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RESEARCH ARTICLE

A scaffolding framework to support the construction of evidence-based arguments among middle school students

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Abstract Problem-based learning (PBL) is an instructional approach in which students in small groups engage in an authentic, ill-structured problem, and must (1) define, generate and pursue learning issues to understand the problem, (2) develop a possible solution, (3) provide evidence to support their solution, and (4) present their solution and the evidence that supports it (Barrows, How to design a problem-based curriculum for the preclinical years. Springer Publishing, New York, 1985). However, research has shown that novice problem-solvers and learners without deep content knowledge have difficulty developing strong evidence-based arguments (Krajcik et al., J Learn Sci 7:313–350, 1998a; Reiser, J Lear Sci 13(3):273–304, 2004). In this paper, we discuss the components of (e.g., claims and evidence) and processes of making (e.g., define problem and make claim) evidence-based arguments. Furthermore, we review various scaffolding models designed to help students perform various tasks associated with creating evidence-based arguments (e.g., link claims to evidence) and present guidelines for the development of computer-based scaffolds to help middle school students build evidence-based arguments.

Keywords Middle school · Scaffold design guidelines · Problem-based learning · Scaffolding · Evidence-based arguments

Recently, science educators have called for the use of inquiry-based instructional frameworks to help middle school students learn the process of science (i.e., the inquiry process), and move beyond instruction focused on declarative knowledge (Keys and Bryan 2001; Krajcik et al. 1998b; Sandoval and Reiser 2004). A major reason for this call is a perceived need for middle school students to learn problem-solving (Keys and Bryan 2001), scientific

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reasoning (Kwon and Lawson 2000; Raghavan and Glaser 1995; Vellom and Anderson 1999) and argumentation (Kuhn et al. 2000; Vellom and Anderson 1999) skills to prepare for high school and, eventually, the 21st century workplace.

One inquiry-based instructional framework, problem-based learning (PBL), is being used increasingly in K-12 contexts (Brush and Saye 2001; Chin and Chia 2005; Gallagher 1997; Gallagher et al. 1995). In PBL, students in small groups are presented with an authentic, ill-structured problem, defined as a problem for which there is no clear solution path and there are multiple possible solutions. Students need to then define the problem, generate and pursue learning issues, and develop a possible solution to the problem (Barrows 1985; Hmelo-Silver 2004). PBL has positively impacted the problem-solving skills (Gallagher et al. 1992; Segers 1997), self-directed learning skills (Lohman and Finkelstein 2000), and content knowledge (Dods 1997; Finch 1999) of students in post-secondary and high school contexts. Furthermore, similar outcomes have been found among middle school students (Kolodner et al. 2003; Pedersen and Liu, 2002–2003).

However, middle school students may not have the argumentation skills to succeed in PBL without support (Ertmer and Simons 2005–2006; Krajcik et al. 1998a; Kuhn et al. 2000; Kyza and Edelson 2005). This is important because one of the main processes of PBL occurs when students present their solution to their teacher, classmates, and/or community leaders (Hmelo-Silver 2004). During this presentation, students need to illustrate the appropriateness of their solution by delivering an evidence-based argument.

In this paper we present a conceptual framework for evidence-based argumentation scaffolding. To accomplish this, we discuss the components of (e.g., claims and evidence) and processes of making (e.g., define problem and make claim) evidence-based arguments. Then we review various scaffolding models designed to help students perform various tasks associated with creating evidence-based arguments (e.g., link claims to evidence) and present guidelines for the development of computer-based scaffolds to help middle school students build evidence-based arguments.

Evidence-based argumentation

Definition

Evidence-based arguments are discussions that present and provide support for claims (a.k.a., hypotheses) with evidence and premises (statements about which the audience of the argument agrees) (Perelman and Olbrechts-Tyteca 1958; van Eemeren et al. 2002). According to Perelman and Olbrechts-Tyteca, an argument that is not a formal mathematical proof (a proof that a theorem is true based on other theorems and axioms) is never universally valid; it can only be considered valid by an audience, and different audiences can understand and interpret arguments differently. Thus, one cannot develop an argument without first considering the audience, and the acceptance of an argument as valid by the audience is the measure of success of an argument (Perelman and Olbrechts-Tyteca 1958).

Importance

Being able to produce convincing (i.e., logical and evidence-based) arguments is central to solving ill-structured problems (Cho and Jonassen 2002). Science educators have increasingly called for elementary and secondary students to solve ill-structured problems in school (Keys and Bryan 2001; Krajcik et al. 1998b). Middle school (Kyza and Edelson

2005), high school (Krajcik et al. 1998a; Reiser 2004), and college (Cho and Jonassen 2002; Ge and Land 2004) students have been shown to have difficulties in constructing evidence-based arguments. This is important to acknowledge because students participating in PBL need to support their solutions with evidence that illustrates why their solution is appropriate (Ge and Land 2004; Krajcik et al. 1998a).

Components

The essential goal of an argument is to persuade the audience to agree with a claim and not object to the claims and/or the premises (Perelman and Olbrechts-Tyteca 1958). Presenters should construct arguments in such a way that the audience agrees that the claims are well supported by evidence and premises. In brief, arguers should link claims with evidence and premises.

When the audience considers a premise common knowledge, such as an object that is thrown in the air will come down if another force does not act upon it, it can remain unstated. But when the audience does not consider a premise to be common knowledge, the premise needs to be stated (Perelman and Olbrechts-Tyteca 1958).

