of specific student-centered instructional strategies in math classrooms. Specifically, some research suggests that when teachers ask students to work in groups to explore complex, conceptual math problems without explicit teacher guidance (i.e., problem-based learning), students demonstrate learning benefits.

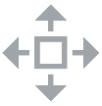
2) Definition and Purpose

Description

Student-Centered Instructional Practices Devote Time and Focus to Learning Instead of Teaching

Student-centered instructional practices in math classes shift the emphasis from teachers' instruction to students' development of knowledge. In 2014, the **American Institutes for Research** and the **Nellie Mae Education Foundation** studied the use and impact of student-centered instruction in math classes. Researchers note that multiple instructional practices qualify as student-centered.

Characteristics of Student-Centered Math Instruction[1]



Expansive
Instruction covers both traditional standards (e.g., numeracy) and 21st century skills (e.g., communication).

Engaging
Lesson plans encourage students to collaborate and to connect learning with their personal experiences.

Student-Centered Instruction

Personal
Teachers promote individualized learning through choice and differentiation.

Connection-Driven
Classrooms foster trust and close relationships between teachers and students.

To further define student-centered instructional practices, the researchers identify four ways that students experience instruction in student-centered math classes.

1) Kirk Walters, Toni M. Smith, Steve Leinwand, Wendy Surr, Abigail Stein, and Paul Baiely, *An Up-Close Look at Student-Centered Math Teaching (*Nellie Mae Education Foundation and American Institutions for Research, November 2014). https://www.nmefoundation.org/getattachment/Resources/Student-Centered-Learning/An-Up-Close-Look-at-Student-Centered-Math-Teaching/An-UpClose-Look-at-Student-Centered-Math-Teaching-(1).pdf?ext=.pdf.

Student Experiences of Student-Centered Math Instruction[2]

In a student-centered math class, **students…**

…reason mathematically to understand the "why" of the math problem, not just the "how."

…communicate mathematical thinking and critique the reasoning of others.

…connect math concepts to their experiences.

…persist to solve puzzles, not just memorize procedures.

Further, students in student-centered math classes spend significantly more time working through problems collaboratively, with guidance from the teacher, instead of listening to lectures.[3] This teacher-supported, exploration-based approach allows students to spend more time engaging directly with mathematical concepts, rather than copying rote procedures demonstrated by the teacher.

Time Spent on Math Lectures at High Schools in One Study of Student-Centered Instruction[4]

21%

Teachers in **traditional high school math classes** devoted 21 percent of class time to lectures.

4%

Teachers in **student-centered math classes** devoted 4 percent of class time to lectures.

Pitfalls of Traditional Instruction

Traditional Math Instruction May Impede Student Engagement, Achievement, and Post-Secondary Readiness

The majority of high school students in the United States graduate without proficiency in math, ill-equipped for 21st century careers. Experts suggest administrators and teachers re-imagine traditional instructional practices to improve student proficiency in math.[5]

2) Kirk Walters, Toni M. Smith, Steve Leinwand, Wendy Surr, Abigail Stein, and Paul Baiely, *An Up-Close Look at Student-Centered Math Teaching (*Nellie Mae Education Foundation and American Institutions for Research, November 2014). https://www.nmefoundation.org/getattachment/Resources/Student-Centered-Learning/An-Up-Close-Look-at-Student-Centered-Math-Teaching/An-UpClose-Look-at-Student-Centered-Math-Teaching-(1).pdf?ext=.pdf.
3) Jo Boaler and Megan Staples, "Creating Mathematical Futures Through an Equitable teaching Approach: The Case of Railside School," *Teachers College Record*, Vol. 110 (3), 608-645, March 2008. https://www.ortingschools.org/cms/lib/WA01919463/Centricity/domain/326/purpose/research/Equitable%20teaching%20approach%20article.pdf.
4) Ibid.
5) Jo Boaler and Pablo Zoido, "Why Math Education in the U.S. Doesn't Add Up," *Scientific American*, November 1, 2016. https://www.scientificamerican.com/article/why-math-education-in-the-u-s-doesn-t-add-up/.

U.S. Students Lack Math Proficiency, Unprepared for High-Growth Fields

Data shows that demand for workers in high-growth, math-based sectors (e.g., health sciences, technology) outpaces the supply of students who graduate high school proficient in math.

United States Lags in Rankings

Out of 35 peer countries, the United States **ranks 30th** in math.[7]

Minority of Students Proficient

In 2015, **40%** of fourth graders, **33%** of eighth graders, and **25%** of 12-graders were proficient in math. This represents a decline from previous years.[8]

Math-Centered Fields Expanding

The U.S. Chamber of Commerce Foundation projects that STEM jobs will **grow by over 9 million** from 2012 to 2022. The organization states that math skills are the key to success in the 21st century U.S. economy.[6]

To Address Lack of Math Proficiency and Workforce Preparation, Re-Examine Traditional Math Instruction

Math education experts identify the structure of traditional math instruction (i.e., lessons centered on memorization of concepts and replication of procedures) as a factor that may contribute to the negative state of math achievement in the U.S.[9]

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Why Math Education in the U.S. Doesn't Add Up[10]

"Research shows that an emphasis on memorization, rote procedures, and speed impairs learning and achievement."

In 2016, math education experts Jo Boaler and Pablo Zoido wrote in **Scientific American** that traditional math instruction practices are ineffective at teaching math. Instead, they suggest instructional practices that require students to engage with math concepts and build deeper understanding of math processes. [11] Similarly, according to the National Council for Teachers of Mathematics, teachers in a successful math classroom create opportunities for students to complete challenging tasks that require students to explore math concepts in unfamiliar contexts, promote

6) U.S. Chamber of Commerce Foundation, "Math is Foundational to 21st Century Success,", *Center for Education and* Workforce, July 11, 2017. https://www.uschamberfoundation.org/blog/post/math-foundational-21st-century-success.
7) Drew Desilver, "U.S. Students' Academic Achievement Still Lags That of Their Peers in many Other Countries," *Pew Research*, February 15, 2017. https://www.pewresearch.org/fact-tank/2017/02/15/u-s-students-internationally-math-science/.
8) Ibid.
9) Jo Boaler and Pablo Zoido, "Why Math Education in the U.S. Doesn't Add Up," *Scientific American*, November 1, 2016. https://www.scientificamerican.com/article/why-math-education-in-the-u-s-doesn-t-add-up/.
10) Ibid.
11) Ibid.

mathematical discourse across students, and make connections across multiple rich topics.[12]

Integrate Student-Centered Instructional Tactics with Traditional Approaches to Support Students

Research from the **Department of Education** finds insufficient evidence to fully endorse student-centered math instruction—but notably reaches the same conclusion (i.e., insufficient evidence to fully endorse) about traditional instruction in math.[13] Experts suggest that math teachers can balance direct instruction of math facts with student-centered instruction to build students' comfort with math and depth of mathematical understanding.[14] Notably, experts maintain that developing an understanding of "math facts" (e.g., multiplication tables)—a pillar of traditional math instruction—remains important for math students.[15]

12) "Principles and Standards for School Math," *National Council of Teachers of Mathematics*, 2000, 16. https://www.nctm.org/Handlers/AttachmentHandler.ashx?attachmentID=YrwYUOB4xnA=
13) U.S. Department of Education, "Chapter 7: Instructional Tactics," in *The Final Report of the National Math Advisory Panel*, 2008, 45. https://www2.ed.gov/about/bdscomm/list/mathpanel/report/final-report.pdf.
14) Jo Boaler, "Research Shows the Best Ways to Learn Math," *Stanford Graduate School of Education*, January 29, 2015. https://ed.stanford.edu/news/learning-math-without-fear.
15) Ibid.

2) Evidence of Effectiveness

Student-Centered Math

Limited Research Explores the Impact of Student-Centered Math at the High School Level

Researchers from the American Institutes for Research and the Nellie Mae Education Foundation report that—though a growing body of research explores student-centered instruction—limited research explores how particular principles of student-centered approaches apply to math teaching at the high school level.[16]

EAB researchers reviewed publicly available, existing research that evaluates the impact of student-centered instruction in high school math/STEM classes. Below EAB profiles four studies—published by reputable authors, journals, or organizations—that highlight different results of student-centered math/STEM instruction in high schools.

