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Middle School Matters Field Guide:
Research-Based Principles, Practices, and Tools

Chapter 1: Research-Based Instruction
Cognitive Science and Advanced Reasoning

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Cognitive Science and Advanced Reasoning

Advanced reasoning and critical thinking skills typically undergo rapid expansion during adolescence and are refined in complexity and maturity throughout adulthood. Adolescence is an optimal, yet vulnerable, stage of cognitive development of higher-order thinking, reasoning, and problem solving. American adolescents are falling behind students in other developed countries in acquiring crucial advanced reasoning skills. The middle grades are referred to as a transitional black hole in education: The child moves out of the supportive and engaging learning environment of elementary school and into an environment with increased personal choices, with greater risk for failure, dropping out, and developing some form of addictive behavior.

Teachers can implement cognitive and reasoning principles to promote learning across all content areas in the middle grades. The cognitive principles of learning are based on reports from (a) the National Academy of Sciences,[1] (b) a practice guide for teachers by the Institute of Education Sciences in the U.S. Department of Education on *Organizing Instruction and Study to Improve Student Learning*,[2] (c) and a joint initiative between the Association of Psychological Sciences and the American Psychological Association on Lifelong Learning at Work and at Home.[3] The recommendations here reflect the wisdom of these reports, which are based on scientific evidence, rather than being consensus opinions of experts. What follows are seven key principles and related practices from this research.

Principle 1:

Distribute presentation, practice, and testing over time.

It is more effective to distribute the presentation of materials, practice, and tests over time than to block the learning experiences in a short time span.[4, 5, 6, 7, 8, 9] Teachers can promote delayed re-exposure to the material through homework assignments, in-class reviews, quizzes, and other instructional exercises. Tests or challenges can help promote distributed learning experiences and slow forgetting.[6, 10,11,12, 13, 14]

Practice 1: *Present material at different points in time in different contexts.*

Teachers can present the same or similar material at different times throughout a course. Presenting the same idea in different contexts is particularly helpful in allowing students to understand it from multiple perspectives.

Practice 2: *Test or challenge students frequently.*

Teachers should give frequent tests, quizzes, or assignments to force the student to regularly focus on the material and to distribute the practice of these skills to improve learning and retention. Instead of always labeling these "tests," teachers can call them "challenges" to foster motivation.

Practice 3: *Use cumulative tests.*

Teachers give cumulative tests because this practice encourages students to restudy earlier course material and thereby distribute their practice.[2] Students benefit more from repeated testing when they expect a cumulative final exam than when they do not expect a final exam.[15]

PRACTICE 1 EXAMPLE APPLICATION: Presenting Material Across Multiple Contexts

Teachers could present many contexts for students to learn about the Great Irish Potato Famine that last from 1845 to 1852:

- Learning about the history of Ireland
- Learning about fungus infections in crops
- Learning how a problem in one country can influence other countries
- Learning how a disease spreads in a population over time, including an exponential formula

PRACTICE 2 EXAMPLE APPLICATION: Game Playing

Educational games can motivate students while also testing knowledge of facts or difficult concepts. A well-designed game can both challenge students and frequently expose them to material.

It is important that the game design be built on principles of learning science. Most commercial games are not designed for learning but rather for entertainment. Teachers should examine evidence provided by game designers on the impact of the game on learning. If they are uncertain about the quality of the data, they should solicit advice from researchers at reputable universities and organizations and from school districts.

Principle 2:

Ground ideas in active, engaging experiences.

Concepts need to be grounded in activities that require students to actively engage in experience that relates to a real-life application of the content.[16, 17, 18, 19] Learners benefit from visualizing a picture of the concept, manipulating its parts and aspects, and observing how it functions over time, particularly in real-life contexts. Experiential learning is important when there is a need for precision of ideas and communication, particularly when content is first introduced, and it is beneficial to integrate experiential representations with more abstract representations.[20, 21, 22] Stories have concrete characters, objects, spatial layouts, and activities that bear some similarity to everyday experiences so they can be used to facilitate understanding and memory.[18, 20, 21, 22]

Practice 1: *Present visual depictions of core concepts and ideas.*

Teachers should present pictures, diagrams, graphs, and other visual depictions of the core concepts in the curriculum. Students have trouble learning abstract notions if they are not grounded in concrete representations. Whenever an abstract notion is presented, it needs to be accompanied by a supporting visual image.

