Crashing the Gate: Improving Student Learning in Introductory STEM Courses

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Background
Relatively few students earn degrees in natural science or engineering in the U.S.
- 15% of U.S. bachelor’s degrees are in sciences/engineering
- Compared to 37% in Singapore, 59% in China, 47% in France, 38% in South Korea.

U.S. needs more undergraduate science majors to maintain achievement and innovation in science and engineering
- U.S. also needs to diversify the scientific workforce and increase representation of women and minorities.

To graduate more bachelor’s degrees in science, U.S. needs students to choose science majors and to maintain interest in science majors
- National increases in proportion of freshmen indicating interest in science, technology, engineering and math (STEM) majors
- Low proportion of students who intend to major in STEM actually graduate with STEM majors.

“Gatekeeper” Courses
One Obstacle to STEM Major Completion
Mechanism for sorting students
First course in a series of courses in which knowledge is cumulative
Relatively high drop-out and failure rates in science gatekeeper courses
- Large lectures
- Highly competitive
- Un-engaging
- Grading on a curve

Classroom Environments & Instructor Pedagogies
Classroom climates impact learning and performance
- Competitive environments have a negative impact on learning, performance, retention, self-confidence

Collaborative environments that emphasize group work can mitigate negative effects of large lectures and competitive environments
- Can also promote critical thinking about scientific concepts and their applications

Supportive Learning Environments and the Skills Needed for Scientific Success
Six necessary conditions for a supportive learning environment:
- Quality of instruction, Teacher’s interest, Social relatedness, Support of competence, Support of autonomy
- Engender greater self-motivation, encourages self-directed learning

Two primary pedagogical techniques in science
- Domain-specific learning = memorization of facts and causal relationships
- Domain-general learning = reasoning strategies and critical thinking skills

Key Direct Effects

Initial Score of Acting and Thinking like a Scientist:
- Prior academic achievement, as measured by class rank (+)
- Self-rated science and math ability (+)
- Intent to pursue a research career (+)
- Tutoring another student in high school

End-of-Term Score of Acting like a Scientist:
- Joined or created a study group (+)
- Had professor who frequently used electronic quizzes (-)
- Had professor who wanted to prepare students for graduate education (+)

End-of-Term Score of Thinking like a Scientist:
- Joined or created a study group (+)
- Frequently felt bored in class (-)
- Had professor who wanted to prepare students for graduate education (+)
- Had professor who utilized more class time for group work (+)

End-of-Term Course Grade:
- Prior academic achievement: class rank and SAT scores (+)
- Pre-college research program (+)
- Crammed for exams (-)
- Felt bored (-)
- Had professor who used more class time for group work (+)

Key Indirect Effects

Thinking and Acting like a Scientist:
- Aspiring to a research career and participating in a pre-college research program (+)
- Self-rated math and science abilities (+)
- Class rank (-)

Thinking and Acting like a Scientist:
- Make connections between different areas of science and math
- Make sense of scientific concepts
- Identify what is known about a problem
- Ask relevant questions
- Draw a picture to represent a problem or concept
- Make predictions based on existing knowledge
- Come up with solutions to problems and explain them to others
- Investigate alternative solutions to a problem
- Translate scientific terminology into non-scientific language
- Act like a scientist
- Relate scientific concepts to real-world problems
- Synthesize several sources of information
- Conduct an experiment
- Look up scientific research articles and resources
- Memorize large quantities of information

Project Team
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Research Program
○ Demographics and Experiences
○ Classroom Environments & Instructor Pedagogies
○ Supportive Learning Environments and Skills Needed for Scientific Success
○ Analytic Strategy
○ Conclusions and Implications
○ Project Team

Structural Equation Model
Demographics and Controls
Race: White
Self-rated math ability
Self-rated science ability
Intend to pursue research career
Pre-College Research Program
SAT Scores

Pretests
Thinking like a Scientist
Act like a scientist
Think like a scientist

Course Activities and Perceptions
Joiend or created study group
Felt bored
Crammed for exams

Outcomes
Thinking like a Scientist
Act like a scientist
Think like a scientist

Course Pedagogy
Electronic quizzes with immediate feedback
Goal: Prepare students for graduate education

Percentage of class time used for group work
Multiple-choice exam questions

Thinking and Acting like a Scientist
Pre-Test Post-Test
Thinking like a Scientist
Make connections between different areas of science and math 0.67 0.70
Make sense of scientific concepts 0.71 0.72
Identify what is known about a problem 0.63 0.64
Ask relevant questions 0.60 0.64
Draw a picture to represent a problem or concept 0.46 0.51
Make predictions based on existing knowledge 0.69 0.71
Come up with solutions to problems and explain them to others 0.67 0.72
Investigate alternative solutions to a problem 0.67 0.68
Translate scientific terminology into non-scientific language 0.57 0.62
Act like a scientist
Relate scientific concepts to real-world problems 0.71 0.75
Synthesize several sources of information 0.70 0.70
Conduct an experiment 0.54 0.54
Look up scientific research articles and resources 0.59 0.57
Memorize large quantities of information 0.41 0.44

Thinking like a Scientist
Make connections between different areas of science and math
Make sense of scientific concepts
Identify what is known about a problem
Ask relevant questions
Draw a picture to represent a problem or concept
Make predictions based on existing knowledge
Come up with solutions to problems and explain them to others
Investigate alternative solutions to a problem
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Relate scientific concepts to real-world problems
Synthesize several sources of information
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Look up scientific research articles and resources
Memorize large quantities of information

Thinking and Acting like a Scientist

Thinking and Acting like a Scientist:
- Prior academic achievement was strongest predictor of course grades
- Students’ gains in thinking and acting like scientists had no significant correlation with their final grade in their introductory course

Last-minute studying for exams negatively related to students’ final grades in the course but had no relationship with the frequency with which they reported thinking and acting like scientists
- Students in courses where instructors spent more course time utilizing group activities reported significantly higher gains in thinking like a scientist and higher course grades
- Findings suggest faculty have an opportunity to adjust grading practices to reflect learning rather than just students’ prior preparation

Data
- STEM Student pre- and post-questionnaire
- 15 campuses, 90 classrooms
- 3,225 longitudinal student responses
- STEM Faculty Survey
- 15 campuses, 90 classrooms
- 76 faculty responses

Variables
- Outcomes: Course grades, frequency of thinking like a scientist, frequency of acting like a scientist
- Predictors: demographics, self-rated abilities, prior academic achievement, course behavior, faculty pedagogy

Analysis
- Confirmatory factor analysis
- Structural equation modeling in EQS

Conclusions and Implications