Study Summaries

Study	Description	Findings	Caveats
An Up-Close Look at Student-Centered Math Teaching (profiled on pages 10-13 of this report)	Researchers selected high-performing high school math teachers with varying degrees of student-centered approaches. Researchers asked students in all selected classrooms to take math assessments and engagement surveys to analyze the potential impact of student-centered approaches.	• Students reported statistically significant greater engagement in more student-centered classrooms. • Students demonstrated statistically significant greater math achievement in more student-centered classrooms.	• The study profiles only high-performing teachers, which may make it difficult to argue that findings apply to all classrooms. • Researchers acknowledge that achievement results are difficult to interpret due to the small sample size.
The Consequences of a Problem-Based Math Curriculum (profiled on pages 13-16)	Researchers investigated the impact of a problem-based high school math curriculum that aligns with student-centered tenets. Researchers compared SAT scores and student engagement questionnaire responses from students in traditional classrooms with students in student-centered classrooms.	• Students in the problem-based classrooms achieved higher mean SAT scores, but the difference was statistically significant in only one high school. • Students in problem-based classrooms report greater confidence in their ability and more positive attitudes toward math.	• In some studied high schools, students could opt into the problem-based curriculum, which implies that the two samples may have differed in preliminary engagement and mathematic achievement.

16) Kirk Walters, Toni M. Smith, Steve Leinwand, Wendy Surr, Abigail Stein, and Paul Baiely, *An Up-Close Look at Student-Centered Math Teaching (*Nellie Mae Education Foundation and American Institutions for Research, November 2014). https://www.nmefoundation.org/getattachment/Resources/Student-Centered-Learning/An-Up-Close-Look-at-Student-Centered-Math-Teaching/An-UpClose-Look-at-Student-Centered-Math-Teaching-(1).pdf?ext=.pdf.

Study	Description	Findings	Caveats
Creating Mathematical Futures Through an Equitable Teaching Approach (profiled on pages 17-20)	Researchers compared student outcomes in student-centered math courses at one high school with students in traditional courses at two others to investigate impacts on achievement and engagement.	• Students at the student-centered high school out-performed students in traditional high schools on curriculum-aligned tests after two years in the program, despite lower achievement levels prior to entering student centered classes. • Students at the student-centered high school were more likely to enjoy math and more likely to continue to pursue math.	• Researchers cannot attribute achievement gains to student-centered practices alone—variables such as increased instructional time in math, student after-school supports, and other characteristics may have contributed to achievement gains. • Students at the student-centered high school did not demonstrate the same achievement gains on some state standardized tests.
Teachers' Roles and Identities in Student-Centered Classrooms (profiled on pages 19-21)	Researchers interviewed 13 STEM teachers who participated in a student-centered training program that asks teachers to work alongside student teaching assistants to lead groupwork based courses.	• Five out of the seven teachers reported difficulty adapting to student-centered practices, and one teacher dropped out of the program. • Teachers note that without the assistance of student teaching assistants, they likely would have struggled with disengaged students and disruptive behaviors.	• The study relies entirely on qualitative, interview-based data and classroom observations.

Study 1: An Up-Close Look at Student-Centered Math Teaching[17]

Background: The Nellie Mae Education Foundation—a large, education-focused philanthropic organization in New England, partnered with the nonpartisan, not-for-profit American Institutes for Research (AIR) to investigate the effectiveness of student-centered math instruction in high schools. AIR researchers designed a two-part study that relied on both case studies of effective teachers and quantitative analysis of student performance across a larger sample of teachers.

Sample: AIR researchers drew a sample of 22 teachers from six New England States and New York. To ensure that researchers could compare effective forms of student-centered and non-student-centered pedagogy, researchers selected teachers by an application circulated to district leaders, school leaders, and representatives from student-centered school networks and organizations. Researchers selected teachers based on both their description of their instructional approach and the degree to

17) Kirk Walters, Toni M. Smith, Steve Leinwand, Wendy Surr, Abigail Stein, and Paul Baiely, *An Up-Close Look at Student-Centered Math Teaching (*Nellie Mae Education Foundation and American Institutions for Research, November 2014). https://www.nmefoundation.org/getattachment/Resources/Student-Centered-Learning/An-Up-Close-Look-at-Student-Centered-Math-Teaching/An-UpClose-Look-at-Student-Centered-Math-Teaching-(1).pdf?ext=.pdf.

which instructional leaders considered that teacher to be one of their best. In other words, researchers selected teachers who were highly regarded and maintained supportive learning environments for students. Researchers analyzed student outcomes and practices from all 22 samples teachers but selected seven teachers for in-depth case studies on effective teaching practices. To select the seven teachers profiled in case studies, researchers both observed teachers as they delivered instruction and interviewed teachers in person. Researchers selected teachers with the highest quality lessons according to an observation rubric (see **pages seven to eight** of the study for a brief description of the rubric) for case studies.

Based on the frequency of use of student-centered techniques, researchers separated teachers into two groups. Teachers in the first group used student-centered practices more frequently, while teachers in the second used them less frequently. Though researchers ensured the groups were roughly balanced in terms of gender, teaching experience, and educational attainment, teachers in the student-centered group possessed more teaching experience on average (i.e., 72.7 percent of teachers had greater than 11 years of experience, as compared to 63.6 percent in the traditional group). Researchers conducted case studies with four teachers from the more traditional group and three teachers from the more student-centered group.

Methodology: Researchers collected both qualitative and quantitative data to assess the performance of case study and sample teachers and the students in their courses. Researchers used observation data from case studies to describe tactics that teachers used in each group to deliver instruction but relied on data from all teachers to determine the relationship between frequency of student-centered practice use and student achievement/engagement.

Sources of Data

Data Source	Nature of Data	Target Classrooms
Videos of math instruction	Researchers recorded three lessons per teacher in which teachers introduced new concepts.	Case study teachers
Instructional logs	Researchers assessed teacher descriptions of instructional practices used throughout a week (one week per month for eight months).	Case study teachers
Teacher interviews	Researchers assessed teacher perceptions of their school, math department, philosophy of instruction, planning process, instructional practices, etc.	Case study teachers
Student focus groups	Researchers interviewed three to five students per year to assess perceptions of their experiences.	Case study teachers
Administrative records	Researchers collected demographic data and grade eight achievement on state math tests.	All sample teachers
Teacher survey	Researchers asked teachers to identify the frequency with which they implement student-centered/non-student-centered instructional practices.	All sample teachers
Challenging assignments	Researchers consulted examples of the most challenging assignment teachers offer.	All sample teachers

Student survey	Researchers assessed student perceptions of the school and their experiences in the math class.	All sample teachers
Mathematical problem-solving assessment	Researchers assessed students' responses to math items from the **Program for International Student Assessment (PISA)**, an assessment given to 15- and 16-year old students.	All sample teachers

To identify the relationship between the degree to which teachers implemented student-centered practices and student outcomes, researchers relied on the following measures:

- **Composite Measure of Student-Centered Math Instruction**: Based on teacher's ratings (from "never" to "every day or almost every day") of how often they used specific student-centered tactics (e.g., how often they use exploratory activities), researchers assigned each teacher a score of zero to three for each tactic. Researchers added up these scores for all surveyed tactics to create a composite measure of the frequency of student-centered instructional practice use by each teacher, called Student-Centered Practices $(SCP)_{TS}$. Researchers combined this score with researcher average ratings (out of 15) of the student-centeredness of four challenging assignments provided by each teacher, which they called SCP_{CA}. Researchers weighted each score (75 percent SCP_{TS}, 25 percent SCP_{CA}) to create a combined overall rating of the degree to which each teacher delivered student-centered math instruction, which they called SCP.
- **Student Engagement**: Researchers used student numeric ratings associated with the following survey items to create a composite score for student engagement:
  - *Student Self-Assessment of Learning*
    - This math class really makes me think
    - I'm learning a lot in this math class
  - *Student Interest*
    - I usually look forward to this math class
    - I work hard to do my best in this math class
    - In this math class, I sometimes get so interested in my work I don't want to stop
- **Problem Solving Assessment**: Students completed nine published items from the 2009 PISA, which focuses on problem-solving rather than course-specific knowledge. Researchers then used measures of students' prior math achievement on eighth grade math tests to account for differences in baseline math competency.

Findings: Researchers argue that when exemplary teachers implement student-centered practices to a greater degree, student engagement and achievement increase.

Student Outcomes in More Student-Centered Math Classrooms

Students reported higher levels of engagement and interest via surveys

Researchers found statistically significant positive relationships (i.e., p-values of approximately .002) between the SCP measure and survey measures for student self-assessment of learning and student interest. In other words, in classrooms with a greater frequency of student-centered practices, students report feeling more engaged.

Researchers also interviewed students in more student-centered and less student-centered classrooms. Students in more student-centered classrooms report that they no longer dread math and some even noted that they grew to enjoy the subject. In contrast, though students in less student-centered classrooms report that they felt more confident in math, they did not report they enjoyed the subject.

