Supplementary Materials 1: This resource provides references to sources of information that explicitly describe the student and teacher actions that were analyzed to identify the observable actions found in 17 reviewed active teaching practices. Further, this resource provides a summary of outcomes from multiple studies conducted about the elevated learning gains that have been documented about each of the 17 practices reviewed in this article. Finally, this resource provides suggest tools for planning and implementation for each of the active instructional practices.

Argument driven inquiry

Students	Instructor
• Engage individual and small group activities • development and implement a procedure to address the question • develop a preliminary explanation or argument, on a whiteboard, • share preliminary arguments by groups • critique arguments made by peers during an "argumentation session" • offer and receive feedback about their preliminary argument • write investigation report • Provide feedback to peers through participation in the double-blind peer review process • Evaluate feedback from double-blind peer review process • Edit individual investigation report • Submit final report	• Identifies the question to be asked or problem to be investigated • Provide resources for students to investigate problem or question as well as the "argumentation session" • Facilitate class discussion about the process students used to investigate the question or problem • Facilitate the double-blind peer review process • Evaluate final report (Walker, Sampson & Zimmerman, 2011)

Variations: ADI is a variation of student inquiry

Associated observable actions: Writing, Reading, Observing, Speaking, Building/ Manipulating, Instructor facilitates activities, Instructor facilitates dialogue

Objective/Learning Goal: Participation in STEM practices, especially the process of developing a claim from evidence, argument critique and peer review.

Research outcomes	
Undergraduate students who engage in ADI about socio-scientific issues were able to produce more developed written arguments including the use of rationales over their traditionally taught peers across two different tasks (Grooms, Sampson & Golden, 2014).	1. Analysis of the first assigned task (Sugar task) revealed that the treatment group generated a larger portion of the more sophisticated arguments on their post-intervention assignments compared to the control group (Pearson X^2(2, N=72) =10.86, p<.01; Cramer's V = 0.38 (moderate to large effect size). 2. Analysis of the second assigned task (EPA task) revealed that the significant differences between control and treatment groups on their post-intervention arguments with the treatment group producing more sophisticated arguments (Pearson X^2(3, N=73)=12.80, p<.01; Cramer's V = 0.42 (moderate to large effect size).
Argument-Driven Inquiry in undergraduate chemistry labs – using the laboratory to improve undergraduates' science writing skills through meaningful science writing, peer-review, and revision. Writing skills are enhanced across all levels of learners who engage in ADI (Walker & Sampson, 2013)	1. Written arguments improved by both stronger and weaker writers based on a comparison of first and final lab reports (Strong writers z=-2.63, p=0.008; weak writers z=-2.68, p=0.007 2. Differences between the median scores of the stronger and weaker writers were ONLY significant on the final report for the first lab, but NOT for reports 2, 3, and 4 (indicating a leveling effect of the intervention of writing and the peer review process). Report 1, p=0.01; Report 2, p=0.16; Report 3, p=0.26; Report, 4 p=0.86.
Students who engage in ADI during undergraduate chemistry labs are better able to provide evidence and demonstrate reasoning in order to support their explanations than students in traditional labs. (Walker, Sampson, Grooms, Anderson & Zimmerman, 2012).	1. Students in BOTH the treatment and control groups demonstrated conceptual growth based on the Chemical Concept Inventory (CCI) scores over the semester. The ADI group participated in FEWER investigations and was able to achieve near equal results. Comparison of scores (t(184)=.22, p=0.82) Control Cohen's d=.33; Treatment Cohen's d=.28 (Small effect size) 2. Students in ADI labs were demonstrated an elevated use of evidence and reasoning compared to students in traditional lab sections (t(161)= 3.90, p<0.001; Cohen's d=0.63) (Moderate effect size) 3. Lab report scores for students in ADI sections were significantly higher than those of students in traditional lab sections (t(62)=2.26, p=.03; Cohen's d=0.57) (Moderate Effect Size)

Planning and implementation resources: http://www.argumentdriveninquiry.com/how-it-works.html

Challenge-based learning

<table>
<tr><th colspan="2">Students</th><th>Instructor</th></tr>
<tr><td colspan="2">• Engage in small groups and in whole class activities
• Participate in the identification of the essential question(s)
• Participate in the identification of specific challenge to be addressed based on the essential question(s)
• Use resources to craft a solution(s) to the challenge
• Implement the solution
• Evaluate the effectiveness of the solution
• Publish results of the solution, implementation and effectiveness through technological resources
• Reflect on the challenge learning process</td><td>• Provides an overview of the big idea
• Facilitates the identification of the essential question(s) and challenge(s) associated with the big idea
• Develop groups
• Discusses the role of students within a group
• Facilitates a discussion of solution assessment
• Develop and facilitate student engagement in learning activities
• Evaluate the group solution, implementation and effectiveness

(Johnson & Adams, 2011)</td></tr>
<tr><td colspan="3">Variations: Problem-based learning and Project-based learning</td></tr>
<tr><td colspan="3">Associated observable actions: Reading, Writing, Speaking, Instructor facilitates activities, Instructor facilitates discussion</td></tr>
<tr><td colspan="3">Objective/Learning Goal: Engagement in concrete, meaningful action through creativity and risk-taking</td></tr>
<tr><th colspan="3">Research outcomes</th></tr>
<tr><td>The Challenge-based learning approach increases student learning outcomes and comprehension. Meta-analysis of the effectiveness, replicability, and generality of Challenge-based bioengineering (Cordray, Harris & Klein, 2009).</td><td colspan="2">1. Studies using challenge-based learning classified as "true experimental designs" produced statistically significant effects that were small in size (p<0.01, z= 8.706; Cohen’s d = 0.417) (Small Effect Size).
2. Studies identified as high-quality quasi-experimental design produced statistically significant weighted average (p<0.001, z = 4.69; Cohen’s d =0.703) (Moderate Effect Size)</td></tr>
<tr><td>Graduate physics students who engaged Challenge-based learning module incorporating computer simulations conducting Fourier spectral analysis demonstrated better understanding relative to students who studied the material using traditional methods (Greenberg, Smith & Newman, 2003).</td><td colspan="2">1. students who engaged in the module (treatment including CBL and interactive computer simulations) outperformed students in the control group on 3 out of the 4 concept groupings relating to spectral analysis (Course Topic) than those in the control (p<0.05)</td></tr>
<tr><td>High school students who participated in bioengineering CBL modules scored better on post-exam assessment measuring recall, application and transfer
(Klein & Geist, 2006).</td><td colspan="2">1. Students in the CBL experimental outscored the control group on posttest application, transfer of knowledge, and repeated pre-test items on the post exam (application (p<0.023) transfer (p<0.001) pre-test (p<0.011)</td></tr>
<tr><td>Undergraduate students enrolled in Biomechanical Engineering course who engaged in Challenge-based Learning performed better on exam questions that students from control group semesters (Roselli & Brophy, 2006)</td><td colspan="2">1. CBL students outperformed the control group students on higher order questions (p=0.02, Cohen’s d = 0.27 (Small effect size).
2. The CBL students outperformed the control group on 26% of the questions, while the control group outperformed the CBI group on only 8% of the questions (p<0.05) (no difference on 66% of questions; overall average difference NOT significant).
3. Based on classroom observation of classroom activities, significantly more events occurred that were learner-centered, community centered and assessment-centered the CBL than the traditional classroom (p<0.05) (learner-centered, Cohen’s d=0.84 (Large effect size); assessment centered Cohen’s d= 0.95 (Large effect size); community centered. Cohen’s d=1.21 (Large effect size)).</td></tr>
<tr><td colspan="3">Planning and implementation resources: https://www.challengebasedlearning.org/pages/about-cbl</td></tr>
</table>