To better understand the nature of evidence-based arguments it is useful to consider examples of arguments. Suppose that Jim is sick. Dave, his friend, had gone with Jim to eat lunch at a new restaurant earlier in the day. Dave remembers that Jim had eaten cream of chicken soup. Knowing that soups are sometimes thickened with wheat and that Jim is allergic to wheat, he calls the restaurant and learns that the soup was thickened with wheat. Dave makes the claim that Jim is sick because of the soup. Before Dave can get his audience to believe that his claim is probable, he should support it with the evidence that the soup was thickened with wheat and that Jim is allergic to wheat. An additional premise on which the believability rests is that people who eat things to which they are allergic get sick. However, this premise would likely remain unstated because most people hold the principle as common knowledge that people get sick when they eat food to which they are allergic.

The more levels in an argument and the more premises the target audience may dispute, the more complex the argument must be (van Eemeren et al. 2002). For example, a student investigating why lake trout in Lake Michigan are dying off may arrive at a claim that the trout are dying off because of an invasion of zebra mussels. The student should support (see Fig. 1) his/her claim with subclaims (e.g., other threats to the lake trout are not more compelling), and should support each subclaim with evidence (e.g., sea lamprey are well controlled now in Lake Michigan). As can be seen in Fig. 1, as a claim becomes more contentious, more levels of argument, and consequently premises, are needed to support the claim.

Mental processes that lead to effective evidence-based arguments in PBL

Represent the problem

At the beginning of a PBL unit, students are presented with an ill-structured problem. Before gathering evidence, proposing a solution, and defending the solution, students need to mentally represent the problem to know what they are trying to solve (Jonassen 2003). For example, if the problem presented to middle school students is: *What is happening to the bass of the Wabash River to cause their polychlorinated biphenyl (PCB) levels to rise, and what would you propose to the governor of Indiana to counter the problem?*, students

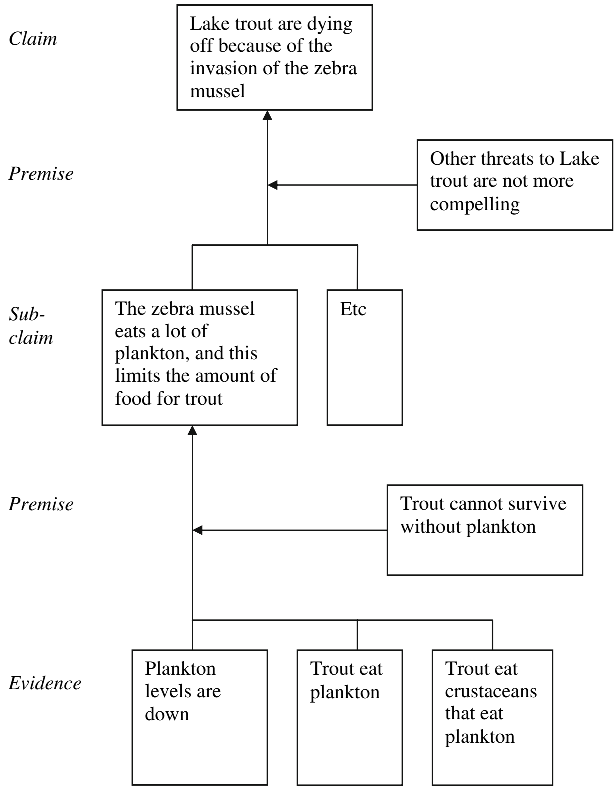

Fig. 1 Complex argument example

need to first put the problem in their own words. In order to successfully address the problem, they should understand that they are not supposed to simply demonstrate that there is PCB contamination in the Wabash—a fact that is not in dispute—but rather the cause and how it affects the bass of the Wabash.

Analyze audience

While students are defining the problem, they need to also analyze the audience (Perelman and Olbrechts-Tyteca 1958). In addition to the teacher, the audience may include community leaders and other students. Because an argument is a discussion between the presenter and the audience, characteristics of the audience should be considered. Such characteristics include what level of knowledge the audience has about the problem and the content area in which it is situated as well as their preconceptions. For example, one characteristic of the audience for the Wabash bass example that would be pertinent is if some members of the audience were not from Indiana or Illinois. People not from Indiana or Illinois may not have prior knowledge about the Wabash. The results of the audience analysis inform the performance of later steps in the argument construction process.

Determine needed information and gather it

Upon adequate representation of the problem, students need to determine what kind of information they need to gather about the problem (Pedersen and Liu 2002–2003). Since the Wabash is a long river, there are many potential sources of PCB contamination. And given that part of the Wabash borders Illinois and Indiana, the contamination could be coming from one or both states. In this case, students should realize and suggest that they need to take several water samples from different locations of the river to be able to learn where PCB contamination is first introduced into the Wabash. Once they have established the appropriate information needed, they need to find the information.

Develop claim

Subsequently, students need to develop a claim (Ertmer and Simons 2005–2006). For example, students in the Wabash bass unit might claim that the PCB levels are rising in the bass of the Wabash because PCBs leaked from an aluminum refining plant on the banks of the Wabash. Upon development of the claim, they should also consult the audience analysis to consider how the claim can be broken down into subclaims that would then be linked to evidence.

Gather additional evidence and link evidence to claims

After developing a solution to the problem that is at the center of the unit, students need to first identify additional evidence needed to support their claims and subclaims, and seek that evidence. Then they should link the evidence to their claims to create an argument in support of their proposed solution (Krajcik et al. 1998a). In doing so they should also consult the audience analysis information to consider the kind of premises necessary to make the links.