Students earned higher PISA assessment scores when controlling for prior mathematic achievement

An increase of .01 on the SCP measure is associated with an increase of .02 scaled score on the PISA. In other words, as classrooms become more student-centered, students demonstrate statistically significant (i.e., p-value just under .05), slightly greater achievement on problem-solving assessments.

Researchers caution that because the study relies on an unrepresentative sample, they could not compare the change in performance to a Z-score change. They thus caution that the relationship is "difficult to interpret."

Study 2: The Consequences of a Problem-Based Math Curriculum[18]

Background: David Clarke, a Professor in the Faculty of Education at the **University of Melbourne**, partnered with the graduate student Margarita Breed and Sherry Fraser, the director of the problem-based Interactive Math Program (IMP) to evaluate the effectiveness of the IMP. Though not nominally student-centered, the IMP incorporates multiple student-centered tenets, and EAB researchers thus incorporated its findings into the report:

- The IMP requires students to act as active learners and investigators.
- It integrates the study of separate mathematical domains (e.g., algebra, geometry, statistics) with one another.
- It asks teachers to act as guides and model learners—teachers minimize teacher-led explanation and encourage student interaction.
- Teachers assess student learning through multiple methods, including student portfolios, self-assessments, and teacher observations.

IMP instructional materials include five-week units that connect historical, literary, and scientific contexts to help students understand mathematical concepts. Curriculum designers designed IMP units to provide a rationale ("why") for each mathematical skill.

Sample: Students could elect to participate in IMP or non-IMP courses at most high schools, but one high school designed IMP course membership to ensure that courses included 60 percent students placed into Algebra and 40 percent students placed below Algebra. Though researchers could not control which students took IMP or non-

18) David Clarke, Margarita Breed, and Sherry Fraser, "The Consequences of a Problem-Based Math Curriculum," *The Math Educator*, vol. 14, no. 2 (2004): 7-16. https://pdfs.semanticscholar.org/59b8/909bc53d3481ea2d683f8c05ccb64d70482a.pdf?_ga=2.111706946.7542556.1568060923-3049762.1565822862%27.

IMP courses, administrators at sample high schools reported that the academic standing of students in IMP courses was no higher than students in standard Algebra courses. However, it is possible that self-selection bias contributes to some of the findings of the study—students who elected to take IMP courses may have been more engaged prior to entering the course.

The study focused on 182 IMP students across three California high schools. Researchers also collected data from 74 non-IMP Algebra II students and 143 non-IMP Algebra IV students from the same schools. Lastly, researchers collected data from 52 non-IMP Algebra II students from a fourth high school to increase the non-IMP Algebra II sample size. Researchers report all findings using only comparisons between IMP students and non-IMP, Algebra II students to compare students at approximately the same level.

Methodology: Researchers asked all participating students to complete two questionnaires. The first—Mathematics Belief—asks students to rate their perceptions of their mathematical competence and their beliefs about mathematical activity and the origin of ideas. The questionnaire also asks students to rate their perceptions of specific activities and their perceptions of math in general.

The second—Mathematics World—asks students to rate the extent to which specific activities are mathematical. This study allowed researchers to see if IMP or non-IMP students differed in their view of math's applicability to real-world situations after taking the distinct courses, but researchers identified no difference between IMP and non-IMP students on this questionnaire. Researchers thus focused on the Mathematics Belief questionnaire.

Sample Items from Math Belief Questionnaire

When I am doing math at school, I am likely to be …

A	Talking Always — Often — Sometimes — Seldom — Never
C	Writing words Always — Often — Sometimes — Seldom — Never
F	Working with a friend Always — Often — Sometimes — Seldom — Never
I	Listening to other students Always — Often — Sometimes — Seldom — Never
K	Working from a textbook Always — Often — Sometimes — Seldom — Never

How do you feel in math classes at the moment? (circle the words which apply to you)

☑ Interested	☑ Relaxed	☑ Worried
☑ Successful	☑ Confused	☑ Clever
☑ Happy	☑ Bored	☑ Rushed
☑ (Write one word of your own)		

Researchers also asked all students to take the Scholastic Aptitude Test (SAT) so that researchers could compare SAT scores between IMP students and their peers in non-IMP classes.

Findings: The study's authors found positive impacts of the student-centered IMP curriculum on student achievement and student perceptions of math.

Selected Impacts of the IMP Curriculum on Student Outcomes

Mathematical Ability

SAT Scores

Where comparison was possible between IMP and Algebra students at the same school, mean SAT scores for IMP classes were higher than mean SAT scores for traditional Algebra/Geometry classes. However, the comparison was statistically significant at only one high school.

School A:

- IMP Mean Score: 443.37
- Algebra Mean Score: 420.48
- P value: .0372 (significant)

School B:

- IMP Mean Score: 373.88
- Algebra Mean Score: 367.56
- P value: .1003 (not significant)

Student Perceptions of Math Ability

IMP students were significantly more likely to rate themselves highly on how good they were at math across schools. Researchers argue that this increased rating reflects increased confidence on the part of IMP students, which they believe leads to increased participation in further math.

- IMP Mean Rating: 7.5
- Algebra Mean Rating: 6.86
- P value: .0012 (significant)

IMP students were also more likely to agree that math could be explained in everyday words that anyone could understand, which implies that they approach math with less trepidation.

Student Engagement

Student Attitudes Toward Math Classes

Researchers created a student attitude index by scoring each positive adjective submitted in response to the question "how do you feel in math classes at the moment?" as +1 and each negative adjective as -1. IMP students were significantly more likely to feel positive about math class across schools.

- IMP Mean Rating: .97
- Algebra Mean Rating: -.52
- P value: .0001 (significant)

Mathematical Activities

Differences in Approaches to Math

Compared to Algebra students in their classes, IMP students were:

- Significantly more likely to write words and draw diagrams and less likely to write numbers.
- Significantly more likely to work with a friend or with a group, and less likely to work on their own.
- Significantly more likely to listen to other students.
- Significantly more likely to work from a worksheet and less likely to be copying from the board or working from a textbook.

These findings suggest that IMP classes were more student-centered than non-IMP classes—students spent more time with one-another, directing their own learning.

Based on the above findings, the study's authors argue that the problem-based IMP curriculum develops students' mathematical skills at least as capably as does conventional instruction, while also instilling measurably different, positive perceptions of math and mathematical ability. However, IMP students in some instances may have already possessed more positive attitudes towards math.

Study 3: Creating Mathematical Futures Through an Equitable Teaching Approach[19]

Background: Researchers Jo Boaler and Megan Staples conducted a longitudinal study of three high schools to investigate the outcomes of heterogenous, reform-oriented math courses. In this study, researchers compare an urban, diverse high school (Railside) with a coastal, primarily white high school (Greendale) and a rural, predominantly White and Latino high school (Hilltop).

Sample: The three studied high schools were comparable in terms of their size and the quality of their teachers (according to researchers), but differed in their location, student demographics, and offered curriculum. At Greendale and Hilltop, students could choose between:

- Traditional courses in which teachers teach via demonstration and individual students practice with short problems.
- IMP Courses in which students work heavily in groups and spend more time working on longer, more in-depth problems.

Courses at both high schools were homogenous—administrators place students into classes with only other students at their level. Administrators place students in either geometry or a remedial course such as "math A" or "business math."

At Railside, all students take math courses that incorporate a reform-oriented, teacher-designed curriculum based on the College Preparatory Math Curriculum and IMP. Courses were heterogenous—all students enter the same Algebra class regardless of their level. Though—like the IMP—the Railside curriculum is not nominally student-centered, it incorporates many tenets of student-centered instruction and thus EAB researchers included the study in this review.

Though researchers monitored three approaches to math instruction—traditional, IMP, and "Railside"—not enough students elected to take the IMP, and researchers thus excluded IMP students from statistical analyses. The study thus compared approximately 300 students in the traditional curriculum at Greendale and Hilltop with approximately 300 students in the student-centered curriculum at Railside.

To compare traditional and Railside curricula, researchers recorded approximately 600 hours of lessons and conducted a quantitative analysis of teacher- and student-time allocation. In this analysis, researchers coded 55 hours of lessons in year-one courses based on the ways in which students spent time throughout the class (e.g., teacher talking, students working in groups). Researchers also coded the types of questions teachers asked into categories such as "probing," "extending," and "orienting."

19) Jo Boaler and Megan Staples, "Creating Mathematical Futures Through an Equitable Teaching Approach: The Case of Railside School," *Teachers College Record*, Vol. 110, no. 3 (March 2008): 608-645. https://www.ortingschools.org/cms/lib/WA01919463/Centricity/domain/326/purpose/research/Equitable%20teaching%20approach%20article.pdf.

