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DEVELOPMENT ARTICLE

Toward a framework on how affordances and motives can drive different uses of scaffolds: theory, evidence, and design implications

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Abstract One way to help students engage in higher-order thinking is through scaffolding, which can be defined as support that allows students to participate meaningfully in and gain skill at a task that is beyond their unassisted abilities. Most research on computer-based scaffolds assesses the average impact of the tools on learning outcomes. This is problematic in that it assumes that computer-based scaffolds impact different students in the same way. In this conceptual paper, we use activity theory and the theory of affordances to build an initial theoretical framework on how and why K-12 students use computer-based scaffolds. Specifically, we argue that affordances and motives drive how and why K-12 students use computer-based scaffolds. Then we examine empirical studies to gather preliminary support for the framework. Implications for research on and the design of computer-based scaffolds are explored.

Keywords Scaffolding · Activity theory · K-12 schools · Computer-based scaffolds · Affordances · Motives

Introduction

A common premise in instructional technology is that "all instructional contingencies can be managed through space and time (i.e., they can be incorporated into the interface between student and material and/or device)" (Heinich 1984, p. 68). This line of thought is present in much research on design. For example, in his theory of the design of everyday

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things, Norman (1988) wrote that everyday objects (e.g., doors) should be designed (e.g., with push plates) so that users know exactly how they are to be used at a glance.

When instruction simply delivers content to students, it is wise to use design cues to make explicit the one acceptable way to interact with the instruction. However, learning in constructivist learning environments requires navigation of wide and deep structures of decisions and responses, rather than the narrow and shallow structures of everyday tasks (Jonassen 1991; Norman 1988). Instructional support in constructivist learning environments can be used in different ways to help students navigate wide and deep structures. It is important to know how students use instructional support because this influences learning outcomes (Clarebout and Elen 2006; Giesbers et al. 2013; Manlove et al. 2009), and knowing this can help instructional designers build scaffolds that students really want and need (Kirschner et al. 2004). Existing research has two limitations: it (a) does not differentiate sufficiently between how students use different types of instructional support, and (b) cannot provide sufficient guidance for the design of scaffolds for K-12 students. In this article, we focus on how and why K-12 students use computer-based scaffolds.

This paper is structured as follows. We first describe scaffolding. Then, we build our theoretical framework of how K-12 students use scaffolds through review of existing work on (a) differential use of instructional support, (b) affordances, (c) activity theory. In the method section, we describe our procedures for searching for literature to uncover empirical support for the framework. In the results section, we review empirical evidence of how and why K-12 students use scaffolds. Finally, in the discussion section, we note (a) how designers can use this information to design scaffolds that students need, and (b) implications for research.

Scaffolding

Scaffolding supports higher-order thinking, which begins in socially mediated interactions and gradually becomes part of an individual's cognition (Vygotsky 1978; Wood et al. 1976). Socially mediated interactions are actions influenced by interactions with other people and cognitive or physical tools. Mediation means that both social interactions and tool use alter individuals' abilities. Scaffolding is a tool—sometimes delivered via computer—that helps mediate and extend student capabilities (Belland et al. 2008; Hannafin et al. 1999). There are important distinctions between how students use scaffolding that supports well-structured problem solving (intelligent tutoring systems) and scaffolding that supports ill-structured problem solving (authentic problem solving scaffolds). Authentic problems have more than one correct solution or solution path (Jonassen 2000) and are similar to those encountered in the real world (Chinn and Malhotra 2002; Tang et al. 2010). Students using intelligent tutoring systems need to follow predefined paths, whereas students can use authentic problem solving scaffolds in many different ways. In this paper, we aim to help instructional designers create authentic problem solving scaffolds with affordances that align with student motives. Thus, we do not review research on intelligent tutoring systems.

Authentic problem solving scaffolds aim to structure and problematize problem solving (Reiser 2004), provide conceptual, strategic, procedural, and metacognitive support (Hannafin et al. 1999), and can either be context-specific or generic (Belland 2014). For example, context-specific authentic problem solving scaffolds in *DecisionPoint!* focuses student attention on things to consider when investigating the civil rights movement (Saye and Brush 2002). A generic authentic problem solving scaffold, the *Collaborative Concept Mapping tool*, helps high school students represent problems (Gijlers et al. 2009).