Difficulties students have in constructing evidence-based arguments

Piaget's insights

Piaget (1947) noted that, in general, children of 8–11 years of age cannot reason hypothetically or support responses to questions with relevant evidence. According to Piaget, children attain the stage of formal operations, in which they can reason hypothetically and support responses to questions with evidence, when they reach adolescence (approximately ages 12–13). Lourenco and Machado (1996) noted that a widespread misinterpretation of Piaget's work is that children reach the stages invariably at the same age and gain the capabilities characteristic of each stage all at once. Inhelder and Piaget (1955) wrote that though many adolescents of 12–13 years have attained formal operations, many others do not fully possess the ability to reason formally until the age of 14–15 years. Twelve and 13-year-old students in their studies often had difficulty creating viable hypotheses about topics such as what makes objects float in water and what makes materials flexible, and then backing their hypotheses with evidence. As making reasonable claims and connecting them to evidence is similar to making viable hypotheses about the nature of objects and connecting them to evidence, elementary and middle school-aged children, most of whom are under 14 years of age, may have difficulty connecting claims with evidence during the course of a PBL unit without the help of scaffolding.

In a study of middle school science students who participated in a project-based learning unit, Krajcik et al. (1998a) noted, "many students did not develop a logical argument to support their claims; they tended to present data and state conclusions without explicitly linking the two" (p. 347). This pattern does not appear to occur because students do not understand what premises and evidence are. Glassner et al. (2005) found that middle school students recognize the difference between evidence-based arguments and simple (premise and evidence-free) explanations. However, Glassner et al. (2005) also found that middle school students tended to explain their positions rather than provide evidence in support of them regardless of whether they were asked to prove or explain their positions. As shown by Cho and Jonassen (2002), even college students sometimes still have difficulty using premises to connect claims with evidence.

Possible reasons for student difficulty

There are conflicting opinions in the literature about whether middle school students can construct evidence-based arguments without support or scaffolding. However, it appears that such students may experience difficulty in creating evidence-based arguments. This difficulty could be due to students' inexperience representing problems. Jonassen (2003) noted that what separates expert problem-solvers from novice problem-solvers is that the former define problems more effectively; that is, they illustrate numerically, graphically, or verbally (a) the stakeholders, or who the problems involves, (b) the relationship between the stakeholders, and (c) what is happening in problems. Both college and secondary students participating in PBL units often represent the problem to themselves based on the surface-level details in the initial description of the problem that they received (Ge and Land 2004; Jonassen 2003). This tendency is problematic because an ill-structured problem is difficult to define at the outset; the statement of an ill-structured problem does not include all of the relevant details about the problem that are needed to fully understand the solution path (Gallagher 1997; Jonassen 2003).

Students' difficulty constructing evidence-based arguments could also be due to struggles with identifying and gathering relevant evidence (Pedersen and Liu 2002–2003). These struggles could stem from a partial or poor understanding of the problem (Krajcik et al. 1998a). For example, students who think that the driving question in the Wabash Bass PCB unit is "Does the introduction of contaminants with PCBs into the Wabash cause the Wabash to have PCB contamination?" would likely decide that relevant evidence could be obtained by taking a sample of water from the Wabash, a sample of a chemical that has PCBs in it, pouring the latter liquid into the former liquid, and then measuring the resulting liquid's PCB content. However, this type of evidence is not relevant and thus does not help solve the posed problem.

Difficulty constructing arguments could also stem from student weakness linking claims to evidence with premises (Cho and Jonassen 2002). For an audience to accept a claim, the argument must be carefully constructed, and include evidence that is linked to the claim with premises (Perelman and Olbrechts-Tyteca 1958). Creating an argument ultimately involves creating a bridge between claims and evidence that the audience can access. This is a difficult task in its own right, and it requires the kind of abstract thinking of which many adolescents and others are not capable without assistance (Cho and Jonassen 2002).

In short, students' inability to construct evidence-based arguments when participating in a PBL unit could be attributed to three major challenges: students' weaknesses in (a) adequately representing the central problem of the unit (Ge and Land 2004; Liu and Bera 2005), (b) determining the most relevant evidence that they need to gather and gathering it (Pedersen and Liu 2002–2003), and (c) synthesizing gathered information to construct a sound argument (Cho and Jonassen 2002). One way of supporting student construction of evidence-based arguments may be through external scaffolding.

Scaffolds for evidence-based argumentation

Definition of scaffolding

Scaffolding can be defined as support provided by a teacher, peer, or other resource that enables students to perform tasks that they cannot perform independently (Wood et al. 1976). Students in medical schools, and in secondary and other university settings often are unable to solve PBL problems by themselves due to two challenges: their lack of (a) domain-specific knowledge (Cho and Jonassen 2002; Evensen et al. 2001; Ge and Land 2003; Liu 2004; Liu and Bera 2005), and (b) sufficient ability to self-monitor their understanding (Cho and Jonassen 2002; Evensen et al. 2001; Ge and Land 2003; Liu 2004; Liu and Bera 2005). Scaffolding can help students accomplish more than what they could accomplish by themselves by providing them with (a) *conceptual* (help with what to consider), (b) *metacognitive* (how to manage the learning process), (c) *procedural* (how to use tools), and (d) *strategic* support (what strategies to use in approaching the problem) that can assist them as they approach and solve ill-structured problems (Hannafin et al. 1999; Wood et al. 1976).

Saye and Brush (2002) distinguish between two types of scaffolding—soft and hard. Soft scaffolding represents just-in-time support provided by a teacher or peer that helps students meaningfully participate in the performance of actions. Scaffolding is a very dynamic and demanding process, and teachers who provide soft scaffolding must continually diagnose what support students need to accomplish the task at hand in order provide just the right amount of support at the right time to each student or to the whole class as needed (de Grave et al. 1999; Hogan and Pressley 1997; Lepper et al. 1997; Saye and Brush 2002). Teachers use such probing strategies as Socratic dialogue (e.g., asking questions to prompt students to think more deeply about issues) and metacognitive coaching (i.e., making students question their understanding) to stretch students' abilities (de Grave et al. 1999; Gallagher 1997; Lepper et al. 1997). Teachers also scaffold by using motivational techniques such as encouragement (Lepper et al. 1997). However, it is important to note that it is challenging to scaffold effectively in a class of many students with varying needs (Gallagher 1997; Hogan and Pressley 1997). This is where hard scaffolds may be an important resource.