Differences in Instructional Approaches Across Studied High Schools

Traditional: Greendale and Hilltop

Students sat individually. Teachers presented new mathematical methods through lectures, and students worked through short, closed problems.

- Teachers spent **21% of class time lecturing** and 15% of class time questioning the whole class
- Students spent 48% of class-time practicing methods in their books individually and spent an average of 2.5 minutes per problem.
- Students presented their work for 0.2% of the time.

Reformed: Railside

Students sat in heterogenous groups. Teachers rarely lectured, posed longer, conceptual problems, and combined student presentations with teacher questioning.

- Teachers spent **4% of class time lecturing** and 9% of class time questioning students in a whole-class format.
- Students spent 72% of class time working in groups while teachers circulated and assisted and spent an average of 5.7 minutes per problem.
- Students presented work for 9% of the time.

Notably, Railside's reformed curriculum aligns with tenets of student-centered instruction. Rather than lecture at students, direct student thinking, and encourage rote, individual drills of problems, teachers at Railside take a supportive role and allow students to determine their own approaches to longer, more conceptual problems.

At Railside, researchers found that teachers asked 62 percent procedural questions, 17 percent conceptual questions, 15 percent probing questions, and 6 percent questions in other questioning categories. Comparatively, teachers at the other two high schools asked between 97 percent and 99 percent procedural questions. In other words, Railside teachers asked questions to encourage students to think about concepts and the "why" behind math instruction, while teachers at the other schools asked questions about procedural actions (i.e., what do we do next?).

However, researchers were careful not to attribute the benefits of the Railside curricula to student-centered instruction alone. Researchers note that variables including teacher collaborative and preparation time, course structure and scheduling differences (i.e., Railside dedicates two, half-year courses to introductory algebra), and growth-mindset messaging likely contributed to student performance gains alongside the student-centered delivery of instruction.

Methodology: Researchers relied on both qualitative and quantitative measures to assess student beliefs and relationships with math and student achievement data. In addition, researchers used recorded classroom observations to produce qualitative descriptions of the types of teaching and learning in different classes and conducted case studies of one-to-two focal teachers at each school to explore how various teacher actions impact student engagement and mathematical activity.

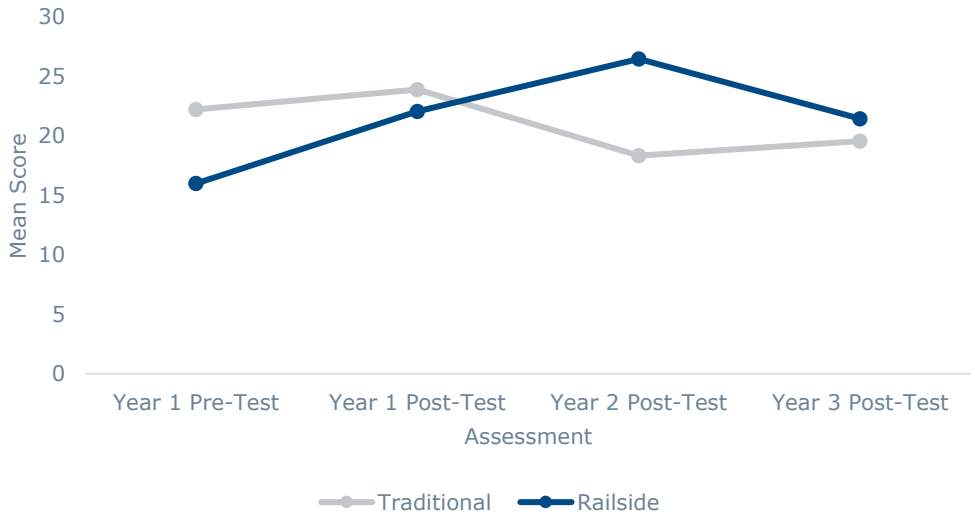
- **Student Beliefs and Relationships with Math**: Researchers interviewed at least 60 students in each of the four years that students attended high school. They selected high and low achievers alongside students from different cultural/ethnic groups. Researchers also asked all students to take questionnaires about their experience in class, their enjoyment of math, and their perceptions about the nature of math.
- **Student Achievement Data**: Researchers asked students to take content-aligned tests and open-ended project assessments (i.e., longer, applied problems

that students complete in groups) written by the research team and reviewed by teachers at all high schools for fairness. Students also took state-administered tests.

- *Content-aligned tests*: Students took a baseline assessment of middle school math at the beginning of year one, an algebraic assessment at the end of year one, the same algebraic assessment at the beginning of year two, and an algebraic/geometric assessment at the end of year two and in year three.
- *Open-ended project assessments*: One class at each school took open-ended project assessments in years one, two, and three. Researchers videotaped students as they worked.
- *State-administered tests*: Researchers gathered data from the California Achievement Test Sixth Edition (CAT6) standardized state assessment and the California Standards Test of algebra.

Findings: Though students at Railside started out with significantly lower levels of achievement than students at the comparison high schools, students at Railside performed at equivalent levels on researcher-developed math assessments after one year of student-centered math education. At the end of year two, Railside students significantly outperformed students in the traditional approach on assessments. Researchers report that all differences in performance were significant except for the difference in performance on the year three post-test, which researchers suggest may be because the Railside math department had not developed the year three curriculum to the same extent.

Changes in Mean Assessment Performances from Year 1 to Year 3



Researches also note that the curriculum successfully ameliorated the achievement gap across ethnic groups at Railside. At the beginning of the ninth-grade year, Asian, Filipino, and White students each significantly outperformed Latino and Black students. By the end of year one, significant differences between White and Latino students and between Filipino, Black, and Latino students disappeared. By the end of year two, achievement disparities between White, Black, and Latino students also disappeared. Achievement differences between Asian students and Black and Latino students persisted, however.

Notably, though Railside students performed better on researcher-developed tests, district tests, and the California Standards test of Algebra, they did not perform better than students in traditional classrooms on the CAT6 standardized test or indicators of adequate yearly progress (also determined through standardized tests). Researchers argue that these performance differences on the CAT6 may be in part caused by linguistic and cultural barriers.

Lastly, when it comes to student perceptions of and relationships with math, the authors cite several benefits of the Railside curricula.

Impact of the Railside Curricula on Student Perception of Math

Student Enjoyment

- 71% of Year 2 Railside students reported "enjoying math class" compared with 46% of Year 2 students in traditional classes.
- 54% of Year 3 Railside students reported they enjoyed math all or most of the time, as compared to 29% of Year 3 students in traditional classes.
- 74% of Railside students agreed with the statement "I like math", as compared to 54% of students in traditional classes.

Student Interest, Authority, and Agency

Based on interviews with students that researchers coded to score for interest, authority, agency, and future plans for math:

- Interviewed Railside students were significantly more interested in math
- Interviewed Railside students believed they had significantly more authority and agency regarding math
- All Railside students interviewed planned to pursue more math courses, as compared to 67% of students in traditional high schools.
- 39% of interviewed Railside students planned a future in math, compared with 5% of students from traditional courses.

Study 4: Teachers' Roles and Identities in Student-Centered Classrooms[20]

Background: The researcher Leslie E. Keller conducted qualitative research to explore the experience of 13 STEM Teachers at two urban secondary schools as they implemented student-centered instruction in their classrooms. The study investigates the benefits and detriments teachers identify with student-centered approaches and catalogs difficulties faced by teachers during implementation.

Sample: The study focuses on schools that implement the Peer Enabled Restructured Classroom (PERC) program, in which high school students act as peer leaders in STEM class and facilitate instruction. The researcher classifies this instruction as student-centered because students take ownership over guiding and delivering instruction. The study cites previous research which suggests that PERC improves STEM learning, performance, and college-readiness for students in high-needs urban schools. Lessons begin with brief whole class instruction, but students spend most class time working in small groups of four, each of which is led by a peer instructor (i.e., a TA) trained by the teacher in a separate class.

The researcher conducted case studies with all thirteen teachers who participated in the PERC program at the two schools. Teachers could choose to participate in PERC. PERC teachers receive intensive training and professional development through

20) Leslie Keller, "Teachers' Roles and Identities in Student-Centered Classrooms," *International Journal of STEM Education,* vol. 5, no. 34 (September 2018). https://stemeducationjournal.springeropen.com/articles/10.1186/s40594-018-0131-6.

summer institutes and regular instructional coaching. Participating teachers varied in teaching experience from two years to 13 years before joining PERC. The sample included four female and nine male teachers. 11 sample teachers were White, and two were Black.

Methodology: The researcher relied on interviews and focus groups with teachers, administrators and PERC coaches, conducted before initial teacher training for the PERC program, at the end of training, and then in October and May of each year of program participation. The researcher also used weekly/bi-weekly observations of teachers conducted by PERC coaches.