Computer Simulation

Students	**Instructor**
• Engage individually or in in small group activities • Use simulation software • Engage in STEM practices 1. Manipulate variables 2. See results of multiple experiments without actual replication • Explore phenomenon that occur over long or extremely short periods of time	• Select appropriate simulation materials to support learning objectives • May provide supplemental instruction in conjunction with simulation experience

Variations: Student inquiry

Associated observable actions: Reading, Observing, Building/Manipulating, Instructor facilitates activities

Objective/Learning Goal: Students participate in STEM practices

Research outcomes

Graduate students who engaged Challenge-based learning module incorporating computer simulations conducting Fourier spectral analysis demonstrated better understanding relative to students who studied the material using traditional methods (Greenberg, Smith & Newman, 2003).	1. Students who engaged in the module (treatment including CBL and interactive computer simulations) outperformed students in the control group on 3 out of the 4 concept groupings relating to spectral analysis (Course Topic) than those in the control ($p<0.05$)
High school students learning about chemical bonding through the use collaborative learning and interactive websites demonstrate elevated understanding when compared to students taught traditionally (Frailich, Kesner & Hofstein, 2009).	1. The post-achievement questionnaire scores were significantly higher in the experimental group compared to the treatment ($t=5.7$, $p<0.001$, Cohen’s $d = 0.764$) (moderate to large effect size) and included all three subtopics within the questionnaire 2. The post-achievement questionnaire scores specific to all subtopics of chemical bonding were ALSO significantly higher in the experimental group compared to the control (Wilk's $\lambda = 0.88$, $F(3, 229)=10.8$ ($p<0.0001$)4) 3. Based on analysis of student interviews three factors contributed to learning and understanding of chemical bonding - (1) identification of student difficulties with the concept of chemical bonding, (2) a constructivist approach to learning including active and cooperative learning, (3) Computer-based visual models contribute to understanding 4. Based on analysis of classroom conversations the themes identified included (1) Students relate to what is required of them in the activity and follow the instructions (2) Students focused on carrying out the activity (3) Student explained the structure of metals, and in the process, connects the visual model in the activity to the theoretical model taught (4) Interactions between students occurred. They cooperate and help each other to understand the model representing metals (5) There is confusion about the kind of negative particles that compose the metal
Undergraduate students enrolled in a second semester calculus-based physics course who engaged in Peer Instruction and the Circuit Constructor Kit (CCK) Computer Simulation demonstrated elevated learning compared to students taught traditionally (Keller, Finkelstein, Perkins & Pollock, 2007)	1. Students who viewed the CCK simulation for 2 of the ConcepTests scored significantly higher than those in the control section that did not ($p=0.002$). There was no difference between groups on ConceptTest where neither group observed a simulation ($p=0.54$).

Undergraduate students in introductory physics who participated in simulated laboratory experiences on DC circuits outperformed their comparison group counterparts on a conceptual survey and tasks related to the assembly of a real circuit. (Finkelstein et al., 2005)	1. Performance on final exam questions relating to circuits was significantly higher from the experimental group that compared to the control group ($p<0.002$). The two groups did not show any statistical difference on non-circuit related questions. 2. The mean scores for student responses to a writing task (“Describe what happens and WHY the bulbs change brightness…”) was significantly higher for the treatment group than the control ($p<0.03$).
In a meta-analysis of research on secondary (grades 6-12) student learning the results indicated correlated positive learning gains from use of simulations (Scalise et al., 2011)	1. Of the 79 studies included in the meta-analysis 53% of studies reported learning gains, 17% gains under right condition, 25% Mixed results, 3% no gains
Undergraduate students enrolled in an introductory biology course taught through interactive web-enhanced practices demonstrated elevated learning compared to students from control group (McDaniel, Lister, Hanna & Roy, 2007).	1. Students in the Web-enhanced course demonstrated elevated learning gains in evolution from evolution and ecology concept questions above those in the control group ($p=0.024$, Cohen’s $d = 0.318$ (Small effect size)) 2. Students in the Web-enhanced course demonstrated elevated learning gains in ecology from evolution and ecology concept questions above those in the control group ($p= 0.0000009$, Cohen’s $d = 0.447$ (Small effect size))
Planning and implementation resources: A simulation is …. “a computer-based interactive environment with an underlying model”. Review of computer-based simulations for STEM Learning in K-12 (D’Angelo, Rutstein, Harris, Haertel, Bernard & Borokhovski, 2013) http://www.sri.com/sites/default/files/brochures/simulations-for-stem-learning-brief.pdf	

Collaborative Learning

<table>
<tr><th colspan="2">Students</th><th>Instructor</th></tr>
<tr><td colspan="2">• Engage group activities
• Engage in discussions with peers
• Engage in reasoning, interpretation and problem solving with their peers</td><td>• Support students working in groups</td></tr>
<tr><td colspan="3">Variations: Think/Write-pair-share, Peer Instruction, Argument-driven Inquiry, Challenge-based Learning, Problem-based Learning, Project-based Learning, Student Inquiry, Studio Courses</td></tr>
<tr><td colspan="3">Associated observable actions: Speaking, Instructor facilitates activities</td></tr>
<tr><td colspan="3">Objective/Learning Goal: Learning through sharing knowledge through dialogue.</td></tr>
<tr><th colspan="3">Research outcomes</th></tr>
<tr><td>High school students learning about chemical bonding through the use collaborative learning and interactive websites demonstrate elevated understanding when compared to students taught traditionally (Fralich et al., 2009).</td><td colspan="2">1. The post-achievement questionnaire scores were significantly higher in the experimental group compared to the treatment ($t=5.7$, $p<0.001$, Cohen’s $d = 0.764$) (moderate to large effect size) and included all three subtopics within the questionnaire
2. The post-achievement questionnaire scores specific to all subtopics of chemical bonding were ALSO significantly higher in the experimental group compared to the control (Wilk's $\lambda = 0.88$, $F(3, 229)=10.8$ ($p<0.0001$)4)
3. Based on analysis of student interviews three factors contributed to learning and understanding of chemical bonding - (1) identification of student difficulties with the concept of chemical bonding, (2) a constructivist approach to learning including active and cooperative learning, (3) Computer-based visual models contribute to understanding
4. Based on analysis of classroom conversations the themes identified included (1) Students relate to what is required of them in the activity and follow the instructions (2) Students focused on carrying out the activity (3) Student explained the structure of metals, and in the process, connects the visual model in the activity to the theoretical model taught (4) Interactions between students occurred. They cooperate and help each other to understand the model representing metals (5) There is confusion about the kind of negative particles that compose the metal</td></tr>
<tr><td>Undergraduate students in a studio physics course demonstrate elevated conceptual understanding correlated with cooperative group problem solving and interactive lecture demonstrations compared to students in studio courses that did not use these strategies (Cummings, Marx, Thornton & Kuhl, 1999)</td><td colspan="2">1. Students in Studio sections with the interactive lecture demonstrations demonstrated increases normalized gains over control studio sections on the Force Concept Inventory (FCI) and Force and Motion Concept Evaluation (FMCE) ($g(FCI) = 0.35$; $g(FMCE) = 0.45$)
2. Students in Studio sections with cooperative learning group problem solving demonstrated increases normalized gains over control studio sections ($g(FCI) = 0.36$; $g(FMCE) = 0.36$)</td></tr>
<tr><td>An analysis of results from the 1992 National Student of Student Learning showed that exposure to collaborative learning practices positively impacted self-reported learning gains related to personal development, understanding science & technology, appreciation of fine arts and analytic skills. (Cabrera, Crissman, Bernal, Nora, Terenzini & Pascarella, 2002)</td><td colspan="2">1. Collaborative learning was the most significant predictor across all four self-reported learning gains (personal development, understanding science & technology, appreciation of fine arts, analytic skills). Collaborative learning was also the variable with the greatest effect on students’ openness to diversity.</td></tr>
<tr><td colspan="3">Planning and implementation resources: (Ruiz-Primo, Briggs, Iverson, Talbot & Shepard, 2011)
http://pagines.uab.cat/melindadooly/sites/pagines.uab.cat.melindadooly/files/Chpt1.pdf</td></tr>
<tr><td colspan="3">All cooperative learning is collaborative, but not all collaborative learning is cooperative</td></tr>
</table>