Hard scaffolds (computer or paper-based cognitive tools) can serve the same scaffolding roles as soft scaffolds, and are developed based on anticipated student needs during an open-ended unit (Saye and Brush 2002). Examples of types of hard scaffolds include videos of experts who explain how they would approach a problem (Pedersen and Liu 2002–2003) and question prompts that make students think about specific issues that are important to consider as they approach the problem (e.g., "if I've never designed a balloon before, where do I start?"; Simons et al. 2004, p. 217). However, hard scaffolds are meant to augment, not replace, soft scaffolding (Land and Zembal-Saul 2003; Saye and Brush 2002).

Fading of scaffolding and transfer

The goal of scaffolding is two-fold: first, to provide temporary support to students as they perform tasks that they have difficulty performing unaided, and second, to help students gain competency in the scaffolded tasks such that they *can* perform the tasks unaided (Puntambekar and Hübscher 2005). Based on continuing diagnosis of student difficulty, scaffolding can be faded as students gain proficiency performing scaffolded tasks (Collins et al. 1989; Puntambekar and Hübscher 2005). Fading of soft scaffolding can be accomplished when performance characteristics indicate that the student no longer needs the scaffolding to complete the task at hand (Wood et al. 1976). Fading of hard scaffolding is not as conceptually parsimonious, as computers and pieces of paper cannot diagnose student difficulty at this time. Thus fading of hard scaffolds, when it does occur, often involves students indicating that they do not need the support (Puntambekar and Hübscher 2005). By scaffolding students' completion of tasks and then fading the scaffolds, instructors may be able to promote transfer of student skills in completing those tasks unaided in the future (Collins et al. 1989; Gaskins et al. 1997).

Examples of scaffolds for evidence-based argumentation

Within the literature, several researchers have discussed how they designed and implemented hard scaffolds to help students create evidence-based arguments. In this section we review and discuss the scaffolds according to what function they address: problem representation, evidence gathering, and linking of claims to evidence. Most scaffolds can be categorized into one of three types: question prompts, expert modeling, and concept mapping. Question prompts are textual questions that ask students metacognitive or conceptual questions related to the problem or the process to solve the problem or create the argument (Ge and Land 2004). Expert modeling scaffolds consist of video of experts who consider the problem or the creation of the argument and discuss how they would approach it (Pedersen and Liu 2002–2003). Concept mapping scaffolds are scaffolds that allow students to create a graphical representation of the problem or the argument (Jonassen 2003).

Problem representation scaffolds

Table 1 includes a review of scaffolds used to help students represent problems. College students in Ge and Land's (2003) study who were exposed to problem representation question prompts, such as "what are the parts of the problem?" and "what are the technical components?," were able to more clearly represent the presented problem than students who were not exposed to such prompts (p. 37). Such students also made "intentional efforts to identify factors, information, and constraints" related to the problem (p. 31).

The hypothesis menu in Bioworld helped high school students in three scaffolding conditions (Bioworld alone, Bioworld with teacher soft scaffolding, Bioworld with graduate student soft scaffolding) to create hypotheses about the presented problem

Table 1 Problem representation scaffolds

System name | Reference	Scaffold type	Description	Context
Alien Rescue Liu and Bera (2005) Pedersen and Liu (2002–2003)	Expert modeling	Expert illustrates how he approached the problem (i.e., how he considered the problem, where he started)	Middle school: 6th grade
Bioworld Lajoie et al. (2001)	Other	Students use hypothesis menu with body systems and disease types to create hypotheses	High school: 9th grade
No name given Ge and Land (2003)	Question prompts	Prompts such as "what are the parts of the problem" and what are the technical components?" (p. 37)	Undergraduate: Information technology course
No name given Lee and Nelson (2005)	Concept mapping	Students can add graphics, text, audio, or video into a database, and can illustrate through concept mapping how the designated concepts are interrelated	None specified

(Lajoie et al. 2001). Middle school students who received expert modeling of how to approach the problem in Alien Rescue were better able to solve problems than students who were didactically told how to conceive of the problem (Pedersen and Liu 2002–2003). Research suggests that these types of scaffolds successfully support students as they consider the parts of central PBL problems.

Evidence gathering scaffolds

Detail about scaffolds to help students identify relevant information can be found in Table 2. College students working in pairs or individually who received question prompts in the study by Ge and Land (2003) identified significantly more relevant information related to the central problem of their unit than students working in pairs or individually who did not receive question prompts. Students selected for case studies perceived that the question prompts led them to investigate information related to the problem that they may have otherwise overlooked.