Results: Seven surveyed teachers asserted that it was easy for them to transition to student-centered instruction, five teachers noted the transition was difficult, and one teacher dropped out of the program after one year. The researcher notes that teachers who already tended toward using groupwork in their classrooms had an easier time transitioning to the model. Teachers who reported more difficult transitions either struggled to let go of their roles as content experts and lecturers or struggled to engage meaningfully with each group during content instruction.

When PERC coaches modeled PERC teacher roles during class and in coaching sessions, these struggling teachers were able to make progress toward successful student-centered instruction. One teacher, however, exited the program because she did not want to relinquish her role in delivering instruction and believed in her traditional approach to instruction. This suggests that some teachers may not be able to transition to student-centered instruction.

Notably, the researcher reports that the PERC Program's incorporation of peer educators addresses common educator concerns with student-centered instruction—most notably, classroom management. One interviewed teacher noted that she previously preferred to use cooperative instruction, but that the typical classroom behaviors of students make implementation unrealistic. Another interviewed teacher notes that when his students completed groupwork, he would worry that groups outside of his attention would discuss matters other than classwork. Lastly, an interviewed teacher noted that she felt that—because she had to spend a lot of time keeping groups on task, she could not necessarily dedicate time to work with struggling groups or students.

Benefits of Student-Centered, Peer-Led Instruction Cited by Teachers

Classroom Management

Support from a team of peer instructors allows teachers to more comfortably roam from group to group, as they know peer instructors will keep other groups on task. Teachers can thus more easily act as facilitators of learning.

Time to Support Individual Students

Because peer educators could keep students engaged and on task in their groups, teachers could dedicate extended time to in-depth conversations with struggling students.

Interviewed teachers suggest that peer instructors helped minimize classroom management issues and keep students engaged while the teacher worked with a different group. Because students were engaged throughout each lesson, PERC teachers felt confident that PERC increased the amount and complexity of content they were able to deliver. The study contrasts this finding with other studies (which do not focus on high school math) where teachers believe student-centered instruction poses challenges for curriculum coverage.

Additional Studies Showcase Mixed Outcomes of Student-Centered High School Curricula

Because research related to the effectiveness of student-centered math instruction is limited, EAB researchers also profiled two studies that explore the effectiveness of high schools that implement a student-centered approach to instruction throughout all content areas. Though these studies do not focus on math instruction specifically, they provide additional context on the impacts of student-centered instructional tactics. These studies cannot assess the impact of student-centered learning in isolation—student-centered high schools incorporate numerous other reforms, including advisory programs, afterschool academic supports, and intensive teacher professional development.

Study Summaries

Study	Description	Findings	Caveats
Student-Centered Schools: Closing the Opportunity Gap (profiled on pages 22-25 of this report)	Researchers investigated student outcomes at four urban student-centered high schools and documented the specific practices in use at those schools.	• Profiled student-centered high schools achieve positive student outcomes related to district and state averages, particularly in the case of underrepresented students.	• Student-centered high schools incorporate numerous other interventions (i.e., advisory programs) that may have also contributed to beneficial outcomes.
A Qualitative Study of Student-Centered Learning Practices in New England Schools (profiled on pages 25-27)	Researchers interviewed teachers and administrators at multiple New England high schools that align with the Nellie Mae Education Foundation's definition of student-centered practices to identify their perceptions of the impact of student-centered practices.	• Teachers report that student-centered tactics slow the rate of instruction and require additional work from teachers. • Teachers and administrators report frustration with competency-based learning and differentiated instruction implementation. • Teachers report that student-centered instruction improves student-engagement.	• The study relies entirely on qualitative data, rather than data on student-achievement. • This study includes teacher opinions on grading and curricular factors outside of pedagogy (e.g., competency-based instruction).

Study 5: Student-Centered Schools: Closing the Opportunity Gap[21]

Background: Researchers from the Stanford Center for Opportunity Policy in Education investigated student outcomes at four urban high schools that use student-centered approaches to instruction and student support. Researchers also documented the specific practices in place at each of the schools. In addition to the

21) Diane Friedlaender, Dion Burns, Heather Lewis-Charp, Channa Mae Cook-Harvey, and Linda Darling-Hammond, *Student Centered Schools: Closing the Opportunity Gap Research Brief* (Stanford, CA: Stanford Center for Opportunity Policy in Education, 2014). https://edpolicy.stanford.edu/sites/default/files/scope-pub-student-centered-research-brief.pdf; Diane Friedlaender, Dion Burns, Heather Lewis-Charp, Channa Mae Cook-Harvey, and Linda Darling-Hammond, *Student Centered Schools: Closing the Opportunity Gap* (Stanford, CA: Stanford Center for Opportunity Policy in Education, 2014). https://edpolicy.stanford.edu/sites/default/files/scope-pub-student-centered-cross-case.pdf

brief, researchers created individual case studies for each school alongside a cross-case analysis.[22] The **cross-case analysis** in particular provides additional information on study methodology.[23]

Sample: Researchers selected high schools that partner with two student-centered initiatives: **Linked Learning**—a statewide initiative that integrates rigorous academics with career-based learning and real-world workplace experience, and **Envision Education**—a small charter network focusing on personalized learning environments. Profiled schools maintain non-selective admissions practices and serve populations that are primarily low-income students of color. Profiled schools enroll between 338-639 students. Two schools operate as district-approved independent charters, and two operate as district schools in partnership with Linked Learning.

Researchers selected schools that incorporate the following features, which they identify as central to a student-centered approach.

Features of Student-Centered High Schools

Collaborative, Relationship-Focused Approaches

School structures support adult-student connections within the school and within the community. Teachers collaborate to engage in professional development, improve instructional practices, and identify individual student strengths, interest, and needs.

Rigorous, Student-Centered Instructional Practices

Teachers design curriculum, instruction, and assessments to help students engage with the learning process and develop analytical, collaboration, and communication skills. Teachers use formative assessments to assess student learning and support mastery.

Shared Leadership

Teachers, staff, administrators, and parents all contribute to key decisions within the school.

Methodology: Researchers collected school outcomes data related to graduation rates, student achievement on assessments, college preparatory course completion, and college persistence.

- **Graduation Rates**: Researchers compared graduation rates at profiled schools to district and state averages.
- **Student Achievement**: Researchers tracked student gains in achievement on two California standardized tests: the California STAR Test (CST) on English language arts and the California High School Exit Exams (CAHSEE), which focus on English and math. Researchers controlled for prior learning through a school productivity analysis that uses multiple regression techniques to project student achievement levels after accounting for student characteristics. Researchers then compared actual student achievement at study schools to projected student achievement to measure each school's productivity.
- **College Preparatory Course Completion**: Researchers tracked completion rates of required "a-g" college preparatory courses at profiled high schools. California requires that schools complete four years of English, 3 years of math, 2 years of lab science, and foreign language and arts courses.

22) "Student-Centered Schools: Closing the Opportunity Gap," Stanford Center for Opportunity Policy in Education, Accessed November 18, 2019, https://edpolicy.stanford.edu/projects/633
23) Diane Friedlaender, Dion Burns, Heather Lewis-Charp, Channa Mae Cook-Harvey, and Linda Darling-Hammond, *Student Centered Schools: Closing the Opportunity Gap* (Stanford, CA: Stanford Center for Opportunity Policy in Education, 2014). https://edpolicy.stanford.edu/sites/default/files/scope-pub-student-centered-cross-case.pdf

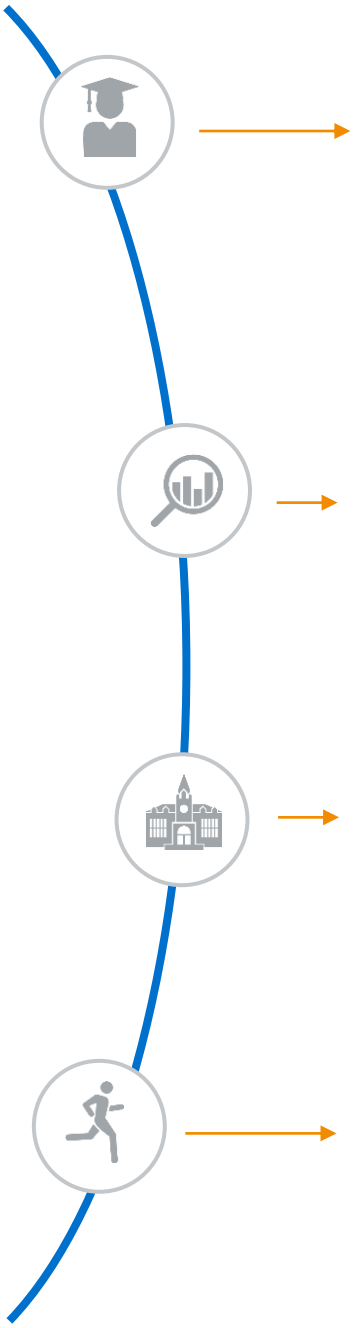
- **College Persistence**: Researchers surveyed graduates to determine what percentage (out of those who enrolled in four-year colleges) remained enrolled in their fourth year of college.