Practice 2: *Encourage students to manipulate aspects of core concepts.*

Students acquire an embodied representation of core concepts when they can manipulate parts and entities and observe the consequences. Whenever a student performs an action accurately, it is likely that the student has mastered the concept. Mastery is entirely uncertain in the absence of student action.[22]

Practice 3: *Capture content in stories.*

Teachers should weave essential concepts into stories with concrete agents, spatial settings, objects, parts of objects, and organized action sequences. Stories can bring abstract content to life.[23, 24, 25] For example, telling a good story is a better way to help students understand history than asking them to memorize a list of dates, locations, and events. Science teachers can tell stories of how researchers discovered new theories or put a theory into practice.

PRACTICE 2 EXAMPLE APPLICATION: Hands-On Student Activities

Science labs provide an excellent opportunity for students to get a hands-on experience with science laws and concepts. Dropping objects of different weights or mass from a building to illustrate Newton's laws is an obvious example of how hands-on experience can teach an important concept.

Another example in mathematics is the activity of graphing data that students collect, such as the number of hours spent studying over time or the amount of algae in water samples in different locations in a city.

Computer environments with interactive simulation are an excellent way of learning about complex systems. Students can manipulate parameters and see what happens in simulations, and they can learn about difficult concepts, such as causal propagation, trade-offs between variables, and managing limited resources.

Principle 3:

Provide timely, qualitative feedback on students' learning activities.

Feedback helps learners tune their knowledge representations, skills, and strategies to include relevant and useful content.[26, 27, 28, 29, 30, 31, 32] The feedback can be supplied by people, computers, or constraints of the world. The feedback may identify and correct errors and misconceptions (errors of commission) or help fill missing information (errors of omission). The optimal timing of the feedback varies for different tasks. Immediate feedback supports correct information, prevents elaboration of incorrect information, and helps students acquire skills of self-regulated learning; however, it does have the potential to interrupt organized activities.[27, 29] Teachers should provide feedback on complex material that qualitatively explains correct and incorrect information, as opposed to merely flagging that an answer is incorrect or giving the student an overall score.[27, 28, 29, 30] A large amount of negative feedback may cause students to disengage because of feelings of low self-esteem and self-efficacy.

Practice 1: *Give students timely and accurate feedback on their performance.*

Teachers should provide accurate, timely feedback about students' ideas, answers, test items, solutions, writing, performances, and other tasks. Computer programs can provide immediate, accurate feedback to students on the answers, solutions, and essays they generate, whereas it may take a few minutes to a few weeks to receive answers from teachers.[30] However, computer-generated feedback may be less meaningful to students because it is less personal.

Practice 2: *Include qualitative explanations in feedback for complex material.*

Teachers should explain why answers are correct or incorrect rather than merely giving numerical scores or positive/negative feedback. Qualitative explanations state why an answer is right or wrong. The characteristics of a good explanation include:

- Identifying the elements in an answer that are problematic or particularly good (e.g., This statement is false.)
- Providing steps in a logical way or giving causal justification for the feedback (e.g., This word is incorrect because ___.)
- Contrasting a faulty piece of information with a correct piece of information (e.g., The numbers should decrease rather than increase because ___.)

Practice 3: *Adjust negative feedback to what the student can emotionally handle.*

Teachers should not provide students with a large amount of negative feedback, which can lead students to tune out. This can be accomplished by assigning easier tasks or by withholding feedback about unimportant errors.

PRINCIPLE 3 EXAMPLE APPLICATION: Providing Just Enough Challenge

Problems in a mathematics text are often scaled on difficulty, such as easy, medium, or difficult.

A student might get discouraged when assigned a large number of difficult problems that he or she answers incorrectly, resulting in negative feedback. To prevent boredom and discouragement, the teacher might assign an easier problem but say to the student, “Try this problem. It may be a challenge, but I bet you can handle it!” When the student readily solves the problem and receives positive feedback, his or her confidence, self-esteem, and self-efficacy increase.