Similarly, the question prompts in Progress Portfolio reminded middle school students that they needed to find evidence (Kyza and Edelson 2005). Students who used Progress Portfolio noted during discussions with group mates that they needed to find evidence to support or counter their hypotheses about the problem, while students in the control group, who wrote in journals that contained a 2-column table with the headings "Main idea" and "Specifics," only mentioned in generalities that they needed to find evidence (Kyza and Edelson 2005). Video-based expert modeling in Alien Rescue helped middle school students in the experimental group generate more relevant questions to investigate than students in the control group (who were told didactically what to consider) (Pedersen and Liu 2002–2003). Bioworld's evidence palette was found to help high school students determine what evidence they needed to find and record based on the hypothesis they

Table 2 Evidence gathering scaffolds

System name | Reference	Scaffold type	Description	Context
Alien Rescue Liu and Bera (2005) Pedersen and Liu (2002–2003)	Expert modeling	Expert tells students what types of questions he would ask	Middle school: 6th grade
Bioworld Lajoie et al. (2001)	Other	Students can copy and paste phrases from problem description to *evidence palette*, and then can research the concepts/symptoms of the patient related to the phrase	High school: 9th grade
No name given Ge and Land (2003)	Question prompts	Prompts such as "What information do you need for this system?" and "How will this system be used, by whom, and for what?" (p. 37)	Undergraduate: Information technology course
Progress Portfolio Kyza and Edelson (2005)	Question prompts	Students type answers to prompts such as "In your story make sure you answer the question "What are the environmental factors on the island that caused so many finches to die?" (p. 548)	Middle school

created (Lajoie et al. 2001). Research suggests that these types of scaffolds successfully support students as they determine relevant information to find and find it.

Linking of claims to evidence scaffolds

Table 3 contains an overview of seven scaffolds to help students construct an evidence-based argument after defining the problem and collecting evidence. College students using Belvedere and a threaded discussion forum produced significantly more claims and evidence during discussion than the control group using only the discussion forum (Cho and Jonassen 2002). College students who used Progress Portfolio continually revised their answers to the questions, and evidenced an "increasing sophistication in explanations" (Land and Zembal-Saul 2003, p. 79). Elaboration prompts in the study by Ge and Land (2003) helped college students create more coherent arguments. College students who used Hypothesis Scratchpads constructed a greater number of hypotheses with greater numbers of variables than students who used unstructured and semi-structured (similar to the structured but did not contain the third prompt) hypothesis scratchpads (van Joolingen and de Jong 1991). The knowledge-building component of Future Learning Environment (Kligyte 2001) also included a component in which students can organize their answers from the problem representation question prompts according to the claim to which they lend support.

Seventy percent (70%) of the arguments created by middle school students using KIE Sensemaker incorporated premises to connect evidence with claims (Bell 1997). Middle school students who used Progress Portfolio discussed the sufficiency or lack thereof of evidence to support a claim. Students in the control group, who wrote in journals that

Table 3 Linking of claims to evidence scaffolds

System Name | Reference	Scaffold type	Description	Context
Belvedere Cho and Jonassen (2002)	Concept mapping	Students show how their evidence is connected to their claims via premises by linking them together in a concept map	Undergraduate: Economics course
Bioworld Lajoie et al. (2001)	Other	Students can organize their found information by types of evidence in the *argumentation palette* in order to justify their hypothesis	High school: 9th grade
Future Learning Environment Kligyte (2001)	Question prompts and concept mapping	Students use the knowledge-building component to group evidence with associated claims	Undergraduate
Hypothesis Scratchpads van Joolingen and de Jong (1991) van Joolingen and de Jong (1997)	Question prompts	Prompts force students to identify (1) variables to be related in a hypothesis, (2) the relationship between the variables, and (3) constraints on the relationship	Undergraduate chemistry
KIE Sensemaker Bell (1997) Davis and Linn (2000)	Concept mapping	Students group evidence and relate evidence groups to claims	Middle school
No name given Nussbaum (2002)	Other	Students use the scaffolds to record claims, evidence, and premises in a flowchart in which they indicated how each piece of evidence related to the claim	Middle school: 6th grade
Progress Portfolio Land and Zembal-Saul (2003)	Question prompts	Students look at phenomenon such as light refraction, record a claim, evidence, and then are asked to explain how the evidence supports the claim	Preservice teacher course
Progress Portfolio Kyza and Edelson (2005)	Question prompts	Prompts ask students to organize evidence in relation to a claim in each *Explanation Page*	Middle school

contained a two-column table with the headings “Main idea” and “Specifics,” either did not discuss evidence sufficiency at all or one group member stubbornly claimed that they proved their point with one piece of evidence (Kyza and Edelson 2005). Students in the experimental condition also created hypotheses and interpreted phenomena in light of their hypotheses and data (Kyza and Edelson 2005). High school students who used Bioworld's argumentation palette both with and without soft scaffolding provided by the teacher were able to build effective arguments (Lajoie et al. 2001). Research suggests that these types of scaffolds successfully support students as they link claims with evidence.

Guidelines for the creation of evidence-based argumentation scaffolding

As seen in the preceding section, the literature offers a fair amount of divergent advice on how to create scaffolding for evidence-based argumentation. Creating a strong evidence-based argument that leads to the audience's adherence to the claim is a difficult process for students at any level. To support designers as they develop scaffolds to support this challenging process among middle school students, we developed some guidelines based on our research review. For each, we first explain the guideline and the research supporting it, and then give an example of its application using the Wabash bass unit example.

Guideline 1: Embed scaffolds within a system

A scaffold designed to help students define a problem would be of little value if students' increased understanding of the problem did not help them to determine relevant information to seek. In PBL, students work in groups to solve problems. Often, one group member might be asked to respond to a particular question about what the problem entails, and another group member may need to find evidence related to a particular facet of the problem. It is important that the outputs of the problem definition step, for example, be recorded such that other group members can access the needed information (Blumenfeld et al. 1996). Otherwise, one student may answer a question prompt or build a better problem representation by listening to an expert modeling problem representation, and the rest of the group may not be able to benefit from the generated information.

The importance of this guideline can be illustrated by the results of the study by Kyza and Edelson (2005). Their scaffolding system required middle school students to write hypotheses, record evidence, and link the evidence and hypotheses all within a common interface. Students in the experimental condition used the information they recorded to construct their argument, while students in the control group, who took notes rather than used the scaffolding system, did not consult their notes when constructing an argument to support their proposed solution.