Researchers also used interviews, observations, and teacher and student survey data to identify characteristics in common across the four profiled high schools.

Findings: The study highlights the following findings related to student outcomes:

Student Outcomes at Profiled High Schools

See **Appendix A** for school by school data on graduation rates and college preparatory course completion.



Improved Graduation Rates

- Graduation rates at all study high schools exceeded their district averages, and graduation rates at all but one high school exceed state averages.
- Graduation rates at study high schools ranged from 71% to 94%, while district graduation rates ranged from 59% to 82%.
- At two profiled schools, 90-95% of African American students graduate (state average: 66%).

Growth on State Assessment Performance

- Students at study schools exhibited greater gains in achievement as measured through productivity coefficients on state tests than did similar students attending other schools in the same district (after accounting for prior learning). Researchers relied on this analysis to control for the influence of student demographic characteristics (e.g., income).
- Productivity coefficients for CAHSEE math scores at student-centered high schools ranged from .13 to .30 in math. For context, researchers assert that a productivity coefficient of .2 is roughly equivalent to an increase of 8% in mean student achievement.

Increased College Preparatory Course Completion

- At profiled schools, college preparatory course completion rates range from 87% to 100%.
- By comparison, district average college preparatory course completion rates range from 24% to 56%, and the state average is 38%.

College Persistence

- At the two profiled schools with graduating classes old enough to progress through a four-year college, college persistence rates nearly met or exceeded national averages, despite the fact that a high percentage of school students (73% and 93%, respectively) are low-income.
- One profiled school saw a four-year college persistence rate of 97% for the class of 2009, while the other recoded a four-year college persistence rate of 69% for the class of 2009.
- The national average for college persistence for the class of 2006 was 71% according to the study.

Researchers suggest that these outcomes arise in part from the rigorous and engaging instruction and assessments in use at profiled schools. Specifically,

researchers note that each of the four schools design coursework to support student leadership and autonomy in the classroom and ask students to apply learning through performance-based assessments. Profiled schools also incorporate numerous other student-centered practices, including inquiry-based instruction.

Instructional Strategies in Use at Profiled Schools

- ☑ Relevant curricula
- ☑ Inquiry-based instruction
- ☑ Collaborative Learning
- ☑ Student-Directed Learning
- ☑ Mastery focus
- ☑ Flexible Uses of Time
- ☑ Ongoing assessments
- ☑ Performance-Based Assessments

Study 6: A Qualitative Study of Student-Centered Learning Practices in New England Schools[24]

Background: Researchers at the University of Massachusetts Donahue Institute collaborated with the Nellie Mae Education Foundation to conduct a qualitative study of student-centered public high schools. Student-centered high schools as defined by the study implement four key tenets:

1. **Learning is personalized**: Teachers provide students with choice in the classroom and how students demonstrate their learning. Teachers differentiate assignments and projects based on student skill. Schools use advisory programs to foster adult-student connections.
2. **Learning is competency-based**: Teachers evaluate students by measuring competencies rather than using traditional grading scales. Students complete work at their own pace.
3. **Learning takes place anytime, anywhere**: Students can leave campus to engage in structured, credit-bearing experiences. Students can access online coursework and course materials through electronic devices.
4. **Students take ownership over their learning**: Students guide their own learning through student presentations, student-led conferences, student governance, peer tutoring, restorative discipline, and self-reflection.

Sample: Researchers assigned student-centered learning scores (zero to 100 percent) for each of the above four tenets to 370 new England public schools based on student-centered learning surveys and secondary research. Researchers averaged scores across all four tenets to identify schools with a high degree of student-centered practices. Researchers then selected the highest-scoring schools from each New England state. To improve the diversity of the sample, researchers added 10 large schools (i.e., schools with more than 1,000 students) with high student-centered learning scores and four schools with high poverty (i.e., 66 percent or more students qualify for free or reduced priced lunch) that also achieved high student-centered learning scores. In total, researchers reached out to 73 schools and selected 12 based on score, state, size, poverty level, and school type.

Methodology: Researchers interviewed principals from all 12 schools and the superintendents that oversee them and used these interviews to select six schools for day-long site visits. Researchers interviewed school leaders and department heads, conducted teacher focus groups, and completed classroom observations.

24) Gabriel Reidf, Greta Shultz, and Steven Ellis, *A Qualitative Study of Student-Centered Learning Practices in New England High Schools* (Hadley, MA: Nellie Mae Education Foundation and University of Massachusetts Donahue Institute, 2015). https://www.nmefoundation.org/getattachment/Resources/Student-Centered-Learning/A-Qualitative-Study-of-Student-Centered-Learning-P/Qualitative-Study-SCL-Practices-in-NE-High-Schools-(1).pdf?ext=.pdf

Findings: Researchers first examined the extent to which each school implemented practices related to the above four tenets of student-centered learning. Researchers report that practices related to student ownership and personalized learning are far more common than practices related to competency-based education or anytime, anywhere learning.

Tenet-Based Analysis of Sample Student-Centered High Schools Based on Teacher Testimony

More Common

Learning is Personalized

- Teachers report that they can integrate student choice into curricula with few obstacles.
- Teachers believe that providing student choice in research topics and work products fosters student engagement in learning.
- Teachers report that differentiated instruction requires more instructional and planning time than traditional methods. Differentiated instruction is thus rarer than other personalization strategies at study schools

Students Take Ownership

- Teachers note that some students are more comfortable taking ownership than others, and that students may exhibit low levels of productivity early on as they adapt to increased responsibility.
- Teachers report that some students may disengage when given ownership, while others may need to continue to rely substantially on the teacher.
- Teachers at study schools rely on project-planning and goal-setting worksheets, structured check-ins, and reflection tools to support students.

Learning is Competency-Based

- Leaders report that competency-based learning implementation is difficult, inconsistent, and stressful. Administrators report community pushback as a significant stressor.
- Teachers express frustration that competency-based learning does not hold students accountable for poor performance. Teachers note that some students do not possess the skills required to succeed in the system.

Learning Takes Place Anytime, Anywhere

- Study schools demonstrate few instances of anytime, anywhere learning.
- Most schools offer place-based learning, but administrators at study schools struggled to find time and funding for place-based learning.

Less Common

Competency/Proficiency-Based Education May Negatively Impact Student Test Scores

A study from the Education Development Center found that—across ten high schools that implemented proficiency-based education in Maine—student exposure to proficiency-based education is associated with decreased 11th grade SAT scores. That said, the study also found that students exposed to proficiency-based education self-reported higher engagement.[25] Administrators may wish to focus on practices that support student choice over proficiency-based education, which aligns with many of the tenets of competency-based education.

25) Karen Shakman, Brandon Foster, Noman Khanani, Jill Marcus, and Josh Cox, *"In Theory It's a Good Idea": Understanding Implementation of Proficiency-Based Education in Maine* (Education Development Center, 2018), 30-32. https://www.edc.org/theory-its-good-idea-understanding-implementation-proficiency-based-education-maine

Researchers also interviewed teachers and administrators about their perceptions of teaching in a student-centered environment and their assessment of the effectiveness of student-centered classroom practices. Overall, interviewees indicated that the advantages of teaching in a school that prioritizes student-centered learning outweigh the drawbacks.

Teacher and Administrator Perceptions on Student-Centered Learning

Student-Centered Teaching

Study participants report that…

- Student-centered teaching requires **more planning and preparation** due to differentiation.
- Classes **cover content more slowly** under student-centered instruction, which makes implementation difficult in face of statewide tests and advanced placement courses.
- Teachers need **multiple years to adapt** to student-centered strategies.
- The sequential nature of math **limits math teachers' ability to provide students with choice**

Perceived Impact of Student-Centered Practices

Study participants report that …

- Student-centered practices **promote student-engagement**
- Student-centered learning requires additional time, which forces some teachers to **cover less content than they would** in traditional settings.
- Some respondents assert that student-centered practices allow students to **explore curriculum with more depth** and retain knowledge more effectively.
- Impacts on student achievement were **mixed**. Educators at a few study schools noted that student-centered learning led to increased student standardized test scores. Other schools did not demonstrate improved test scores.

