REVIEW OF

Research on Teaching Problem Solving

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The following reference document provides a brief review of academic research and relevant reports on best practices for teaching and assessing problem-solving skills. The purpose of this research was to support the development of the Skills for Success Practitioner Competency Framework and was part of a series of research reviews on best practices for teaching each of the Skills for Success. This summary provides an overview of evidence-based teaching methods in the area of problem solving, key considerations when applying these practices, and a list of resources for further consideration.

METHODOLOGY

Several search queries were conducted on Google and Google Scholar using combinations of the following keywords: problem-solving, critical thinking, teaching, teaching approaches, teaching strategies, problem-based learning, inquiry-based learning, project-based learning, outcomes, evaluation, adult, workplace.

STATE OF THE LITERATURE

Given the limited information on problem solving in adult and workplace-specific contexts, these keywords were dropped in subsequent searches to broaden the scope, allowing for a more fulsome review of the literature.

The review found that there is limited research on the effectiveness of different problem-solving teaching strategies where *problem solving* is the specific domain of knowledge. There is, however, considerably more literature on various pedagogical approaches that have implications for improving learners' problem-solving skills such as *critical thinking* skills and teaching methods such as problem-based learning that provide instruction in various content areas through a problem-based approach.

Given the interconnectedness of *problem solving* and *critical thinking*, the latter was also included as a keyword in the literature search to ensure relevant findings from this literature were captured. Likewise, the literature review was broadened to include a range of problem or inquiry-oriented teaching approaches that aim to improve learners' understanding of various content areas while developing problem solving and critical thinking skills.

CONCEPTS

Problem Solving

The new Skills for Success Framework (SRDC, 2021) defines problem solving and the problem-solving process as follows:

DEFINITION:

"Your ability to identify, analyze, propose solutions, and make decisions to address issues; monitor success; and learn from the experience. For example, at work we use this skill to make hiring decisions, select courses of action, and troubleshoot technical failures."

CONSTRUCTS (SRDC, 2021):

1. Identify the issue to be addressed
2. Gather information to help address the issue

3. Analyze the issue
4. evelop multiple routes of action
5. Address the issue
6. Evaluate the effectiveness of the solution or decision

Critical thinking

Pascarella and Terenzini (2005, as cited in Tiruneh et al. 2014) summarize various critical thinking definitions as an individual's ability to do some or all of the following:

- Identify central issues and assumptions in an argument;
- Recognize important relationships;
- Make correct inferences from data;
- Deduce conclusions from information or data provided;
- Interpret whether conclusions are warranted based on given data;
- Evaluate evidence or authority;
- Make self-corrections; and
- Solve problems.

The Skills for Success Framework (SRDC, 2021) states that critical thinking is key to problem-solving processes, which involve "think[ing] critically about the issue using the information gathered" and "[u]sing thinking strategies to choose the best course of action."

There is ongoing debate within the field regarding how problem solving and critical thinking skills should be taught. Some researchers perceive critical thinking as a distinct knowledge domain that should be taught separately from other content areas, whereas others argue that these skills should be embedded within the teaching of core subject or content areas, such as math, science, social studies, etc. (Ennis, 1989; Mayer, 1992; McPeck, 1990; Nickerson, 1988; as cited in Tiruneh et al. 2014).

APPROACHES TO TEACHING PROBLEM SOLVING & CRITICAL THINKING SKILLS

Factors and considerations in the teaching of problem solving and critical thinking

Instructional techniques: Various instructional techniques show promise in improving critical thinking and/or problem-solving skills, such as:

- Teaching existing problem-solving models, such as IDEALS (Identify, Define, Enumerate, Analyze, List, Self-Correct), that enable learners to understand and follow processes to effectively solve problems (Facione, 2007, as cited in Snyder & Snyder, 2008);
- Discussion, brainstorming, teamwork/ collaboration, self-reflection, flipped classroom, and blended learning approaches (Baum, 2013; Prince, 2004; as cited in McCormack, 2015);
- Problem-based, project-based, and inquiry-based learning instructional approaches (Friesen & Scott, 2013);
- Assessment approaches that explain correct answers and model the critical thinking process (Brown & Kelly, 1986; Duplass & Ziedler, 2002; Schafersman, 1991; as cited in Snyder & Snyder, 2008);
- Teaching experiential techniques to solve problems - learning, discovering, and understanding via experimentation (Nokes, Dole, & Hacker, 2007; as cited in Snyder & Snyder, 2008);
- Questioning techniques – asking the right questions to stimulate critical thinking skills (Haynes & Bailey, 2003; as cited in Snyder & Snyder, 2008);
- Having students compare each other's work and thus critique alternative problem-solving strategies (Evans & Swan, 2014);

- Engaging learners with a problem early in the learning process has proved more effective in improving understanding than approaches where the solution is provided first and then students practice solving similar problems (DeCaro and Rittle-Johnson, 2012; Loehr, Fyfe, and Rittle-Johnson, 2014; as cited in Government of Ontario, 2020).[1]

Student involvement & motivation: Studies show that active engagement of learners in the problem-solving process is a critical element of success. This may entail project-based or collaborative activities that encourage critical thinking (Snyder & Snyder, 2008).