Theoretical framework for K-12 student scaffold use

Theories that contribute to this framework, what they add to a theory of K-12 student scaffold use, and why no one theory is enough are presented in Table 1. The model for how identified variables influence scaffold use is presented in Fig. 1.

Existing research on instructional support use

Clarebout and Elen (2006) did not find a consistent pattern of student characteristics' influence on the use of information resources, cognitive tools, knowledge-modeling tools, performance-support tools, information-gathering tools, conversation tools, and elaboration tools in computer-based learning environments. For example, factors such as field

Table 1 Theories and how they inform theory of K-12 students' scaffold use

Theory	Key findings/premises	What it adds to a theory of K-12 students' scaffold use	Why it is not enough
Instructional support use	No consistent pattern of student characteristics' influence on tool use	Provides evidence that instructional support is not always used in the same way by different students	Does not differentiate between information resources, performance support tools (e.g., calculators), communication tools (e.g., videoconferencing) and scaffolds Focuses largely on university students; university students are a subset of those who graduate from high school, with qualitatively different characteristics from the average high school graduate
Affordances	Tools may have multiple potential uses (affordances) Affordances can be grasped when users perceive the affordance and have an intention that aligns with the affordance	Provides theoretical basis for tools being usable to address different goals Provides clues on how to design to promote the perception of affordances	Does not sufficiently explain social mediation process by which individuals form intentions (motives)
Activity theory	Human activity is shaped by a complex, dialectical interaction between the individual, his/her motives, and other individuals or tools (signs) Signs are built based on culture, motives, and the individual's history with the entity	Helps explain social mediation process by which individuals form intentions (motives) and perceive affordances (signs) Highlights students' agency Promotes holistic assessment of systems in which students operate	Does not explain enough how differential scaffold use informs the design of scaffolds

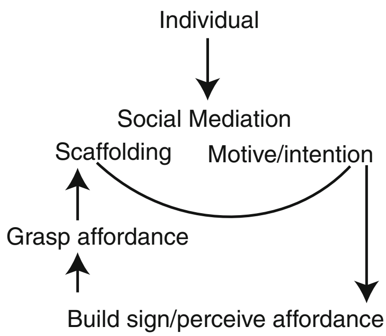

Fig. 1 How social mediation, motives, and perceived affordances interact to influence scaffold use

independence and ability influenced tool use sometimes, but failed to influence tool use other times. Students who are field-independent tend to be able to process information in component parts and are not "influenced by the existing structure of a field," whereas field-dependent students process information in contexts and do not tend to do well at "extracting relevant information from a complex whole" (Angeli et al. 2009, p. 1356). Similarly, Jiang et al. (2009) found that prior knowledge and goal orientation are related to tool use patterns. Goal orientation refers to the purpose for which students engage in learning tasks. Students with mastery goal orientations do so to achieve mastery in the target content or skills, whereas students with performance goal orientations do so to perform better than peers (Pintrich 2000). However, such characteristics did not significantly explain variance in all tool use (Jiang et al. 2009). Clarebout and Elen (2006) found that explicit encouragement led to increased tool use. In a later study, they found that explicit encouragement had limited effect on university students' use of a problem-solving tool (Clarebout and Elen 2008).

Kirschner et al. (2004) wrote that educational resources have technological, social, and educational affordances. Affordances are potential uses as perceived by users (Gibson 1986; Osiurak et al. 2010; Wagman and Carello 2001). Technological affordances refer to the usability of the resource. Social affordances refer to how resources can be used to satisfy social interaction intentions. Educational affordances refer to how resources can be used to meet learning intentions. For affordances of an educational artifact to be useful, they need to be perceived and lead to the fulfillment of a student's learning intention (Kirschner 2002).

Why existing research on instructional support use is not enough

For researchers interested in studying and or designing instructional scaffolds, existing research on instructional support use has at least three limitations. Existing work (1) covers many types of support, including information resources, performance-support tools, and instructional scaffolding, (2) does not clearly distinguish how and why students use these different resources, and (3) focuses largely on university students (Clarebout and Elen 2006, 2008; Jiang et al. 2009; Kirschner 2002). Information resources provide organized information to students. Performance-support tools, such as job aids, are not meant to lead to learning. Students likely have different goals regarding and approaches to using information resources and performance support tools versus instructional scaffolds. When participants are drawn from universities, it may make sense to generalize research results to university populations; however, it does not make sense to generalize such results to K-12 students, because they are from a fundamentally different population (Ary et al. 2002; Patton 2002).