It is important to integrate all of the scaffolds into one system in such a way that students are aware that the scaffolds are all related and are part of one system. Such integration of scaffolds can help ensure that the outputs of one step in the process of constructing an evidence-based argument (problem representation, identifying relevant areas to research and finding evidence to support claims, and connecting claims with evidence via premises) inform the subsequent steps. Scaffolds can be integrated by being included in one general template, such as in Gallagher et al.'s (1995) problem log. Students using this tool were required to answer problem representation prompts, and record activities and constraints. Nussbaum's (2002) integrated scaffolding system required students to write out their claims, link evidence to the claims, and justify the link all within the same interface. He found that the elementary school students who used these scaffolds were able to construct more convincing arguments with the scaffolds than they could without.

Example

If group members are exposed to a problem representation scaffold that leads them to the conclusion that it is important to consider from whence PCB contamination comes, it is important that they record the conclusion so that they then can collect relevant evidence. In a scaffolding system developed based on this guideline, students could record their conclusions in either a textual or graphical (e.g., concept map) format, and this could be stored in a database. In evidence-gathering scaffolds, the problem representation could be echoed (retrieved and shown) from the database.

Guideline 2: Have students articulate their thoughts

It is also important that students articulate their thoughts while engaging in the argument construction process to help to ensure that their ideas are firmly rooted in the students' minds (Bell 1997; Chi et al. 1989; Nussbaum 2002). Students can articulate their thoughts either verbally (Kyza and Edelson 2005) or graphically (Cho and Jonassen 2002). Chi et al. (1989) investigated college students who studied worked out examples on Newton's laws of motion. They found that by verbalizing their self-explanations as they studied the worked out examples, students were able to monitor their understanding and subsequently perform better in problem-solving tasks. Bell found that students perceived that externalizing their thoughts in the argument construction process helped them to learn more.

Example

In addition to the benefits of deeper comprehension that idea articulation has, articulation is also the engine that drives systemic scaffolding systems. To provide for the flow of problem representations, gathered information, and other ideas from one group member to another, and from one stage of the unit to another, it is important that the ideas be articulated and recorded. For example, by articulating their problem representation, students in the Wabash bass unit could not only strengthen their understanding of the unit's driving question, but also drive evidence gathering during later stages of the unit. Without articulation, middle school students especially may arrive at a representation of the central problem, and subsequently forget the representation and have to start again.

Guideline 3: Constrain the problem space

Instructors who develop PBL units have specific content and intellectual skill learning goals in mind (Gallagher 1997). The process of the creation of evidence-based arguments is long and involved, and it helps to constrain the problem space to those elements most relevant to the learning goals (Simons and Ertmer 2005–2006). When students complete steps that are not relevant to their learning goals, the amount of cognitive capacity remaining for tasks that do pertain to learning goals is reduced (van Merriënboer et al. 2003).

For example, performing an audience analysis often does not contribute to the attainment of a unit's learning goals. Where instructors judge that a task in the argumentation process is not relevant to students' attainment of the learning goals, the former may simplify the argumentation process by completing rather than scaffolding the steps that are not relevant to the learning goals, and providing the information from the completed step to the students.

Example

In this case the learning goals may be that students (a) learn about factors that contribute to PCB contamination of the Wabash and how these can be controlled, and (b) be able to solve problems and build arguments. Being able to perform an audience analysis would not likely be relevant to such learning goals. Thus, the developer of the Wabash bass unit might simply give students a bulleted list of the relevant characteristics of the audience (e.g., high prior knowledge of the Wabash's path, little prior knowledge of the food chain in the Wabash).

Guideline 4: Consider motivation

Just as soft scaffolding is sometimes not well received by students (Hogan and Pressley 1997), there are conditions under which the same may be true for hard scaffolds. When one considers that hard scaffolds are sometimes ignored by students (Brush and Saye 2001; Ge and Land 2003; Greene and Land 2000; Oliver and Hannafin 2000; Puntambekar and Kolodner 2005), it seems to make sense to try to build motivational strategies into the scaffolds. This may be accomplished through the suggestions below.

Help students see scaffold relevance

If a scaffold is constructed such that students can readily identify its relevance to what they are seeking to accomplish, then it is more likely to be used. Furthermore, students who do not use scaffolds cannot be helped by the scaffolds (Oliver and Hannafin 2000). Students often do not use hard scaffolds unless they are specifically directed to do so (Brush and Saye 2001; Ge and Land 2003; Oliver and Hannafin 2000; Puntambekar and Kolodner 2005; Simons and Klein, 2007). Therefore, when designing evidence-based argumentation scaffolding, designers should make sure that (a) the scaffold is designed such that students can clearly see why using it can help them to create evidence-based arguments, and (b) the teacher leading the unit stresses that the class's goal is to develop a potential solution to the problem and create an argument to support the solution.

As Reiser (2004) noted, a scaffold, like any other tool, cannot force students to do what it is supposed to help them do. For example, it cannot force students to define a problem in the appropriate way, find appropriate evidence, or link claims to evidence. It can only help them do so if they choose to use it appropriately. Whether students use the scaffolds or not appears to depend in large part on the way that the teacher represented the problem and the goal of the unit to students. For example, if at the beginning of the unit the teacher stressed the technical requirements (e.g., at least 10 slides long, proper color scheme, appropriate pictures) of the final product (e.g., a PowerPoint presentation providing evidence for the group's solution), then students may not see argumentation as important, and thus evidence-based argumentation scaffolding as relevant, to their project (Nystrand and Graff 2001). This is because they may see the unit as a PowerPoint unit, rather than a PBL unit. If given the choice to use or not use evidence-based argumentation scaffolding, many students may choose not to use the scaffolding.