Cooperative Learning

Students	Instructor
• Engage group activities • Engage in discussions with peers • Engage in reasoning, interpretation and problem solving with their peers (Slavin, 2011) • develop and practice group social skills including 1. trust-building 2. leadership, 3. decision-making 4. communication 5. conflict management	• Facilitate group development • May define roles for group members • Highlight the importance of group responsibility for individual student learning, success or achievement • Support and evaluate group success based on social as well as academic criteria • Provide tools for conflict management • Intervene if group dynamic struggles

Variations: Jigsaw

Associated observable actions: Speaking, Instructor facilitates activities

Objective/Learning Goal: Learning through sharing knowledge through dialogue. Develop skills associated with group activities

Research outcomes

High school chemistry students using cooperative learning techniques demonstrated fewer elevated knowledge of metallic bonding as compared to traditionally taught students. (Acar & Tarhan, 2007)	1. Experimental group had significantly higher mean scores on their post Metallic Bonding Concept Test (MTCT) than the control group (t=7.79, p<.05, Cohen's *d*= 2.737) (Large effect size).
Undergraduate mechanical engineering students who engaged in cooperative learning performed better on homework and unit tests, over time, than those who worked independently (Hsiung, 2012)	1. A shift in performance scores occurred from the unit 1 to unit 4 homework exams. Initially, the students in the individualistic treatment performed better or equal to their cooperative learning counterparts. A shift in achievement began to occur in hw test 3 and was dramatic by test 4. The researcher completed mean, sd, effect size, and Wilcoxon signed rank statistics. (Unit 3 Cohen's *d*=0.47 (moderate effect size); Unit 4 Cohen's *d*=0.73 (moderate to large effect size). 2. A shift in performance scores occurred on the unit test of students in the cooperative learning group demonstrating a gradual improvement and achievement over those in the control group over the 4 Unit tests (Unit 2 Cohen's *d*=1.36 (large effect size; Unit 3 Cohen's *d*=0.55 (moderate effect size); Unit 4 Cohen's *d*=0.69 (moderate effect size).
Undergraduate student in biology develop correct conceptions about Darwinian evolution when supported by paired problem solving and a historically rich curriculum (Jensen & Finley, 1996)	1. The alternative curriculum in conjunction with the paired problem solving demonstrated the greatest positive shift in Darwinian responses (*p*=0.027) and the greatest negative shift in alternative conceptions (*p*=0.0214). Paired problem solving had a significant shift in students Darwinian responses (*p*=0.030) but not their alternative conceptions (*p*=0.826).
Undergraduate students in a biology course who worked in cooperative groups demonstrated higher exam scores. (Prezler, 2009)	1. Students in the cooperative group treatment demonstrated a larger percentage of students earning "A's" and "B's" (45% increase) and fewer students earned "F's" or dropped the course compared to the semesters prior to the implementation of the cooperative group model ($X^2 = 61.85$, df = 5, p<0.001)
Undergraduate science majors in a general chemistry course demonstrated elevated success in course using guided inquiry and cooperative learning strategies (Farrell, Moog & Spencer, 1999)	1. Students who were taught using guided inquiry strategies in conjunction with cooperative learning demonstrated reduced DFW occurrences (from more than 20% to less than 10% combined) compared to students who took the course prior to implementation of the guided inquiry/cooperative learning techniques.

Planning and implementation resources: (Dooly, 2008; Felder & Brent, 2007; Johnson, Johnson & Smith, 1998)

All cooperative learning is collaborative, but not all collaborative learning is cooperative

Interactive Lecture Demonstration

Students	Instructor
• Engage individually, in small groups and in whole class activities • Engage in the following cycle 1. Prediction 2. Observation 3. Reflection 4. Discussion • Work independently and with peers • Collaborate through discussion with peers • Examine results of demonstration • Compare results with predictions • Attempt to explain observed phenomenon	• Select and present demonstration appropriate to the desired learning objective(s) • Facilitate the predict, observe, reflect and discuss cycle for students

Variations: Interactive Lecture

Associated observable actions: Observation, Speaking, Instructor facilitates discussion, Instructor explaining, Instructor facilitates activities

Objective/Learning Goal: Each of the steps contributes to student understanding “Prediction links new learning to prior understanding. The experience engages the student with compelling evidence. Reflection helps students identify and consolidate what they have learned” (serc.carlton.edu, 2012).
http://serc.carleton.edu/sp/library/demonstrations/index.html
“enhance conceptual learning [during] lectures through active engagement of students in the learning process” (Solokoff & Thornton, 2006, n.p.)
http://www.wiley.com/WileyCDA/WileyTitle/productCd-EHEP001706.html

Research outcomes	
Science and engineering students in an introductory physics that integrated demonstrations and interactive teaching show benefits of these teaching practices based on academic performance (Chang, 2011).	1. Students in the treatment group demonstrated elevated academic performance over the control group on the end of course exams (t=4.46, p<0.001) 2. Scores on the Concept Survey of Electricity and Magnetism were higher in the control than the treatment group (n.s.)
Undergraduate students in a studio physics course demonstrate elevated conceptual understanding correlated with cooperative group problem solving and interactive lecture demonstrations compared to students in studio courses that did not use these strategies (Cummings et al., 1999)	3. Students in Studio sections with the interactive lecture demonstrations demonstrated increases normalized gains over control studio sections on the Force Concept Inventory (FCI) and Force and Motion Concept Evaluation (FMCE) (g(FCI) = 0.35; g(FMCE) = 0.45) 4. Students in Studio sections with cooperative learning group problem solving demonstrated increases normalized gains over control studio sections (g(FCI) = 0.36; g(FMCE) = 0.36)
Undergraduate pre-medical students in an introductory physics course who engaged in observe, predict, discuss interactive lecture demonstration practices demonstrate greater understanding than students who passively observe demonstrations or do not view demonstrations at all (Crouch, Fagen, Callan & Mazur, 2004)	1. Based on results on end-of-semester tests, students who engaged in ANY portion of the learning engagement with the demonstration (observe, predict, discuss) were able to provide the correct outcome and/or an accurate explanation at a higher rate those students who had NO demonstration at all (Observe, p=.03, Cohen’s h= 0.09 (Small effect size); Predict, p<.01, Cohen’s h = 0.35 (Small effect size); Discuss, p<.0001, Cohen’s h = 0.47(Small to moderate effect size). 2. Demonstrated improvement of question explanations on end-of-course exams by students who engaged in (predict or discuss treatments) above what was achieved by those students who had NO demonstration at all, or only were allowed to observe (Observe, p=.64, Cohen’s h = 0.05 (Small effect size) ; Predict, p=.04, Cohen’s h =0.18 (Small effect size); Discuss, p=.02, Cohen’s h =0.23(Small effect size))

Undergraduate students enrolled in an introductory physics studio course that incorporates interactive demonstrations and peer instruction demonstrated elevated learning gains compared to students who were taught through traditional lecture/lab methods (Sorenson, Churukian, Maleki & Zollman, 2006)	1. Compared to the traditional method, students in the studio courses that used demos were nearly 2 ½ times higher on both Force Concept Inventory, (Fractional g~0.40)
Planning and implementation resources: http://serc.carleton.edu/sp/library/demonstrations/index.html http://www.wiley.com/WileyCDA/WileyTitle/productCd-EHEP001706.html	

Interactive Lecture/Engagement

Students	Instructor
• Work individually or with peers • Participate in learning activities associated with "lecture breaks" which may include: 1. Peer dialogue 2. Activity 3. Writing/Problem solving	• Present content to students • Pause during instruction • Facilitate students in dialogue, activity or writing/problem solving

Variations: Peer instruction, Think/write-pair-share, Interactive lecture demonstration, Studio

Associated observable actions: Speaking, Writing, Instructor facilitates dialogue, Instructor explaining

Objective/Learning Goal: Engage students in thinking through participation.