- Students should be regarded as users of information rather than receivers of information (Snyder & Snyder, 2008).
- Newer models of instruction (e.g., problem and project-based learning) are better at engaging and motivating students than traditional/lecture-based models, and the learning process should be active rather than passive (McCormick, 2015; Lai, 2011).
- There is a statistical relationship between student motivation and critical thinking skills. Researchers hypothesize that emphasis on critical thinking skills in the classroom may affect student motivation (Rugutt & Chemosit, 2009, as cited in McCormick, 2015).

Learning styles: Learners often have different learning styles; however, the findings on the relationship between learning styles and problem-solving ability are mixed. Further research is necessary to determine which teaching methods are most effective for improving critical thinking skills when centered on students' learning styles (McCormick, 2015).

Teaching problem solving to adults in vocational/technical colleges

Jozwiak (2004) conducted a broad review on various problem-solving models and interviewed experts in the field who taught adults at vocational and technical colleges. The following summarizes their recommendations on the effective teaching of problem solving.

- Teachers are responsible for exposing adult learners to structured methods of approaching problems, which include:
  1. Basic problem-solving concepts;
  2. Key terminology; and
  3. Methodology.
- Teachers should develop an appreciation for why structured methods should be used when approaching problems.
  - For instance, underscoring the necessity of taking extra time to do detailed groundwork and analysis in order to pursue a thorough approach.
- Pedagogy should include:
  - Providing a short refresher on problem-solving concepts before the selected activity;
  - Presenting a novel problem with one or more unknowns that can be solved;
  - Guiding without giving the solution;
  - Providing sufficient time to solve;
  - Involve a post-mortem at the end as a reflection on the whole process.

[1] The following resource from the Government of Ontario provides a detailed guide on how to effectively teach problem-solving. The resource is written to inform mathematical instruction; however, the strategies could readily be generalized to other contexts: High Impact Instructional Practices in Mathematics. https://www.dcp.edu.gov.on.ca/resources/en/subjects/mathematics/high-impact-instructional-practices-in-mathematics-resource-and-supports

- Overall, teaching or problem-solving instruction should involve:
  - More open-ended problems / open-ended activities;
  - Projects;
  - Other instructional activities that force students to use problem-solving skills;
  - It is imperative that students realize that they are not bound to using only one method.

The various problem-solving methods outlined in Jozwiak's (2004) work aligns well with the problem-solving construct outlined in the Skills for Success Framework (SRDC, 2021), and has the following implications for teaching.

1. **Problem definition:** Teachers should begin by presenting a problem that has one or more unknowns and allow learners to develop a "problem statement". Learners need to develop a clear picture of the problem. A clear definition also allows the learner to know precisely when they solve the problem.
2. **Data collection and organization:** Learners must be shown how to gather useful information and how to effectively organize it to help solve the problem.
3. **Brainstorming:** Teachers should provide instruction and practice in brainstorming. This collaborative process is often a crucial element in real-world settings when pursuing the solution to a problem.
4. **Reflection:** Instruction must emphasize the need to follow-up and reflect on the entire process, which should involve documenting so that students can solve similar problems in the future more quickly.
5. **Document:** a) the problem, b) the process involved in solving the problem, and c) the solution.

Teaching critical thinking (CT): comparing instructional approaches & teaching strategies

Tiruneh et al. (2014) conducted the most systematic review on the effectiveness of direct and implicit teaching strategies for improving CT skills of students in higher education. The authors caution that there are limitations to the conclusions drawn from the research due to the limited number of studies focused on explicit instruction and the diversity of assessments used to measure CT skill improvement.

The **four instructional approaches** involved in their review include:

- **General:** CT is taught separately or independently from the presentation of the content of existing subject matter (e.g., science);
- **Infusion:** CT is integrated into the instruction of standard subject matter (e.g., science) and the general principles of CT are made explicit to learners. Learners are encouraged to acquire and explicitly practice CT skills through structured subject matter instruction;
- **Immersion:** CT principles and procedures are not made explicit to students, assuming that learners will acquire the thinking skills as a consequence of engaging with the subject matter;
- **Mixed:** The mixed approach combines the general approach with ether infusion or immersion. There is typically a separate course focused on the general principles of CT, but students are also involved in subject-specific CT instruction where the CT objectives are either explicit or implicit.

Problem-Based Learning | Inquiry-Based Learning | Project-Based Learning

To meet the demands of a changing labour market, various competency and skills frameworks were developed that emphasize new skills, such as soft skills, problem solving, collaboration, etc. These methodologies aim to better equip students with these skills, such as problem, inquiry, and project-based models.

These models have much in common, and there are varying definitions of these approaches and considerable overlap between them. Overall, problem-based, inquiry-based and project-based learning put an emphasis on actively engaging learners in the discovery process to solve problems and acquire knowledge in a manner more akin to real world contexts. These approaches contrast starkly with the traditional, lecture-based approach to teaching, where teachers act as the knowledge transmitters and students as information receivers, thus acquiring knowledge in a more passive manner (Friesen & Scott, 2013).