In brief, scaffolds should clearly indicate how their use will help students reach their goal. This can be accomplished through a simple phrase at the top of the scaffold that indicates its function in simple terms such as "This will help you do X, which is important because Y."

Situate the task within the overall context

Students will be able to see the relevance of the steps that they are performing more clearly if they know where they are in the overall argument construction process, and how the step that they are performing relates to the overall goal of creating an evidence-based argument. For example, often students dislike spending a great amount of time defining a problem, and as a result usually spend little time in this step (Ge and Land 2004). To highlight where students are in the steps, designers can include in the scaffolding system a visual model with which students can always see where they are in the overall process.

The strategies outlined above may help ensure that scaffolds are motivational, and subsequently used, but developers may consider other strategies as well. For example, if the scaffolds are to be developed for elementary school students, then the use of an appealing character who guides them through the steps may be appropriate.

Example

Problem representation scaffolds in the Wabash bass unit example should be developed such that they clearly indicate the importance of defining the problem. This could be done through simple statements such as "Before we start investigating, we need to make sure we know what we're trying to solve." The relevance of other scaffolds could be established in a similar way. Our experience observing middle school students during PBL units has taught us that such students often fail to see the importance of defining the problem or searching for a clearly defined type of evidence unless they are shown the importance of it. But it would also be important to graphically or otherwise remind students on all scaffolds where they are in the overall process of creating an argument. As mentioned previously, this could be done with a graphical model of the argumentation process, of which the current step is highlighted. Our experience has shown us that middle school students often have little patience when they do not see the end in sight of their task. A graphical aid in the form of a model of the argumentation process may help such students gain confidence that their efforts are leading somewhere.

Guideline 5: Make scaffolds explicit for students with less prior knowledge

A lack of clear instructions for use may be one reason students often do not use hard scaffolds unless specifically asked to (Oliver and Hannafin 2000). For example, some scaffolds simply give students hints; one of the metacognitive scaffolds used in Oliver and

Hannafin's study provided middle school students with hints such as "When looking for additional information to solve a problem, it is often useful to look for ways in which other people have tried to solve the problem" (p. 87). Students who have little prior knowledge of the content of a PBL unit already endure high cognitive load to learn the content they need to solve the problem. Asking students to search for the ways in which others have approached the problem may cause cognitive overload (van Merrienboër et al. 2003). Indeed, Oliver and Hannfin (2000) noted, "few students indicated that they read the metacognitive hints" (p. 87).

Some authors have provided evidence that suggests modeling may not be an appropriate scaffold because different students may use it in qualitatively different ways. Chi et al. (1989) asked college students with little prior knowledge of physics to examine worked-out examples of physics problems and then solve physics problems themselves. Students who performed better when solving problems examined the worked-out examples for strategies for solving problems and specific facts, whereas students who performed poorly when solving problems looked at the worked-out examples for the answer to the problems on which they were working. The similarity between modeling (video or narration in which an expert solves a problem or performs a step in the solving of a problem) and worked examples (essentially a textual representation of the results of an expert solving a problem) suggests that modeling may not be an appropriate scaffold for students with little prior knowledge. It makes little sense to develop scaffolding that is only used by those with a lower scaffolding need.

Other authors have also indicated that students tend not to use scaffolds that do not give explicit step-by-step instructions for their use. Brush and Saye (2001) designed scaffolds that provided a forum for secondary students to summarize key historical events as well as keep track of group progress. Very few groups made full use of the scaffolds, and the majority only filled out the requested information in a superficial manner.

Some secondary students tended to use more extensively procedural scaffolds that were more explicit on how they were to be used (Brush and Saye 2001; Oliver and Hannafin 2000). However, Brush and Saye's (2001) scaffold that listed recommended tools to investigate each event was widely used. Students in Oliver and Hannfin's study used such strategic scaffolds as one that told students, "read through the 'core set' of evidence. Try to understand the many different reasons why buildings collapse."

Example

Telling middle school students, for example, to search for the ways other people have identified the sources of toxins in fish would likely not be an efficient way to help them solve the problem. Given such guidance, they might find how mercury levels rise in tuna. However, as tuna are ocean-dwelling fish, such information has an indirect relation to the task at hand. Adults would most likely be able to see that. However, due to their lack of prior knowledge, middle school students would likely be sidetracked and conclude that toxins in fish come from air pollution. While that is not incorrect (many toxins do enter water bodies that way), it is not how PCBs enter rivers.

Guideline 6: Focus on the development of conceptual, strategic, and procedural hard scaffolds

Most literature seems to indicate that metacognitive hard scaffolds rarely accomplish what they are supposed to accomplish: that is, to support students at a metacognitive level as they engage in problem solving. Few middle (Oliver and Hannafin 2000) or high school (Brush and Saye 2001) students used exclusively metacognitive scaffolds. Therefore, it may be more useful to limit the development of metacognitive hard scaffolds, and leave the task of supporting K-12 students' metacognition to teacher soft scaffolding. The support of metacognition is one of the most important tasks of scaffolding. However, teachers are uniquely positioned and equipped to provide metacognitive scaffolding. They possess the ability to determine on the fly what metacognitive support students need and provide it (Hogan and Pressley 1997). Furthermore, students—especially in middle schools—have a harder time ignoring teachers than they do metacognitive hard scaffolds (i.e., ignoring a web page or a piece of paper). Energy expended for the development of conceptual, strategic, and procedural scaffolds may lead to greater gains in student performance than equal expenditures of energy to develop metacogntive scaffolds.