Student-Centered Tactics

Research Supports the Use of Specific Student-Centered Instructional Strategies in Math

Though the studies profiled above highlight mixed student achievement outcomes related to student-centered approaches to math more generally, research does support the use of specific student-centered instructional strategies in math. Specifically, some research suggests that when teachers ask students to work in groups to explore complex, conceptual math problems without explicit teacher guidance (i.e., problem-based learning), students demonstrate learning benefits. This section first explores specific, student-centered tactics related to problem-based learning and then summarizes research supporting these tactics.

Effective Student-Centered Lessons Incorporate Collaborative Exploration and Mathematical Communication

Researchers from the Nellie Mae Education Foundation synthesized insights from observations of effective, student-centered teachers to identify specific classroom tactics that provide all students opportunities to engage meaningfully with math. Researchers describe two categories of student-centered tasks—instructional activities and mathematical communication—and identify effective components of each. Notably, researchers argue that all student-centered classroom strategies should focus not on procedural tasks, but instead on underlying mathematical concepts (i.e., focus on the "why" as well as the "how"[26]

Components of Student-Centered Tactics Highlighted by the Nellie Mae Education Foundation[27]

Instructional Activities/Tasks Should

- Allow for multiple entry points and solution methods
- Challenge students to reason about math by looking for patterns, making conjectures, conducting explorations, examining connections between and among mathematical concepts, and justifying mathematical solutions/results
- Make explicit the connections between math and real-life experiences
- Encourage the use of different tools, including technology, to explore math
- Provide opportunities for collaboration to communicate and critique mathematical reasoning

Mathematical Communication Tasks Should

- Encourage students to justify and explain their solution strategies
- Encourage students to critique the mathematical reasoning of others
- Incorporate opportunities for teachers to provide support to students as they engage in a productive struggle with math, but not take over student thinking by providing solutions or next steps
- Elicit and make connections between different mathematical ideas and/or approaches to the same problem

26) Kirk Walters, Toni M. Smith, Steve Leinwand, Wendy Surr, Abigail Stein, and Paul Baiely, *An Up-Close Look at Student-Centered Math Teaching (*Nellie Mae Education Foundation and American Institutions for Research, November 2014), 25. https://www.nmefoundation.org/getattachment/Resources/Student-Centered-Learning/An-Up-Close-Look-at-Student-Centered-Math-Teaching/An-UpClose-Look-at-Student-Centered-Math-Teaching-(1).pdf?ext=.pdf.

27) Ibid.

Notably, Nellie Mae researchers highlight group-work focused tasks (i.e., task where students work together to solve problems) because these tasks require both critical thinking and mathematical communication. Researchers highlight an example in which a teacher asked students to build a scatter plot with data related to the hip angle and height of a set of horses. Rather than provide a clear answer or direction, the teacher allowed students to debate among themselves which variable should be on the x-axis, and which on the y-axis. This instructional approach allowed students to practice critiquing the reasoning of others.

The teacher, when asked to assist, asked probing questions (i.e., what was your reasoning behind that?), which required students to identify gaps in their own reasoning to determine the correct answer. Researchers contrast this approach with a common, less-student-centered strategy in which teacher questions clearly indicate a solution path for students.[28]

Researchers also note that in many observed classrooms, teachers reinforce mathematical concepts by asking students to complete rote, procedural problems that ask students to apply a protocol demonstrated by the teacher. Researchers suggest this approach does not allow students to reason about mathematical concepts, communicate their thinking, or critique the reasoning of others, even when working in groups—protocol application does not require reasoning. Instead of these procedural problems, researchers suggest that teachers present problems that force students to evaluate the approaches of other students when solving problems.[29]

Example Problem that Requires Reasoning, Critical Thinking, and Communication[30]

Faced with the following system of equations, two students, Lincoln and Claire, both decided to use the substitution(s):

5x-y = -115

x + y = -3

Problem requires students to critique two flawed reasoning structures rather than enact a procedure.

Lincoln's Method	**Claire's Method**
• x = -3 – y	• y = -3 – x
• So, 5(-3 – y) = -15.	• So, 5x – (-3 – x) = -15.
• -15 – y – y = -15	• 5x + 3 = -15
• -15 – 2y = -15	• 4x + 3 = -15
• -2y = 0	• 4x = -18
• y=0	• x=-4.5
• So, x = (0) = -3.	• So, (-4.5) + y = -3.
• x = -3	• y = 1.5
• THE SOLUTION IS (-3, 0).	• THE SOLUTION IS (-4.5, 1.5, 0).

Students must evaluate multiple reasoning steps to identify the specific flaw.

There are errors in the work of both Lincoln and Claire, but one of them was "lucky" and got the correct solution.

- What are the errors in each case?
- Which student got the correct solution? How do you know?

Problem emphasizes that the "correct solution" is not valuable if arrived at without conceptual knowledge.

28) Kirk Walters, Toni M. Smith, Steve Leinwand, Wendy Surr, Abigail Stein, and Paul Baiely, *An Up-Close Look at Student-Centered Math Teaching (*Nellie Mae Education Foundation and American Institutions for Research, November 2014), 20-24. https://www.nmefoundation.org/getattachment/Resources/Student-Centered-Learning/An-Up-Close-Look-at-Student-Centered-Math-Teaching/An-UpClose-Look-at-Student-Centered-Math-Teaching-(1).pdf?ext=.pdf
29) Ibid., 22-24.
30) Ibid.

Use the Launch, Explore, Discuss Framework to Design Student-Centered, Problem-Based Lessons

In partnership with the Student-Centered Learning Research Collaborative, researchers at the Center for Research on Equity and Innovation (CREI) at the High Tech High Graduate School of Education recruited a network of 32 teachers across 12 schools to join the Mathematical Agency Improvement Community (MAIC). CREI faculty worked with network teachers to identify promising student-centered practices from research and from network classrooms. Across multiple meetings, teachers practiced student-centered practices, which they then implemented in their classrooms during meetings.[31]

Researchers compiled multiple student-centered instructional strategies, including strategies to anticipate student needs during lessons, make student thinking visible, and promote equitable groupwork. Most notably, MAIC researchers suggest that teachers use a launch, explore, discuss lesson structure, which replaces procedural instruction with problem-focused lessons that encourage student exploration and discussion of problem-solving strategies used by students. Teachers use this lesson structure in elementary, middle, and high schools.[32]

In these lessons, teachers assign a single problem of the day and ask students to struggle towards solving it, first on their own, then in peer groups, and finally as a whole class. MAIC researchers recommend that teachers use the protocol for any problem/task that asks students to use different strategies to solve the problem.[33] Notably, the launch-explore-discuss framework aligns with the components of student-centered instructional tactics highlighted by Nellie Mae Education Foundation researchers—students collaborate to solve long, complex problems without direct teacher guidance and analyze and critique one another's thinking.

31) "Recent Findings," Student-Centered Learning Research Collaborative, accessed November 20, 2019, https://studentsatthecenterhub.org/research-collaborative/published-studies/; "Mathematical Agency Improvement Community," Mathematical Agency Improvement Community, accessed November 20, 2019. https://www.mathagency.org/network-research-findings
32) "Launch, Explore, Discuss," Mathematical Agency Improvement Community, accessed November 20, 2018, https://www.mathagency.org/whole-class-discourse
33) "Launch Explore, Discuss Instructional Routine," Mathematical Agency Improvement Community, accessed November 20, 2019. https://docs.google.com/document/d/1mxXJhTQm8yQ_0duESorOx9-c4gc9kWm1lLj6PpXu9ZI/edit#heading=h.e6zqoy0atod

MAIC Launch, Explore, Discuss Framework[34]

1 Launch

- The teacher poses a problem for the student to answer.
- The teacher directs two-to-three students to repeat the problem to gauge the class' understanding of the problem.
- The teacher asks a simple comprehension question to help students begin to examine the problem.

2 Explore

- Students spend five-to-ten minutes working individually to address the problem. The teacher circulates to review student strategies but does not help students.
- Depending on the difficulty of the problem, the teacher then asks students to get into groups to discuss and workshop their strategies.
- The teacher circulates and asks students to explain their thinking. If a student uses an interesting strategy and can clearly articulate their thinking, teachers ask those students to prepare to speak during the next phase.
- Teachers can also ask probing questions to assist struggling students.

3 Discuss

- The teacher asks two-to-four students to share their strategies with the class.
- The teacher then facilitates a discussion in which students provide feedback on the different approaches.
- The teacher asks students to identify commonalities and differences between the approaches to the problem to connect the discussion to the central goal of the lesson.