Research outcomes	
Undergraduate Bioscience students enrolled in Collaborative Learning through Interactive Sense-making in Physics (CLASP) interactive courses at UC Davis demonstrated elevated grade point averages (GPA's) compared to students in non-interactive physics courses at the same university. Students in the interactive course demonstrated learning gains based on pre-post administration of the Force Concept Inventory (FCI). The interactive course did not inhibit student performance on the Medical College Admissions Tests (MCAT) (Author, 2013).	1. CLASP Students demonstrated higher upper division GPA's than students in traditionally taught courses (p=0.05) 2. CLASP Students normalized learning gains on the FCI 0.39 +/- 0.01 3. MCAT scores from students enrolled in the interactive courses were not statistically different that traditionally taught physics course (p = 0.29).
Undergraduate students enrolled in interactive introductory physics courses demonstrated elevated learning gains based on Force Concept Inventory (FCI) scores during the first semester of instruction compared to traditionally taught students. No differences in conceptual learning as measured by the Brief Electricity and Magnetism Assessment (BEMA) were identified between the two groups during the second semester of instruction (Cahill et al., 2014)	1. Normalized learning gains for first semester in the active-physics course were higher than traditional-lecture physics (p<0.05). 2. Conceptual learning gains as measured by BEMA during the second semester were not different between the Active and traditional students
Undergraduate students enrolled in an environmental ecology course demonstrate learning gains in conjunction with interactive engagement techniques throughout the course (Arthurs & Templeton, 2009)	1. Demonstrated learning gains on 14 matched questions used in pre/pose course exams (g= 0.99) (Large effect size).
High school students in a quantum physics course demonstrate elevated learning gains based on the Quantum physics achievement test (QPAT) when instruction in provided through interactive engagement as compared to a traditional lecture. Females in the interactive engagement group demonstrate elevated learning gains above their male counterparts within the same group (Adegoke, 2012).	1. Males pre-test scores were significantly higher than female pre- test scores t(119) = 4.39, p<0.05. 2. Students in the interactive engagement group scored higher on the QPAT post-test than students in the control (lecture) group. F(1,117) = 42.75, p<0.05, effect size 26.8%. 3. Across groups, males scored higher than females after instruction based on the QPAT. F(1,117) = 6.23, p<0.05, effect size 5.1% 4. Females in the interactive group demonstrated a marginal mean difference above males (1.32), while males in the control group demonstrated considerably higher mean differences than females (13.63).Between subject effects (interactive engagement*gender) shows the observed mean difference as significant. F(1,117) == 1.25, p<0.05, effect size 5.6%.

Planning and implementation resources: (Steinert & Snell, 1999)
http://serc.carleton.edu/introgeo/interactive/index.html

Jigsaw

<table>
<tr><th>Students</th><th>Instructor</th></tr>
<tr><td>• Work individually or in groups to develop knowledge expertise on a given topic
• Report learned content to group
• Share responsibility of learning load across group</td><td>• Select topic for students to research
• Divide the topic into chunks for students to research
• Facilitate the development of jigsaw groups</td></tr>
<tr><td colspan="2">Variations:</td></tr>
<tr><td colspan="2">Associated observable actions: Reading, Writing, Speaking, Instructor facilitates activities</td></tr>
<tr><td colspan="2">Objective/Learning Goal: Share the responsibility of learning large amount of content across group members</td></tr>
<tr><th colspan="2">Research outcomes</th></tr>
<tr><td>Undergraduate students enrolled in a general chemistry class who participated in Jigsaw cooperative learning about “Acid-based theories” demonstrated elevated learning about the students in the control group (Tarhan & Sesen, 2012)</td><td>1. After participation in the Jigsaw instructional method, students in the treatment group had statistically higher mean scores on the Acid-Base Theories Concept Test (t = 4.65, p=0.002, Cohen’s d = 1.44 (Large effect size).
2. Students in the treatment group demonstrated fewer misconceptions after participation in the Jigsaw based on responses to the Acid-Base Theories Concept Test (reported as percentages).
a) Because HS_ has hydrogen, it is Lewis acid. (Exp 0%, Cont 45%)
b) Because HS_ give its proton, it is Bronsted–Lowry acids.(Exp 6%, Cont 40%)
c) CN_ ion takes proton from the base and thereby it is Arrhenius base. (Exp 0%, Cont 35%)
d) There is no electron transfer between NH3 and BF3 molecules. (Exp 6%, Cont 40%)
e) Acids are the substances that only give H+ ions and bases are the substances that only gave OH_ ions. (Exp 11%, Cont 45%)
f) Bases are the substances that give proton and acids are the substances that gain proton. (Exp 11%, Cont 50%)
g) Arrhenius theory explains transferring of H+ and Bronsted–Lowry theory explains transferring proton. (Exp 6%, Cont 55%)
h) According to Lewis Theory, ions should be combined to make new products. (Exp 0%, Cont 45%)</td></tr>
<tr><td>Undergraduate students in general chemistry class who participated in Jigsaw cooperative learning performed better on a standardized achievement measure than students in the control group (Doymus, 2008).</td><td>Jigsaw groups outperformed the control on all 4 modules of the Chemical Bonding Achievement Test (CBAT) (p<0.01)
1. Module A: Ionic bonding, ionic compounds and ionic crystal structures (t=3.760, <i>p</i>=0.001, d= 0.969) (large effect size)
2. Module B: characteristics of covalent bonds, polar and apolar molecules, and covalent compounds (t=5.666, <i>p</i>=0.001, d= 1.514) (large effect size)
3. Module C: hydrogen bonding and van der Waals forces (t=2.892, <i>p</i>=0.008, d= 0.778 (moderate to large effect size)
4. Module D: bond angles, Lewis structures, bond energy, geometry structure of molecules, and intermolecular and intramolecular bonds (t=3.334, <i>p</i>=0.002, d= 0.924) (large effect size)</td></tr>
<tr><td>Undergraduate pre-service elementary school teachers enrolled in a Concepts of Biology course learned better when they taught material to, or learned material from other students in the course (Tessier, 2007)</td><td>1. By the end of the course, students were performing significantly better on material that they taught to each other over information taught during lecture. Also, students retained information that they taught to each other better than information covered in lecture (p<0.05).</td></tr>
<tr><td colspan="2">Planning and implementation resources: http://serc.carleton.edu/introgeo/jigsaws/index.html
https://www.jigsaw.org/#steps</td></tr>
</table>