Other students might get bored when not challenged. These students need to be assigned more difficult problems to work on.

There is a *zone of challenge* for most students according to the Goldilocks principle,[29] where problems or texts are not too easy, not too difficult, but just right. Computers can calibrate this level by tracking the performance of each student and scaling materials based on difficulty.

Principle 4:

Encourage the learner to generate content.

Students should be encouraged to actively generate language, content, solutions to problems, and reasoning rather than passively processing the new material.[33,34, 35, 36,37] It is not surprising that tutors learn more than tutees in peer tutoring because tutors are often more engaged with the material, while tutees are passive recipients of it.[38, 39, 40] Free recall or essay tests that provide minimal cues often produce better learning than recognition tests and multiple choice tests that require only that a student recognize correct answers. Outlining, integrating, and synthesizing information produces better learning than rereading materials or other more passive strategies. *Writing and Writing Interventions* describes ways to improve students' writing skills and support the active generation of information. Some computer programs provide immediate feedback on writing; however, it may not be as effective as a teacher's feedback when writing needs to be precise and make subtle discriminations.

Practice 1: *Assign tasks that require writing or other forms of generation.*

Teachers should assign tasks that require students to generate ideas, write, perform actions, solve problems, and reason. Students should not merely be passive recipients of information.[41]

Practice 2: *Arrange for students to teach other students.*

Teachers should set up peer teaching or tutoring that requires the student teacher/tutor to actively generate content. All students should have the opportunity to serve in the role of a teacher/tutor.[40, 42]

PRACTICE 2 EXAMPLE APPLICATION: Students Helping Students Activities

Teachers can use different ways to encourage students to tutor their peers and thereby benefit from active generation of information:

1. Pair students and have them take turns teaching topics to each other.

2. Present a difficult problem to the class and ask students to raise their hand as soon as they solve it. The first student to raise his or her hand presents the solution to the rest of the class.

3. Use the jigsaw method, whereby students are divided into groups and are asked to solve a problem. Each group member is given a particular piece of the solution that the other group members need to learn about. In this activity, students teach one another information in service of a concrete goal.

4. Ask groups of students to write justifications for their positions, and then have each student vote for a particular position on a controversial issue (e.g., how to solve world overpopulation, how to minimize global warming).

Principle 5:

Select challenging tasks that require explanations, reasoning, and problem solving.

Learning is facilitated when students need to construct explanations during the course of grasping difficult concepts or solving problems through reasoning.[35, 43, 44, 45, 46] Explanations consist of causal analyses of events, logical justifications of claims, and rationales for actions. Explanations are elicited by deep questions, such as *why, how, what-if* and *what-if-not*, as opposed to shallow questions that require the learner to simply fill in missing words, such as *who, what, where,* and *when*.[43] Training students to ask deep questions facilitates comprehension of material from text, classroom lectures, and electronic media.[47, 48] One method of stimulating explanations, reasoning, and deep questions is to present challenges, obstacles to goals, contradictions, scenario breakdowns, and difficult decisions that place the learner in cognitive disequilibrium.[48] Such "desirable difficulties" slow down initial learning, but promote long-term retention and transfer.[48, 49]

Practice 1: *Assign tasks that require explanation-based reasoning.*

Teachers should assign challenging tasks that require the students to explain their reasoning. The *Reading and Reading Interventions* section of this document provides different techniques to promote explanation-based reasoning. Types of explanation-based reasoning include:

- **Cause-effect:** Understanding how one action or event can cause another.
- **Problem-solution:** Defining the problem (or dilemma), explaining potential causes or background context of importance, identifying all possible solutions, and selecting an optimal solution based on context, resources, etc.
- **Claim-evidence:** Making a claim, a potential answer to a question or a problem, using evidence (data or other evidence) to support it, and providing an oral or written justification of how the evidence supports the claim.
- **Claims-logical conclusion:** Reviewing claims and evidence at detailed levels, leading to claim justification; then investigating processes to determine whether sufficient evidence exists at the aggregate level to support each particular claim or group of claims and to draw a logical conclusion.