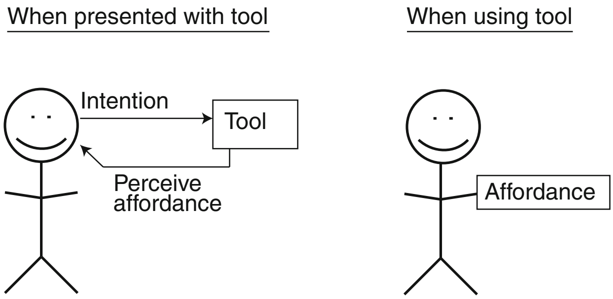

Fig. 2 How users perceive and grasp affordances according to affordances research

Affordances

Affordances research provides a theoretical basis for tools being usable to address different goals. It also helps designers consider how to promote the perception of affordances. The process of users perceiving and grasping affordances is illustrated in Fig. 2.

When considering affordances, one needs to consider capacity (Gibson 1986), intentions (Gibson 1986; Osiurak et al. 2010; Scarantino 2003), and perceptions (Gibson 1986; Osiurak et al. 2010; Wagman and Carello 2001).

Capacity

Consider a telescope. One can use a telescope to discover new stars or attributes of planets. One can also use a telescope to validate physics theories, or simply to admire the beauty of outer space. But just like any other tool, it does not have an unlimited number of affordances. For example, one cannot use a telescope to brush one's hair.

Intentions

Users' intentions shape the affordances they perceive (Gibson 1986; Osiurak et al. 2010; Scarantino 2003). That is, their intention drives that for which they seek support, which in turn flavors their perception of tools. Returning to the telescope example, an astrophysicist and an artist likely have different intentions when they interact with a telescope.

Perceptions

When viewing a tool, users see not only the tool's properties (e.g., lenses, a wooden handle) but also its affordances. Perceiving affordances involves technical reasoning in which users determine what can be accomplished with the tool (Osiurak et al. 2010) and their capacities to interact with the tool (Young et al. 2002). That is, they can engage in an internal, dialectical debate related to perceptions of affordances and technical reasoning about how to accomplish a task and why (Osiurak et al. 2010). Continuing with the telescope example, users may perceive a telescope as having the affordances of entertainment, discovery, or validation. Entertainment affordances are likely to be perceived by a person viewing the beauty of space. An astronomer may perceive the telescope's affordances of discovery when she uses a telescope to aid in the discovery of new stars or new attributes of planets.

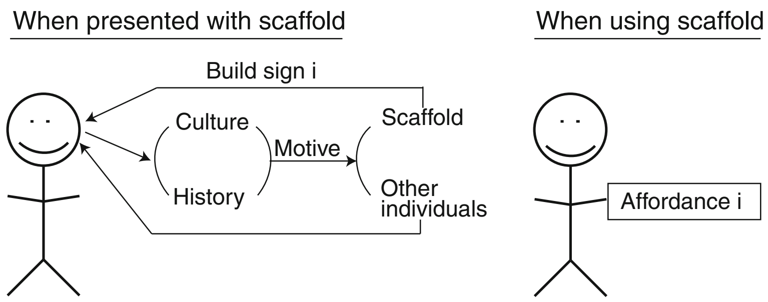

Fig. 3 How K-12 students perceive and grasp affordances in scaffolds according to combined framework

Why affordances research is not enough

Research on affordances does not consider the social mediation process by which individuals form intentions and engage with scaffolding.

Activity theory

Activity theory provides tools to explain the social mediation process of scaffolding (Engeström 2009; Jonassen and Rohrer-Murphy, 1999; Roth 2012). The process of perceiving and grasping affordances when activity theory is added is illustrated in Fig. 3. Activity theory holds that human activity is shaped by a complex, dialectical interaction between three entities—the individual, his/her motives, and signs (Leont'ev 1974).

As any instructor can attest, each student is different and will face differing challenges during learning tasks (Graf and Kinshuk 2006). These differing challenges can lead to differing (a) motives, (b) construction of signs related to tools, and (c) subsequent interaction with the signs (Leont'ev 1974).