Just-in-Time Teaching

<table>
<tr><th colspan="2">Students</th><th>Instructor</th></tr>
<tr><td colspan="2">• Engage individually, in small groups and in whole class activities
• Engage in web-based warm-up assignment and pre-instruction activities
• Complete web-based formative assessment
• Engage in group activities during in-class time</td><td>• Develop web-based instructional materials
• Develop formative assessments aligned with on-line instructional materials
• Use formative assessment to inform in-class instruction and/or activities
• Develop and facilitate in-class activities</td></tr>
<tr><td colspan="3">**Variations:**</td></tr>
<tr><td colspan="3">**Associated observable actions**: Speaking , Instructor facilitate dialogue, Instructor facilitate activities, Instructor explaining</td></tr>
<tr><td colspan="3">**Objective/Learning Goal:** Structured out-of-class learning assists with learning and guides in-class activities to further learning. Improve students' preparation for class by motivation learning through ongoing formative assessment which inform in-class activities targeting student learning gaps (serc.carleton.edu, 2013)</td></tr>
<tr><th colspan="3">Research outcomes</th></tr>
<tr><td>Undergraduate students in an introductory physics course “taught using the Just-in-Time teaching strategy better understand Newton’s Third Law after instruction than do students in traditional lecture courses” (Formica, Easley & Spaker, 2010, n.p.)</td><td colspan="2">1. JiTT treatment students demonstrated significantly increased normalized gains over non JiTT control students in overall FCI scores. (JiTT g=37.6%; Control g=17.9%)
2. Treatment also demonstrated higher scores on the N3 specific questions on the FCI over control group (JiTT g=51%; Control g=6.6%).</td></tr>
<tr><td>Undergraduate students enrolled in an introductory biology course taught in the Learn Before Lecture (JiTT) format in conjunction with interactive exercises can demonstrate a significant increases in learning gains compared to students who did not engage in these practices as measured over multiple semesters of course implementation (Moravec, Williams, Aguilar-Roca & O’Dowd, 2010)</td><td colspan="2">1. Based on a comparison of student responses to matched paired questions between treatment and control students the percentage of student who correctly answered multiple choice questions for each of the match question topics was significantly higher for the treatment group. The mean increase in percentage correct calculated for the six matched questions pairs was 21.3 ± 7.5% (p<0.001)
2. “The large and significant increase in mean performance on the LBL-related matched questions pairs (21%) in contrast to the <3% increase in exam performance on non-LBL questions, and similarity in preclass academic indices and composition of the 2007, 2008, and 2009 cohorts, indicate the majority of the increase in performance is associated with LBL-related learning gains” (p. 477)</td></tr>
<tr><td>Undergraduate students in a non-majors general science class over two semesters demonstrated learning gains in a course using JiTT strategies (Guertin, Zappe & Kim, 2007)</td><td colspan="2">1. Results from two implementations of the JiTT strategy in the Dinosaurs and other Extinctions course indicate learning gains as a result of engagement in the course (Spring implementation t=-18.03, p<0.000) (Fall implementation t=-21.71, p<0.000)</td></tr>
<tr><td>Undergraduate students enrolled in a second semester statistics course using JiTT practices demonstrated elevated learning gains compares to control group students on their final course examination (Benedict & Anderton, 2004)</td><td colspan="2">1. Students in the JiTT statistics course performed better (M=76.25, SD 11.07) than student in the control class (M=72.39, SD 8.89) t(119) = 2.13, p=0.04, Cohen's d= 0.38) (Small effect size)</td></tr>
<tr><td colspan="3">**Planning and implementation resources:** http://serc.carleton.edu/introgeo/justintime/index.html
http://officeofresearch.ucsc.edu/broader-impacts/resources/teaching/jitt.pdf</td></tr>
</table>

Models/Analogies/Representations

Students	Instructor
• Engage individually and in whole class activities • Build models (physical or through drawing) • Discuss their models • Identify patterns • Refine their models • Participate in activities	• Facilitates discussion about student models • Guides students through the process of model refinement • Identification and facilitation of activities to support model refinement

Variations:

Associated observable actions: Building/Manipulating, Speaking, Instructor facilitates activities

Objective/Learning Goal: Build understanding by establishing connections between newly taught content and prior knowledge. Moving from naïve or alternative conceptions toward a target or desired mental construct.

Research outcomes

Undergraduate students (males, females, majority, under-represented) enrolled in an introductory physics course using modeling instruction demonstrate increased conceptual understanding compared to control group students on the Force Concept Inventory (FCI) (Brewe, Sawtelle, Kramer, O'Brien, Rodriguez & Pamela, 2010)	1. Overall impact of modeling instruction demonstrated elevated conceptual learning by all groups compared to control group based on FCI scores ($p<0.001$; Cohen's d = 1.05) (Large effect size) 2. Female students in the modeling instruction group demonstrated elevated learning gains on the FCI above females in control group ($p<0.001$; Cohen's d= 0.91 (Large effect Size). 3. Underrepresented students in the modeling instruction group demonstrated elevated learning gains on the FCI above under-represented students in the control group ($p<0.001$; Cohen's d= 0.99) (Large effect size) 4. Modeling instruction increases the gap on FCI score between males and females even when controlling for pre-instruction preparation 5. Modeling instruction does not increase the gap on FCI scores between majority and under-represented students when controlling for pre-instruction preparation.
Undergraduate students in a calculus-based physics course that used analogy to teach about electromagnetic (EM) waves demonstrated elevated learning above traditionally taught students (Podolefsky & Finkelstein, 2007)	1. Students taught using analogy demonstrated elevated shifts in answering EM concept question correctly compared to traditionally taught students (21% shift to correct response vs. 7%; $p=0.001$)
Teachers who engaged in a biology workshop on energy transfer using model-building experiences demonstrated increased knowledge above that of control group teachers based on a multiple choice exam and a draw and explain assessment (Batiza et al., 2013).	1. Teachers who participated in SUN workshop significantly increased their achievement on the multiple choice exam above the control group teachers ($p<0.001$; Cohen's d= 1.16) (Large effect size) 2. Teachers who participated in SUN workshop demonstrated long-term knowledge retention on the multiple choice exam above those of the control group teachers ($p = 0.049$) 3. Teacher who participated in the SUN workshop made significant knowledge gains based a drawing and explanation assessment, above that of the control group teachers ($p<0.001$; Cohen's d = 1.58) (Large effect size)
Undergraduate students in a biochemistry course who work in groups and used external representations of virus self-assembly demonstrate learning gains (Host, Larsson, Olson & Tibell, 2013)	1. Students in both conditions (static image and tangible model) improved their knowledge scores with no significant difference detected between the two groups

Planning and implementation resources: Clement & Rea-Ramirez, 2008; Falk & Brodsky, 2013