The Wisconsin RtI Center/PBIS Network notes that the Wisconsin Department of Public Instruction selected a similar math framework as the framework for Common Core implementation. This framework adds two additional steps to the Launch, Explore, Discuss framework: individual student **reflection** and the **application** of the central lesson concept to other contexts or scenarios.

Evidence of Effectiveness

Research Suggests that Problem-Based Math Instruction Improves Student Learning

Both the Nellie Mae Education Foundation student-centered practices and the Launch-Explore-Discuss framework align closely with the tenets of problem-based learning, in which students work in groups to investigate a meaningful problem, generate/implement solution strategies, and evaluate their work/generate new strategies until they solve the problem. Teachers play a supplemental role in

34) "Launch Explore, Discuss Instructional Routine," Mathematical Agency Improvement Community, accessed 11/20/2019. https://docs.google.com/document/d/1mxXJhTQm8yQ_0duESorOx9-c4gc9kWm1ILj6PpXu9ZI/edit#heading=h.e6zqoy0atod; "Launch, Explore, Discuss," Mathematical Agency Improvement Community, accessed November 20, 2018, https://www.mathagency.org/whole-class-discourse; "Math Instructional Framework Launch-Explore-Summarize-Reflect-Apply," Wisconsin RtI Center/PBIS Network, accessed November 20, 2019. https://dpi.wi.gov/sites/default/files/imce/math/LESRA_Overview.pdf

problem-based instruction—they encourage students to make their thinking visible on whiteboards, guide the group process and monitor participation, and ask questions to encourage group thought.[35]

A book chapter exploring research around problem-based learning reports that problem-based learning is comparable to more traditional instruction when it comes to factual learning. That said, the chapter found that problem-based learning better prepares students to use flexible approaches to problem solving, apply knowledge, and generate hypotheses.[36]

Additional Research Evidence to Support Problem-Based Learning[37]

Students who participated in problem-based experiences are better able to generate accurate hypotheses and coherent explanations.

Students who participated in problem-based experiences are better able to support their claims with well-reasoned arguments.

Students who participated in problem-based experiences experience larger gains in conceptual understanding in science contexts.

Medical students enrolled in programs with problem-based curricula score higher on clinical problem-solving measures and on actual ratings of clinical performance than students in non-problem-based curricula.

When it comes to problem-based instruction in math, researchers James W. Stigler and James Hiebert investigated math teaching practices in the United States and in multiple other countries through two Trends in International Math and Science (TIMSS) video studies in 1995 and 1999. In these studies, the researchers studied videos of classroom practices from national samples of eighth grade math teachers. Researchers in 1999 compared instructional practices in the United States with instructional practices in five higher-achieving countries (as indicated by student math test scores). Specifically, Stigler and Hiebert investigated whether teachers asked students to work on *using procedures* problems (i.e., problems that focus on basic computational skills and procedures) or *making connections* problems (i.e., problems that focus on concepts and making connections among mathematical ideas).[38]

Stigler and Hiebert noted that the percentage of *making connections* problems versus using *procedures problems* presented in classrooms varied greatly across countries. In fact, the United States (17 percent *making connections* problems) exceeded the percentages of *making connections* problems in three of the five higher-performing countries. However, when researchers more closely examined videos of *making connections* problems to see how teachers implemented them in classrooms across countries, they found that observed teachers in the United States implemented all *making connections* math problems as *using procedures* math problems.[39]

In other words, observed U.S. teachers converted exploratory, conceptual questions into procedural exercises almost 100 percent of the time, and sometimes simply

35) Brigid Baron and Linda Darling-Hammond, *Book Excerpt: Teaching for Meaningful Learning: A Review of Research on Inquiry-Based and Cooperative Learning* (Edutopia and the George Lucas Educational Foundation, 2008), from Linda Darling-Hammond et al., *Powerful Learning: What We Know About Teaching for Understanding*, (San Francisco, CA: John Wiley & Sons, 2008), 4. https://backend.edutopia.org/sites/default/files/pdfs/edutopia-teaching-for-meaningful-learning.pdf
36) Ibid., 6.
37) Ibid., 4-6.
38) James W. Stigler and James Hiebert, "Improving Math Teaching," *Educational Leadership*, vol. 61, no. 5 (2004): 12-17. http://www.ascd.org/publications/educational-leadership/feb04/vol61/num05/Improving-Math-Teaching.aspx
39) Ibid.

supplied students with the answer. By comparison, teachers in most high-performing countries actually implemented the majority of *making connections* problems—they allowed students the chance to explore and struggle with mathematical concepts.[40]

Stigler and Hiebert's research does not prove that when teachers challenge students to complete conceptual, difficult, *making connections* problems, student achievement increases. It does suggest—however—that in higher-achieving countries, teachers give students more opportunities to explore mathematical concepts themselves and determine their own solutions—a core tenet of problem-based instruction and of student-centered learning.

Professional Associations Endorse Problem-Based, Student-Centered Practices

Researchers from the National Council of Teachers of Mathematics endorse instructional strategies that align with problem-based learning and the launch-explore-discuss framework. National Council of Teachers of Mathematics standards explicitly recommend that problems that instill reasoning skills (i.e., "drawing logical conclusions based on assumptions and definitions") and sense making (i.e., "developing an understanding of a situation, context, or concept by connecting it with existing knowledge") should be "the central foci of high school math."[41] National Council of Teachers of Mathematics researchers suggest that teachers design lessons to allow students to explore tough, conceptual problems without prior support. In these lessons, students develop their own approaches to problems to cement understanding.

Sample Instructional Task that Promotes Reasoning and Sense-Making[42]

Problem	Teacher Approach
The captain of a shipping vessel must consider the tides when entering a seaport because the water depth can vary greatly from one time of day to another. Suppose that high tide in a certain port occurs at 5:00 am, when the water is 10.6 meters deep, and the next low tide is 6.5 meters deep. Develop a mathematical model that will predict the water depth as a function of the elapsed time since midnight	• Ask students to restate the problem in their own words • Give students time to analyze the problem intuitively, explore the problem using models, and then proceed to a more formal approach • Resist the urge to tell students how to solve the problem when they become frustrated • Ask students questions (e.g., how do you know?) that stimulate their thinking • Provide adequate wait time after a question for students to formulate reasoning • Encourage students to ask probing questions of one another • Expect students to communicate reasoning to classmates and the teacher • Highlight exemplary explanations and ask students to identify what makes them effective • Make students feel comfortable to share mathematical arguments and critique the arguments of others

40) James W. Stigler and James Hiebert, "Improving Math Teaching," *Educational Leadership,* vol. 61, no. 5 (2004): 12-17. http://www.ascd.org/publications/educational-leadership/feb04/vol61/num05/Improving-Math-Teaching.aspx
41) *An Administrators Guide to High School Math* (National Council of Teachers of Mathematics, 2009), 2. https://www.nctm.org/uploadedFiles/Standards_and_Positions/Focus_in_High_School_Math/FHSM_AdminGuide.pdf
42) Ibid., 2-3.

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5) Appendix A

Graduation Rate and Course Completion Data from Student-Centered High Schools[43]

Graduation Rates (Class of 2012)

Cohort Graduation Rate for Class of 2012

Types of Students	School 1	District 1	School 2	District 2	School 3	District 3	School 4	District 4	State
All	85%	82%	94%	74%	92%	71%	71%	59%	79%
African American	84%	71%	95%	65%	90%	64%	n/a	53%	66%
Latino	85%	67%	94%	76%	88%	67%	68%	52%	74%
English Learners	84%	68%	100%	65%	83%	57%	50%	46%	62%
Economically Disadvantaged	87%	80%	95%	70%	94%	69%	71%	58%	73%

College Preparatory Course Completion Rates (2011-12)

Percent of Graduates Completing All Courses Required for University of California/California State University Admission

Types of Students	School 1	District 1	School 2	District 2	School 3	District 3	School 4	District 4	State
All	99%	56%	96%	24%	100%	44%	87%	51%	38%
African American	100%	28%	94%	15%	100%	34%	100%	34%	29%
Latino	100%	36%	100%	15%	100%	39%	82%	54%	28%
Limited English Proficient	100%	38%	92%	24%	100%	34%	n/a	46%	23%
Socioeconomically Disadvantaged	100%	54%	95%	22%	100%	45%	n/a	48%	30%

43) Diane Friedlaender, Dion Burns, Heather Lewis-Charp, Channa Mae Cook-Harvey, and Linda Darling-Hammond, *Student Centered Schools: Closing the Opportunity Gap* (Stanford, CA: Stanford Center for Opportunity Policy in Education, 2014). https://edpolicy.stanford.edu/sites/default/files/scope-pub-student-centered-cross-case.pdf