Relying on soft scaffolding to meet students' metacognitive needs appears to be feasible if teachers view such scaffolding through the lens of the community scaffolding approach (Hogan and Pressley 1997). That is, teachers may facilitate on occasion a whole class discussion to clear up particularly widespread misguided approaches. When metacognitive support needs are not as widespread, teachers can provide individualized metacognitive scaffolding.

Example

Metacognitive hard scaffolds in the Wabash bass unit would likely ask students questions like "How sure are you that PCB contamination came from there?" Research suggests that secondary students rarely use metacognitive hard scaffolds (Oliver and Hannafin 2000; Brush and Saye 2001). Even if they were to use the scaffold, our experience observing middle school students during PBL units suggests that such students may say something to the effect of "I know it's right because I read it on that web page." Clearly, middle school students need metacognitive support during PBL units, but soft scaffolding may be more effective because a teacher could then reply, "But how do you know that web page is right?" Despite advances in technology, hard scaffolds to our knowledge cannot respond to every possible student reply.

Remaining questions and suggestions for future research

Several questions remain regarding evidence-based argumentation scaffolding. First, if the developer of a unit completes certain tasks of the argumentation process, does that take away from the benefits of PBL that have been attributed to the complexity of the process of solving ill-structured problems? In other words, does completing the audience analysis for students change the problem of the argument construction process from ill-structured to well-structured? If so, does that change the entire unit's problem from ill-structured to well-structured, or make it less ill-structured? Put briefly, does constraining the problem space to aid student argumentation take away the student struggle that is so important to student growth during PBL units (Simons and Ertmer 2005–2006)? These are important questions to consider because making the entire unit well-structured may make the transfer of problem-solving skills impossible (Jonassen 2003). Researchers should attempt to implement a PBL unit in which they give students a bulleted list of audience characteristics and investigate their problem-solving process to see if it aligns more with ill-structured or well-structured problem solving.

Second, if developers focus their efforts on the development of hard scaffolds for conceptual, procedural, and strategic support, will the soft scaffolding of a teacher of a class of 20–25 students be enough to provide the metacognitive support that students need? There is little research that investigates just how much metacognitive support students need relative to conceptual, strategic and procedural support. It is likely that there are no definitive answers to this question, and that the level of each type of support students need depends on the grade level, subject, and the specific content of the unit, as well as on the students' abilities to self-regulate their learning. Empirical research is needed that investigates the amount of support students of varying grade levels and in various subjects need.

When a classroom contains a wide range of student skill-levels, how can a developer determine which types of scaffolds to develop? We suggest that hard scaffolds be developed to allow about 90% of the students in the target class to perform successfully. We chose this number because it seemed reasonable given the goals of mastery education (as cited in Smith and Ragan 1999), and also because this way it is likely that most of the members of each group can perform within their respective skills levels. However, this standard was not based on empirical research, as we could not find any studies that examined this specific question. More research needs to be done in this area to better inform the development of hard scaffolds.

Additionally, if scaffolds are developed to target multiple skill levels, then there will likely be some scaffolds that are needed by some students and not by others. As such, does it make sense to make all scaffolds part of a system in which the outputs of one scaffold become the inputs of another scaffold? It is easy to imagine students being frustrated by a system of scaffolds in which they would be required to answer questions or view modeling that they do not need, for example, in order to have the inputs for the next scaffold. In such a case it may be appropriate to specify alternatives for each scaffold so that students who perceive that they do not need the scaffold would not be required to use it. But students often do not make good instructional decisions (Williams 1996), so some students who really need the scaffold may opt for the alternative. The only way to find definitive answers to these questions is through empirical research that examines the interaction of students of varying abilities with a system of integrated scaffolds.

Finally, the original intent of scaffolding—to serve as a *temporary* support until students are able to accomplish scaffolded tasks by themselves—has been seemingly forgotten as few researchers have addressed fading of hard scaffolds (Pea 2004; Puntambekar and Hübscher 2005). Due to this lack of research, we know very little about how to ensure that scaffolded skills are transferred to new settings, as fading is critical to transfer (Pea 2004; Puntambekar and Hübscher 2005). We also know very little about how students react when hard scaffolds are removed (Pea 2004). This begs several questions. First, how can evidence-based argumentation be supported by computer-based scaffolding such that students' argumentation skills can transfer? For example, if all scaffolds are part of a networked system, in which all student inputs in response to question prompts are available to group mates, what happens when one student decides that s/he does not need the scaffolds any more? Can such scaffolds be faded by students? If so, what happens to group mates who still need the scaffolds?

Conclusion

Eighteen years ago, the Carnegie Council on Adolescent Development (1989) noted that American middle schools were in crisis, and that drastic changes needed to be made to such schools to ensure success of middle school students in life and work in the 21st century. It noted that one of the most distressing challenges middle school students faced was in their critical reasoning skills, and suggested an increased use of inquiry-based methods in middle schools as one way to help remedy the challenge. There appears to be ample evidence that challenges in critical thinking still remain at the middle school level (Keys and Bryan 2001; Kuhn et al. 2000; Kwon and Lawson 2000; Vellom and Anderson 1999), but that PBL has the potential to help middle school students overcome the challenges (Gallagher et al. 1992; Gallagher 1997; Kolodner et al. 2003; Pedersen and Liu 2002–2003). To be successful in PBL, students need to create strong evidence-based arguments (Cho and Jonassen 2002). The scaffolding guidelines presented in this paper should help developers design evidence-based argumentation scaffolds that are (a) systemic, (b) motivational, and (c) tailored to the ability level of the target students, and which lead students to (a) articulate their thoughts, and (b) complete only tasks relevant to the unit's learning goals. With appropriate support, middle school students can succeed in PBL units (Kolodner et al. 2003; Simons and Ertmer 2005–2006), and it is our hope that the framework presented in this paper will help ensure such support.

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