Peer Instruction

<table>
<tr><th colspan="2">Students</th><th>Instructor</th></tr>
<tr><td colspan="2">• Engage individually, in small groups and in whole class activities
• Answer questions individually using assistive technology (i.e., student response system, response cards)
• Discuss responses to questions with peers
• Participate in whole-class discussion regarding individual and shared ideas about assessment questions</td><td>• Explain content
• Prepare formative assessment questions
• Provide time for students to respond to questions
• Facilitate class discussion</td></tr>
<tr><td colspan="3">Variations: Think/Write-pair-share</td></tr>
<tr><td colspan="3">Associated observable actions: Writing, Speaking, Instructor Waiting, Instructor explaining, Instructor facilitating dialogue</td></tr>
<tr><td colspan="3">Objective/Learning Goal: Monitor the current understanding of students within the classroom in order to adjust activities if necessary, as well as use the dispersed understanding among students to support the development of individual understanding of all students through sharing of ideas through the iterative process of questioning and dialogue.</td></tr>
<tr><th colspan="3">Research outcomes</th></tr>
<tr><td>Undergraduate students taught through Peer Instruction “demonstrate better conceptual learning and similar problem-solving abilities than traditionally taught students”. The effectiveness of peer instruction evaluated between two post-secondary institutions (2-year college and 4-year university. (Lasry, Mazur & Watkins, 2008, p. 1066)</td><td colspan="2">1. treatment group demonstrated significantly greater normalized gains after PI instruction over those of the control group as measured by the FCI (P<0.05, 2-year college difference g = 0.17 HIGHER; 4 year university difference g= 0.26 HIGHER)
2. Peer Instruction groups from both schools (2-year college, 4-year university) demonstrated equal learning gains even though they were significantly different prior to instruction. (g=0.50 for 2 year; g=0.49 for 4-year).
3. Students in the PI groups at both schools identified as having HIGH or LOW background knowledge demonstrated significantly more conceptual learning thank those in the control groups (Low Background Knowledge g=0.39; High Background Knowledge g=0.26)
4. Student in the PI group at the 4-year school obtained a higher average score on problem solving than the control group from the same school (p<0.001)</td></tr>
<tr><td>Undergraduate students in an upper level Developmental Biology course who engaged in interactive lecture strategies (Peer instruction) demonstrated elevated learning when compared to students who were taught traditionally in previous semesters (Knight & Wood, 2005)</td><td colspan="2">1. The average performance on the posttest was significantly higher for the treatment group in both raw scores (+ 9%) and normalized learning gains (+16%) (p=0.001)
2. When the researchers used the treatment during a subsequent semester, the results for student normalized learning gains matched those of the first implementation of the treatment.</td></tr>
<tr><td>An analysis of 10-years of implementation of peer instruction with undergraduate students enrolled in calculus and algebra-based physics for non-majors indicates “increased student mastery of both conceptual reasoning and quantitative problem solving” when compared to traditionally taught students (Crouch & Mazur, 2001, p. 970).</td><td colspan="2">1. Increase learning gains from those courses (Calculus and Algebra-based physics) taught using PI over those taught traditionally during previous semesters based on FCI scores (Traditional typical g=.23; PI typical g=.48)
2. Elevated gains on the Mechanics Baseline Test from those students who participated in PI in calculus-based physics over those that were in traditional classes</td></tr>
<tr><td>Undergraduate students enrolled in a second semester calculus-based physics course who engaged in Peer Instruction and the Circuit Constructor Kit (CCK) Computer Simulation demonstrated elevated learning compared to students taught traditionally (Keller et al, 2007)</td><td colspan="2">1. Students who viewed the CCK simulation for 2 of the ConcepTests scored significantly higher than those in the control section that did not (p=0.002). There was no difference between groups on ConceptTest where neither group observed a simulation (p=0.54).</td></tr>
</table>

Highly-structured course designs, including the use of peer-instruction techniques benefit undergraduate students enrolled in introductory biology courses by closing the achievement gap (Haak, HilleRisLambers, Pitre & Freeman, 2011)	1. Through Generalized Mathematical Lineal Modeling, the combination of Active learning (including peer instruction techniques) +predicted grade + Educational Opportunities Program (EOP) status +interactions was the model that had the best explanatory power. Results indicate a substantial shift specifically in scores of EOP students (dramatically closing the gap between EOP and non-EOP students; by 45%). (p=0.0023)
Planning and implementation resources: Mazur (2001)	

Problem-based learning

<table>
<tr><th>Students</th><th>Instructor</th></tr>
<tr><td>• Engage individually, in small groups and in whole class activities
• Search for information to solve problem including
1. Identifying and clarifying terminology
2. Defining the problem
3. Discuss and accumulate background information
• Engage in activities related to problem-solving
1. Brainstorming
2. Listing and analyzing possible solutions
3. Collect necessary information needed to understand the problem/solution relationship
4. Synthesize and test the information that was collected
• Share findings
• Evaluate the process</td><td>• Provide the problem to be addressed by students
• Provide resources and activities to facilitate problem solving</td></tr>
<tr><td colspan="2">Variations: Project-based learning</td></tr>
<tr><td colspan="2">Associated observable actions: Reading, Writing, Speaking, Instructor facilitates activities</td></tr>
<tr><td colspan="2">Objective/Learning Goal: Engage students in the process of learning through solving real-world problems. “The emphasis in projects-based learning is on applying or integrating knowledge while in problem-based learning is on acquiring it” (Prince & Felder, 2006, p. 130).</td></tr>
<tr><th colspan="2">Research outcomes</th></tr>
<tr><td>Undergraduate students enrolled in an electrical engineering course an engaged in problem-based learning demonstrated elevated learning on topics taught based on PBL verses those topics that were not (Yadav, Subedi, Lundeberg & Bunting, 2011)</td><td>1. Students scored equally well or better in the problem-based learning approach as compared to the lecture approach. Gain scores in all four paired pre-post quizzes indicated that students scored significantly higher in the post test (after instruction). The treatment effect (PBL) produced average gains at least TWICE as high on conceptual understanding as compared to the lecture approach. (Control 1 t(54)=1.822. p=.074; Control 2 t(54)= 6.213, p<0.001, Cohen’s d = 0.83 (Large effect size); Treatment 1 t(54) = 5.571, p<0.001, Cohen’s d – 0.75 (Moderate-large effect size); Treatment 2 t(54) 6.142, p<0.001, Cohen’s d = 0.83 (Large Effect size))</td></tr>
<tr><td>Undergraduate students in different STEM courses who engage in limited Problem-based learning are generally better problem solvers that students who do not participate in Problem-based learning (Klegeris, Bahniwal & Hurren, 2013)</td><td>1. Students in the class using problem-based learning demonstrated elevated problem-solving test scores compared to control group students (p<0.05)</td></tr>
<tr><td>Undergraduate pre-service teachers studying the first law of thermodynamics who engages in problem-based learning demonstrated learning gains (Tatar & Oktay, 2011)</td><td>1. First Law of Thermodynamics Achievement Test (FLTAT) statistically significant difference in scores between pre and post-test (t(47)=-19.57; p<0.05.)
2. Science Process Skills Test statistically significant difference in scores after PBL instruction (t(47)=3.60; p<0.05)</td></tr>
<tr><td>Undergraduate students who engage in a problem-based learning introductory thermal physics module demonstrate improved learning compared to students from a previous comparison semester based on implementation of the new learning strategy (van Kampen, 2Banahan, Kelly, McLoughlin & O’Leary, 2004).</td><td>1. Data suggest that students performed remarkably better on the exam than students in previous years, from an average of 49% and 4 students failing to an average of 58 with NO failures.</td></tr>
<tr><td colspan="2">Planning and implementation resources: http://www.umpblprep.nl/pbl-step-by-step/
http://www.hep.lu.se/staff/akesson/Kurser/6.2.1/6.2.1.0-intro.pdf</td></tr>
</table>