All activity is undertaken with a motive in mind, even if the motive is implicit (Leont'ev 2009). The motives that individuals maintain toward a task vary according to cultural and historical factors. Cultural and historical factors include tacit knowledge and values as instilled by an individual's cultural experiences and personal history related to the task. Motives matter in that they affect how individuals construct signs.

Signs can be defined as other individuals or tools, and are defined based on culture, motives, and the individual's history with the entity (Leont'ev 1974; Wertsch 1991). As an example of how culture can shape individuals' perceptions of a tool, consider language. Language can be a tool to communicate needs/desires or to oppress others, and the way in which it can be used in these ways depends on one's culture, and specifically subculture (Bourdieu 1982). One's perception and use of language can then influence thought patterns (Luria 1976).

Why activity theory in not enough

Activity theory helps designers understand the social mediation process, but does not help them think about how to design scaffolds to encourage perception of needed affordances.

In the next section, we investigate empirical literature on authentic problem solving scaffolds to examine whether such scaffolds have been found to have different affordances and to be used accordingly. This is not meant to be a comprehensive review but rather to provide preliminary empirical support for this idea.

Methods

Search terms

We searched Education Full Text, Academic Search Premiere, ERIC, Google Scholar, and PsychInfo using combinations of the following search terms:

- Differential use
- (Computer-based) Scaffolds/supports
- Cognitive tools
- K-12
- Elementary school
- Middle school/level/grade
- High school/secondary school
- Interaction
- Qualitative
- Activity theory/CHAT

Inclusion criteria

To be included, studies needed to (a) be on authentic problem solving scaffolds, and (b) describe differences in how students used scaffolds and attempt to explain the reasons behind that use. Studies that did not meet these criteria were excluded. When sources reported findings from the same data set, the source with the most information was retained.

Procedure

Each research team member ($n = 3$) conducted literature searches using different databases, and applied the inclusion criteria to filter the results. Then, sources were compiled, resulting in 85 articles, dissertations, and conference proceedings. Next, two members of the research team applied the same inclusion criteria, plus a fourth criterion that the research needed to be on K-12 students. This brought the total number of sources down to nine—including five journal articles, three dissertations, and one conference proceeding—describing nine scaffolds. Two research team members summarized what each source said about how students used scaffolds. Due to lack of descriptive detail, three scaffolds (and two sources) were omitted. Of the remaining studies, five were conducted in middle schools, and two in high schools.

Differences in scaffold use

The seven published works that met the criteria to be included in this review are listed in Table 2. In each section, the Scaffold description, Differential scaffold use, and Why scaffold use varied—original authors' interpretation sub-sections report what the original

Table 2 Included scaffolds

Scaffold ∣ reference	Description	Grade level and subject	Relevant findings
Artemis[a] ∣ Abbas (2002)	Digital library interface designed to help students understand scientific language. It contains Persistent workspace Website abstracts Collaborative space	6th grade Science	Differences in components used and the order in which they were used may be attributed to differing teacher emphases and challenges faced by students
Explanation Constructor[b] ∣ Sandoval and Reiser (2004)	Students Pose questions Propose answers Gather related evidence	9th grade Biology	Differential use based on differing engagement, scaffold understanding, and/or problem-solving approach.
Galapagos Finches[b] ∣ Kyza (2009)	Helps students engage in evolutionary inquiry in a manner similar to that of evolutionary biologists; includes a database of relevant information	7th grade Science	Differences in scaffold use could be attributed to differing prior knowledge and higher-order thinking skills and understanding of the task and actions required to complete it
Shared Proposition Scratchpad[b] ∣ Gijlers and de Jong (2009)	Allows students to construct hypotheses and conduct simulations	High school Physics	Low prior knowledge and high prior knowledge students used the scaffolds differently based on their learning goals
Connection Log[a] ∣ Belland 2008, 2010	Students define problems, determine and find needed information, develop claims, and link claims to evidence	7th grade Science	Students used the *Connection Log* in different ways to overcome different challenges
WISE[b] ∣ Kim and Hannafin (2011)	An online suite of inquiry tools that allows teachers to develop units that center on a problem and that provide students with all relevant materials related to the problem	6th grade Science	How students interacted with *WISE* appeared to vary based on the level of engagement with the content and their problem-solving style

[a] Generic

[b] Context-specific

authors said. The why scaffold use varied—applying lens of motives and affordances subsection represents our application of the lens of affordances and motives.