Practice 2: *Ask students deep questions and train students to ask deep questions.*

Teachers ask deep questions, such as *why, how, what-if, what-if-not,* and *so-what*, rather than shallow questions such as *who, what, when,* and *where*. These teacher questions encourage the construction of explanations. If encouraged to do so, students will ask deeper questions and achieve deeper standards of comprehension. What follows is an illustration of using a question taxonomy.[48, 49]

Practice 3: *Present desirable difficulties that place the student in cognitive disequilibrium.*

Teachers should present challenges that involve obstacles to goals, contradictions, system breakdowns, trade-offs, anomalies, and other types of desirable difficulties. The resulting cognitive disequilibrium will stimulate deep questions, explanations, reasoning, and problem solving.

PRACTICE 2 EXAMPLE APPLICATION: Using a Question Taxonomy

Students can be explicitly instructed in the types of questions that lead to deeper standards of comprehension. Questions vary in depth and also how much information the student needs to provide in an answer:

1. **Verification.** Is X true or false? Did an event occur? Does a state exist?
2. **Disjunctive**. Is X, Y, or Z the case?
3. **Concept completion**. Who? What? When? Where?
4. **Example**. What is an example or instance of a category?
5. **Feature specification**. What qualitative properties does entity X have?
6. **Quantification**. What is the value of a quantitative variable? How much? How many?
7. **Definition**. What does X mean?
8. **Comparison.** How is X similar to Y? How is X different from Y?
9. **Interpretation**. What concept or claim can be inferred from a pattern of data?
10. **Causal antecedent.** What state or event causally led to an event or state? Why did an event occur? Why does a state exist? How did an event occur? How did a state come to exist?
11. **Causal consequence**. What are the consequences of an event or state? What if X occurred? What if X did not occur?
12. **Goal orientation.** What are the motives or goals behind an agent's action? Why did an agent do some action?
13. **Instrumental/procedural**. What plan or instrument allows an agent to accomplish a goal? How did an agent do some action?
14. **Enablement**. What object or resource allows an agent to accomplish a goal?
15. **Expectation.** Why didn't an expected event occur? Why doesn't some expected state exist?
16. **Judgmental**. What value does the answerer place on an idea or advice? What do you think of X? How would you rate X?

PRACTICE 3 EXAMPLE APPLICATION: Using Counterintuitive Facts to Stimulate Student Thinking

Students are often fascinated, confused, or sometimes even disturbed by facts that clash with their knowledge or beliefs. Examples of counterintuitive facts are that whales are mammals rather than fish, that violent crimes are decreasing in the United States, and that setting fires in forests sometimes helps the ecology.

Cognitive disequilibrium is experienced, and students try to restore clarity (equilibrium). They want to know how and why and to receive explanations. It is good to challenge students with counterintuitive facts, particularly ones that illustrate important material. Teachers are encouraged to:

- Identify facts that conflict with students' beliefs.
- Ask students to defend positions that are different from what they believe (as is done in formal debates).
- Ask students to explain the fact or why an event occurred.
- Ask students to find counterintuitive facts in different media and to verify that the facts are accurate by accessing reliable sources.

Principle 6:

Design curricula, tasks, and tests in different contexts, media, and practical applications.

Knowledge, skills, and strategies acquired across multiple and varied contexts are better generalized and applied flexibly across a range of tasks and situations.[50, 51, 52, 53, 54] Information is encoded and better remembered when it is delivered in multiple modes (such as verbal and pictorial), sensory modalities (such as auditory and visual), or media (such as computers and lectures) than when delivered in only a single mode, modality, or medium.[52, 53, 54, 55] Cognitive flexibility increases when there are multiple viewpoints and perspectives about a phenomenon[55, 56, 57] because multiple layers of knowledge interconnect facts, rules, skills, procedures, plans, and deep conceptual principles. Cognitive complexity and multiple viewpoints are helpful when learners face transfer tasks that have unique complexities that cannot be anticipated proactively. There are benefits in connecting and interweaving both abstract and concrete representations of problems in the domains of mathematics, science, and technology. [20, 57, 58, 59] These research- and evidence-based practices are described as follows.