Project-based learning

Students	Instructor
• Engage individually, in small groups and in whole class activities • Participate in negotiation of evaluation criteria • Design a plan for the project • Discuss and accumulate background information • Participate in activities that will assist with project development • Engage in project-development, testing and production • Present project • Reflect on the process and participate in evaluate	• Identify and share the essential question • Assist students in designing a plan for their project(s) • Facilitate negotiated of evaluation criteria • Identify and facilitate activities that will assist with project development • Create a schedule for project development 1. Set benchmarks 2. Provide guidance in time management • Monitor student progress • Evaluate project outcome • Facilitate the evaluation of the learning process
Variations: Problem-based learning	
Associated observable actions: Reading, Writing, Speaking, Instructor facilitates activities,	
Objective/Learning Goal: Engage students in learning through complex, real-world problem solving. “The emphasis in projects-based learning is on applying or integrating knowledge while in problem-based learning is on acquiring it” (Prince & Felder, 2006, p. 130).	
Research outcomes	
Undergraduate students who engaged in First Year Engineering Project course demonstrated elevated retention in engineering programs than those students who did not (Fortenberry, Sullivan, Jordan& Knight, 2007).	1. Those students who participated in the First Year Engineering Projects course were retained in school through the 7th semester at a higher rate than those who did not take the FYEP course ($p<0.05$)
Undergraduate pre-service teachers demonstrate gains in science and mathematics understanding based on engagement in project-based learning about lunar concepts (Wilhelm, Sharrod & Walters, 2008)	1. Participants demonstrated a significant increase in the mean scores on Lunar Phases Concept Inventory after participation in PBL about moon ($F(1,23)=17.871$, $p<0.001$)
Undergraduate science and engineering majors enrolled in chemistry courses using Project-based learning techniques demonstrated elevated learning gains above control group students (Barak & Dori, 2005).	1. No significant difference between groups based on pre-test scores 2. Experimental group (Project-based learning) scored significantly higher on the post-test than the control group students ($F=57.49$, $p<0.01$, Cohen's $d= 1.04$) (Large effect size) 3. Experimental group (Project-based learning) scored significantly higher on the final exam than the control group students ($F=5.19$, $p<0.02$, Cohen's $d= 0.372$) (Small effect size)
Planning and implementation resources: http://www.ascd.org/publications/books/106031/chapters/The_Nine_Steps_of_Project-Based_Learning.aspx	

Science Writing Heuristic

<table>
<tr><th colspan="2">Students</th><th>Instructor</th></tr>
<tr><td colspan="2">• engage individually, in small groups and in whole class activities
• create a concept map to elicit prior knowledge.
• engage in a laboratory investigation (generate authentic data or observe phenomenon).
• make claims about data and observations collected individually through journal writing.
• negotiate understandings of data with peers.
• read to evaluate their current understanding as compared to authoritative texts.
• Complete an assigned writing project to communicate their current understandings.
• Participate in reflection on learning through concept-mapping exercise (Keys, Hand, Prain & Collins 1999).</td><td>• Select topic of investigation
• engage students in a pre-lab investigation such as brainstorming
• Select and facilitate laboratory investigation activities
• engages students in a post investigation concept-mapping exercise as part of reflecting on learning</td></tr>
<tr><td colspan="3">Variations: Student inquiry</td></tr>
<tr><td colspan="3">Associated observable actions: Writing, Reading, Observing, Speaking, Instructor facilitates activities, Instructor facilitates dialogue</td></tr>
<tr><td colspan="3">Objective/Learning Goal: “Students learn to negotiate meaning both publicly and privately from the results of their work and to argue for their ideas by posing questions, gathering data, and generating claims based on evidence. Critical to this approach is the emphasis on language, both written and oral, through all the negotiation opportunities that are created.” (http://www.education.uiowa.edu/projects/science-writing-heuristic)</td></tr>
<tr><th colspan="3">Research outcomes</th></tr>
<tr><td>High school students enrolled in Chemistry courses using the Science Writing Heuristic demonstrated elevated test performance compared to students taught traditionally (Kingir, Geban & Gunel, 2012)</td><td colspan="2">1. There was a statistically significant mean difference between control and treatment groups when comparing Chemical Change and Mixture Achievement Test (CCMAT) pre- scores (these two groups were NOT the same). (F(1,114)=6.69, p=0.011)
2. When controlling for pre-CCMAT scores, students in the treatment group had higher post-CCMAT scores than those in the control group. (F(1,112) = 70.97, p<0.001, Cohen’s d = 1.6 (Large effect size)
3. “Implementation of the SWH approach helped low and medium-achieving students to develop conceptual understanding of chemistry concepts" [above their control group counterparts] ...The gap between low- and high-achieving students in the treatment group disappeared at the end of the study (p. 434) (Low achieving F(1,51)= 106.34, p<0.001, Cohen’s d = 2.6 (Large effect size) ; Medium achieving F (1,21) 10.48, p=0.004, Cohen’s d = 1.4 (Large effect size))</td></tr>
<tr><td>Middle school students who engage in activities associates with the science writing heuristic demonstrate elevated writing skills (Keys et al., 1999)</td><td colspan="2">1. Students writing improved from the first to the second draft and provided evidence of engagement in the cognitive processes. Themes include: Using metacognition and reflection to understand knowledge growth, Generating meaning for data in relation to specific knowledge claims, Extending, Elaborating and Enhancing Science ideas
2. Development of students’ Nature of Science understanding demonstrated between first and second writing drafts included: Collaboration and argumentation in science, Nature of evidence, the nature of scientists' work</td></tr>
<tr><td>Undergraduate science and engineering students enrolled in a general chemistry laboratory demonstrate improved understanding of general equilibrium compared to traditionally taught laboratory students (Greenbowe, Rudd & Hand, 2007)</td><td colspan="2">1. The comparison groups were statistically different based on pre-test analysis (t = 3.160, p = 0.003).
2. Using baseline knowledge as a covariate, the SWH sections demonstrated a greater ability to identify the equilibrium condition and to explain aspects of equilibrium than control group despite starting with LOWER baseline knowledge (F=4.913, df 1,49; p=0.031)</td></tr>
<tr><td>Fifth-grade students engaged in science using the SWH approach demonstrated no differences between small group and whole group treatments (Cavagnetto, Hand & Norton-Meier, 2011)</td><td colspan="2">1. No statistically significant differences in student achievement were detected between small group and whole class treatments based on the Iowa Test of Basic Science Skills and pre/post unit exams throughout the school year.</td></tr>
<tr><td colspan="3">Planning and implementation resources: http://www.education.uiowa.edu/projects/science-writing-heuristic</td></tr>
</table>

Student inquiry

Students	Instructor
• Engage individually or small groups and in whole class activities • ask questions/define problems, • plan and carry out investigations, • analyze and interpret data • construct explanations • obtain, evaluate, justify and communicate information	• Facilitate the inquiry process by: 1. helping students process information, 2. communicating with groups of learners, 3. coaching learner actions, 4. facilitating thinking, 5. modeling learning, 6. allowing for flexible use of materials

Variations: ADI, Project-based learning, Problem-based learning, Science Writing Heuristic

Associated observable actions: Reading, Writing, Observing, Speaking, Building/Manipulating, Instructor facilitates activities

Objective/Learning Goal: Students actively process information, through participation in or through modeling STEM activities with an emphasis on reasoning, problem solving, building from existing understanding, and explaining complex problems (Anderson, 2002; Spronken-Smith, 2007).

Student inquiry - Research outcomes

Undergraduate science students enrolled in Introduction to Cell and Molecular Biology who engaged in student inquiry demonstrated significant learning gains in comparison to students who were taught through traditional methods. (Luckie, Aubry, Marengo, Rivkin, Foos & Maleszewski, 2012)	1. One-stream (one 14-week investigation) lab scores on the Medial Assessment Test (MAT) $M=64.73\%$ were significantly higher that two-stream (two 7-week investigations) lab MAT scores $M=61.97\%$ ($p<0.01$); and BOTH were higher than MAT scores of students taught via traditional “cookbook” labs $M=53.84\%$ ($p<0.0001$). 2. A decade of data supports learning gains on content exams trending upward even when the amount of the content coverage decreased.
Undergraduate students enrolled in an introductory biology course for non-majors revealed a higher academic success and elevated process skills among students who participated in student inquiry on in-class assessments compared to traditionally taught students. Students in the inquiry group also demonstrated elevated scores related to their attitude toward science (Lord & Orkwiszewski, 2006).	1. Students in the inquiry treatment group performed significantly better on weekly quizzes ($t=3.78$, $p<0.05$) 2. Student Science Process Skills survey responses were statistically higher for the inquiry treatment group during second semester ($F=4.5$, $p<0.05$). First semester ($F=2.4$, n.s.) 3. Student Science Attitude Survey responses were statistically higher for treatment group during both semesters of study (Semester 1, $F=3.9$, $p<0.05$; Semester 2 $F=4.8$, $p<0.05$)
Undergraduate biology students who engaged in collaborative learning in conjunction with student inquiry demonstrated significantly greater gains in reasoning and achievement (Jensen & Lawson, 2011).	1. Inquiry students out-performed didactic students on high-level blooms taxonomy questions on the common course final exam ($F=4.15$, $p=0.04$).
Undergraduate science majors in a general chemistry course demonstrated elevated success in course using guided inquiry and cooperative learning strategies (Farrell et al., 1999)	1. Students who were taught using guided inquiry strategies in conjunction with cooperative learning demonstrated reduced DFW occurrences (from more than 20% to less than 10% combined) compared to students who took the course prior to implementation of the guided inquiry/cooperative learning techniques.
A meta-analysis of research on student inquiry in K-12 classrooms indicates increased conceptual understanding as compared to traditional teaching methods (Minner, Levy & Century, 2010)	1. In the 138 studies reviewed, 51% of the studies indicated positive impacts on student content learning and retention based on some level of inquiry engagement. 33% demonstrated mixed impact, 14% showed no impact, 2% showed negative impact.