The University of Texas Arlington (2021) describes key features of inquiry-based learning, which are similar to problem-based and project-based approaches:

- **Process focused:** When students solve problems themselves, they internalize conceptual processes. Inquiry-based teaching prioritizes process over product;
- **Investigation:** The teacher may pose a problem derived from the class content or students' questions. The students then investigate the issue to find an answer;
- **Group learning:** Students may work in pairs or in small groups when exploring a problem. Students assist one another throughout the learning process, which enables them to share and build upon ideas as well as articulate how they arrived at a solution;
- **Discussion monitoring:** As the students work together, the teacher can move from group to group, listening to their discussions. Teachers may ask questions to gauge students' understanding and correct any misconceptions;
- **Real-life application:** Students solve problems that have a meaningful life application. For example, a teacher may present a multiplication problem as an interesting story: "Brittany has 2 bags of candy. Each bag has 4 candies inside. How many candies does Brittany have altogether?"

Effectiveness of Inquiry and Problem-Based Teaching Approaches

Students instructed through problem-based learning approaches performed as well or better than their lecture-based counterparts across most studies that were included in two large-scale meta-analyses, which involved various disciplines (primarily post-secondary). It is worth noting that a limitation of meta-analyses is the potential of the under-reporting of non-significant or negative findings (Walker & Leary, 2009; Dochy et al., 2003).

Overall, inquiry-based teaching approaches appear to have a positive impact on students' skills. In particular, these models have been shown to improve problem-solving, reasoning skills, and the generation of accurate hypotheses and coherent explanations. However, some studies have shown that they are less effective than traditional models in acquiring content knowledge (Friesen & Scott, 2013).

Of the various inquiry-based approaches to learning, the minimally guided pure discovery approach tends to be ineffective (Kirschner et al., 2006). Hence, structured guidance is a necessary component of these new models of teaching to ensure effective outcomes (Friesen & Scott, 2013).

Inquiry-based approaches to learning can be maximized with the use of the following approaches.

- **Scaffolding:** Defined as: "Bracketing out elements of a task initially beyond the learner's capability in a way that allows the learner to concentrate upon and complete only those elements that are within their range

of competence" (Simons & Klein, 2006, as cited in Friesen & Scott, 2013).

- **Formative Assessment:** This form of assessment has shown the largest learning gains compared to all other educational interventions (Hattie, 2009).
- **Powerful, critical, and essential questions:** Inquiry projects should involve driving questions that make clear connections between the activities students are involved in and the underlying conceptual knowledge that one hopes to foster (Friesen & Scott, 2013).

ASSESSMENT OF PROBLEM SOLVING

Various assessments for problem solving were considered as part of the research in developing the Skills for Success Framework (SRDC, 2021), although there is a lack of consensus on which are the most effective. The following summarizes key points with regard to the assessment of problem-solving skills.

There are a few examples of objectively scored or rigorously developed assessments for problem solving (e.g., PIAAC's Problem Solving in Technology-Rich Environments assessment, and PISA's Collaborative Problem-Solving assessment). These assessments can be lengthy and burdensome. For instance, completion of the literacy and numeracy sections of PIAAC frequently to take 40-50 minutes (OECD, 2019). Given the challenges in objectively assessing problem-solving skills, there is a reliance on self-report assessments.

The existence of some objectively scored assessments provide evidence that it is feasible to develop rigorous tests to measure problem solving.

Instructors can consider various forms of assessments, such as task-based assessments scored by trained assessors, or situational judgement tests. These tests may be subject to limitations, such as evaluator bias and low inter-rater reliability. Consequently, more research and testing are required to determine the most effective means to assess problem solving.

Striking a balance between rigor and usability is an important consideration in the development of assessments for problem solving.

CONSIDERATIONS FOR TEACHING PROBLEM-SOLVING & CRITICAL THINKING SKILLS

Jozwiak (2004) outlines three key areas that pose barriers to teaching and assessing problem-solving skills.

- **Assessment:** "Book knowledge" is very easy to evaluate via exams and traditional methods, whereas problem solving may be more subjective and require carefully designed assessments.
- **Attitudes:** The teaching of problem solving requires a change in attitudes of both teachers and learners.
  - Adult learners are often less interested in material on soft skills and feel it is unimportant or less important than technical material.
  - Instructors are often less comfortable or adept at teaching concepts such as problem solving, particularly given the lack of agreement and resources on effective teaching methods.
- **Resources:** Teaching problem solving requires more time and, ideally, is carried out in settings with lower student-teacher ratios. As a result, constraints, such as class time, class size, and the amount of technical information/curriculum to be covered, can limit efforts to effectively teach problem solving.

Snyder and Snyder (2008) highlight many of the same constraints as Jozwiak (2004) with respect to teaching critical thinking skills.

- Lack of training, limited resources, biased preconceptions, and time constraints create barriers to the promotion of critical thinking in learning environments.

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