Practice 1: *Vary the context and applications of tasks and problems.*

Teachers should assign tasks and problems in different contexts and practical applications. This variability gives students opportunities to apply knowledge and skills to new situations.[54]

Practice 2: *Present learning materials through multiple media.*

Teachers can combine graphics with text, graphics with spoken descriptions, speech sounds with printed words, and other combinations of modalities to vary how they present materials. Graphic depictions with spoken descriptions are particularly effective for subject matters in science and technology.

Practice 3: *Encourage students to construct ideas from multiple points of view and different perspectives.*

Teachers should encourage students to assess claims from different points of view, using different empirical evidence and including both pros and cons. A singular monolithic mindset does not support cognitive flexibility and variability in representations. An example of how to encourage students to construct ideas from multiple viewpoints is to have them justify a position that is opposite to what they believe in a debate.

PRACTICE 3 EXAMPLE APPLICATION: Multiple Viewpoints for Examining Chemical Reactions

In chemistry, students are often fascinated by the role of catalysts in chemical reactions. Students can explore the dynamics of a particular chemical reaction from multiple viewpoints, such as:

- An animation with the molecules before, during, and after the presence of the catalyst
- A graph that plots the presence of different chemicals as functions of time
- A mathematical formula that captures a diffusion process over time
- A chemist pouring chemicals together and presenting the catalyst

Principle 7:

Promote self-regulated learning.

Children and adults have very limited metacognition[46, 60, 61] (i.e., knowledge or judgments of memory, comprehension, learning, planning, problem solving, and decision processes). In fact, most adults are not good at calibrating their own comprehension of text and at planning, selecting, monitoring, and evaluating their strategies of self-regulated learning.[46, 60, 61,62] Therefore, teachers need to provide explicit training, modeling, and guided practice before students can acquire adequate strategies of comprehension, critical thinking, meta-comprehension, and self-regulated learning. These skills can be acquired and applied in a learning environment that allows students to have knowledge and control over their own mastery of knowledge, skills, and strategies.[46, 63] These research- and evidence-based practices are described in more detail as follows.

Practice 1: *Train students on metacognition and strategies for self-regulated learning.*

Explicit instruction is often needed for acquiring abstract cognitive content and strategies. Teachers should use well-designed, explicit instruction that is structured, scaffolded, and intensive in different contexts and practical applications.

Practice 2: *Provide students with an open learning environment.*

Open learning environments allow students to take responsibility for their learning by selecting resources to learn more about a topic, gathering and manipulating data to understand the problem, and working with peers. Teachers should provide individual students with fine-grained feedback about their mastery of different aspects of the learning. Students should then use the feedback as a guide to select and work on mastering different knowledge, skills, and strategies. By taking the initiative to fill in gaps in learning, students acquire self-regulated learning skills.

PRACTICE 1 EXAMPLE APPLICATION: Teaching Students Metacognitive and Self-Regulating Learning Strategies

There are many commercial books and programs on how to study and manage time, and these are often helpful. Researchers have also identified a number of metacognitive and self-regulated learning strategies that help with time management. These strategies guide students on setting goals, formulating plans to achieve goals, monitoring progress on goals, revising goals after receiving feedback, applying relevant learning strategies, and reflecting on learning activities to improve the goal-setting process. A list of these strategies, along with definitions, is an important start in helping students manage their own time; however, application of the strategies takes considerable time and feedback.

Students are generally not very good at comprehension calibration, the ability to evaluate how well they comprehend material. The common problem is that low comprehenders believe they understand material when they do not. Fast ways for them to evaluate their level of understanding are asking them to paraphrase, summarize, or think aloud about the text's meaning. Poor learners quickly discover that they do not understand because they have trouble generating content in the verbal protocols. Therefore, requiring students to give feedback about content allows them to learn how to accurately calibrate their own comprehension of material.

Conclusion

The principles and practices informed by research in this section can be applied to all content areas in middle grades education. For example, physical education teachers can use these strategies to help students retain information, such as the rules of sports and different sports strategies. More importantly, these principles and practices can provide students with study skills they can use with the more rigorous coursework of high school, where they may experience final exams for the first time. Therefore, the more these principles and practices can be adopted and implemented school wide, the more proficient students will become in their use. Middle grades students will then have the skills they need to succeed in high school, postsecondary education, and future careers.

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