Planning and implementation resources: Anderson, 2002; Quinn, Schweingruber & Keller, 2012; Loucks-Horsley & Olson, 2000

Studio courses

<table>
<tr><th>Students</th><th>Instructor</th></tr>
<tr><td>• Engage in individual small group and in whole class activities including
1. Group discussion
2. Problem solving
• Use studio resources (technology, whiteboards)</td><td>• Secure studio location and necessary resources
• Present content related material
• Establish protocols for group interactions
• Select problems to be solved
• Coach students during activities</td></tr>
<tr><td colspan="2">Variations: N/A</td></tr>
<tr><td colspan="2">Associated observable actions: Writing, Reading, Observing, Speaking, Building/Manipulating, Instructor explaining, Instructor facilitates activities</td></tr>
<tr><td colspan="2">Objective/Learning Goal: A combination of lecture and laboratory activities along with engagement in a research based context (physical and social) with appropriate materials will result in student learning.</td></tr>
<tr><th colspan="2">Research outcomes</th></tr>
<tr><td>Undergraduate students enrolled in introductory mechanics courses demonstrate elevated learning gains on the FCI and FMCE compared to students in traditionally taught sections over three different semesters. (Hoellwarth, Moelter & Knight, 2005)</td><td>1. Students in the studio courses during fall 1998 demonstrated elevated learning gains on the FCI above those students enrolled in the traditional lecture sections (g (traditional) = 0.39; g (studio) = 0.60).
2. Students enrolled in the studio courses during winter 1999 demonstrated elevated learning gains on the FMCE above those students enrolled in the traditional lecture sections (g (traditional) = 0.23; g(studio) = 0.65).
3. Students enrolled in the studio courses during spring 2000 demonstrated elevated learning gains on the FMCE above those students enrolled in the traditional lecture sections (g (traditional) = 0.20; g(studio) = 0.66)</td></tr>
<tr><td>Undergraduate students in calculus-based introductory physics studio course have elevated conceptual understandings and attitudes about physics compared to students taught traditionally (Biechner et al., 2007)</td><td>1. Students in the studio sections demonstrated greater improvement in conceptual understanding based on FCI compared to traditional lecture/lab configurations.
a) Traditional Lecture/Lab (regular) h= .0204
b) Traditional Lecture/Lab (honors) h= 0.176
c) Studio course h = 0.483 (more than double regular and honors traditional sections)</td></tr>
<tr><td>Undergraduate students enrolled in an introductory physics studio course that incorporates interactive demonstrations and peer instruction demonstrated elevated learning gains compared to students who were taught through traditional lecture/lab methods (Sorenson, Churukian, Maleki & Zollman, 2006)</td><td>1. Compared to the traditional method, students in the studio courses that used demos were nearly 2 ½ times higher on both Force Concept Inventory, (Fractional g~0.40)</td></tr>
<tr><td>Undergraduate student enrolled in introductory mechanics, taught in the studio format demonstrated learning gains on the Force and Motion Conceptual Evaluation (FMCE) regardless of instructor variables (Hoellworth & Moelter, 2011)</td><td>1. Average normalized learning gains increased across all sections, regardless of instructor variables (g=0.59).</td></tr>
<tr><td colspan="2">Planning and implementation resources: Beichner et al., (2007)</td></tr>
</table>

Think/Write-Pair-Share

Students	Instructor
• Engage individually, in small groups and in whole class activities • Answer questions individually • Discuss responses to questions with peers • Participate in whole-class discussion regarding individual and shared ideas about questions	• Ask questions • Provide time for students to respond to questions • Facilitate class discussion
Variations: Peer Instruction	
Associated observable actions: Writing, Speaking, Instructor Waiting, Instructor facilitates dialogue	
Objective/Learning Goal: Use the dispersed understanding among students to support the development of individual understanding of all students through sharing of ideas through the iterative process of questioning and dialogue.	
Research outcomes	
Undergraduate students enrolled in organic chemistry II course engaging in cooperative learning groups including the use of the Think/Write-pair-share strategy demonstrate elevated retention (Hagen, 2000).	1. Results indicate that the cooperative learning intervention demonstrated a 20% increase in the retention of students (DFW) over previous semesters. 2. Implementation of the cooperative learning strategies demonstrate no decrease in performance on an American Chemical Society Standardize Final Exam
Undergraduate students enrolled in an introductory molecular and cell biology course focused on the development an application quantitative skills using learner-centered techniques (including think-pair-share) demonstrated elevated learning gains about students in traditionally taught sections (Hester, Buxner, Elfring & Nagy, 2013)	1. Results on the outcome assessment indicate that students in the experimental section using learner-centered techniques demonstrated higher learning gains on the quantitative "BioMath" questions compared to the students in control sections of the course. (36% gain in the experimental group compared to highest control group section gain = 19%, p=0.020) 2. Results on the outcome assessment indicate that students in the experimental and control sections performed equally well on questions relating specifically to biology content. "...integrating quantitative skill application alongside biology concepts, we can increase students' ability to use mathematics in biological contexts without harming their understanding of the biology concepts (p. 62)
Undergraduate students enrolled in sections of (1) mechanics and (2) electricity & magnetism (E&M) courses that incorporating the use of interactive learning strategies (including think-pair-share) demonstrated improved physics learning compared to students in sections of these same courses that did not implement interactive learning strategies based on post FCI and CSEM scores (Rudolph, Lamine, Joyce, Vignolles & Consiglio, 2014).	1. Multiple liner regression modeling including (1) level of course interactivity, (2) first semester mechanics exam score and (3) FCI pre-score on Newton's 3rd Law questions as independent variables demonstrated the strongest influence on Mechanics students FCI gain on Newton's 3rd Law questions (R2 = 0.269). 2. Multiple liner regression modeling including (1) CSEM pre score, (2) level of course interactivity as independent variables demonstrated the strongest influence on Electricity & Magnetism students post CSEM gain (R2 = 0.208). 3. Multiple liner regression modeling including (1) first semester Mechanics final exam, (2) hours of study per week and (3) level of course interactivity as independent variables demonstrated the strongest influence on Mechanics students final course conceptual exam problems (R2 = 0.244) 4. Multiple liner regression modeling including (1) Parents level of education, (2) first year overall grade, (3) hours of study per week and (4) level of course interactivity as independent variables demonstrated the strongest influence on Electricity & Magnetism students common final exam problems (R2=0.228)
Planning and implementation resources: Think-pair-share http://serc.carleton.edu/introgeo/interactive/tpshare.html	

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