Connection log

Scaffold description

The Connection Log is an authentic problem solving scaffold designed to help middle school students create evidence-based arguments while engaged in problem-based learning (Belland 2010). Students type responses to prompts individually, then come to consensus with their groupmates. Responses can be accessed later.

Differential scaffold use

In Belland (2010), two small groups made up of average- and higher-achieving students, respectively, were selected for case studies. Discussion about the scaffold prompts helped the average-achieving group determine what information they needed to find and what they needed to do with that information, and divide up tasks. The higher-achieving group used the scaffold to organize their evidence and to help them stay on task.

In Belland (2008), a lower-achieving group that included a student with low English language proficiency used the *Connection Log* to aid communication, record ideas, and think of ideas. The scaffold prompts helped group members think of what to find by encouraging group members to articulate and justify information to find. The *Connection Log* helped a higher-achieving group articulate information to find based on the system's categories, which served as a reference for creating their arguments later in the project. The scaffold also served to ensure that the group included all required project elements in the final project.

Why scaffold use varied—original authors' interpretation

One group in Belland (2008) faced communication challenges early on because one of the group members was a level 1 ELL student. The group described using the scaffold to mediate their communication since the ELL student felt most comfortable reading and writing in English. The higher-achieving group faced challenges getting started, and used the scaffold to respond to these challenges (Belland 2008).

In Belland (2010), the average achieving group faced challenges developing their overall strategy for the unit and dividing up tasks, and used the *Connection Log* to help them develop a strategy and divide up tasks. The higher-achieving group used the scaffolds to help them overcome those challenges in organizing information and staying on task. The difference in scaffold use does not imply that one group used the scaffold in a "better" manner than another: each use led to project success (Belland 2008, 2010).

Why scaffold use varied—applying the lens of motives and affordances

In analyzing student actions and comments in Belland (2008), we noted that the ELL student in the lower-achieving group behaved in a manner consistent with a motive to be involved in the group. However, talking with her groupmates was not working. Her subsequent actions can then be interpreted as her perceiving the affordance of the scaffold in aiding her communication with her group and using it accordingly. Based on the higher-achieving group's comments (Belland 2008), we deduced that they had a motive to get started so that they could perform well in the unit. Thus, it follows from their performance that they perceived the affordance of the scaffold in posing questions to get them started, and then used the scaffold to articulate information to find.

In Belland (2010), members of each group again displayed what could be seen as diverse motives (e.g., the average-achieving group to form a strategy for efficiently completing the task, the higher-achieving group to maintain focus). In each case, students appeared to perceive affordances aligned with their needs and use those affordances to accomplish their motives.

Artemis

Scaffold description

Artemis is a web-based interface through which middle school students can research topics in a digital library (Abbas 2002). It contains three scaffolds—*a persistent workspace,* in which students can post driving questions and "cool sites;" *website abstracts*, which preview resources; and a *collaborative space*, in which students can share and receive feedback on driving questions and cool sites from other groups.

Differential scaffold use

Sixth grade students in four schools used *Artemis* differently (Abbas 2002). Some students looked at driving questions shared by previous groups to get ideas for their own driving questions, while others developed driving questions before looking at shared driving questions. One group viewed shared cool sites, then searched for and viewed website abstracts, but did not view the associated websites. Another group viewed shared driving questions, searched, and viewed abstracts, associated resources, and shared cool sites.

Why scaffold use varied—original author's interpretation

Abbas (2002) attributed differences in scaffold use to differences in teacher emphases, but was unable to attribute specific teacher emphases to successful use of the scaffold. However, if all variation in scaffold use could be attributed to teachers, then there would be consistency in student use of scaffolds within classes, which was not the case beyond problem initiation; higher-achieving, average-achieving, and lower-achieving students within the same classes all used the scaffolds differently. A plausible explanation is that teachers emphasized different scaffold uses to students based on their ability levels. However, data is not available to support this explanation.

Why scaffold use varied—applying the lens of motives and affordances

We believe a plausible explanation for within-class variation in Abbas (2002) is that lower-achieving students faced different challenges than average- and higher-achieving students. As a result, they had different motives for using the scaffolds and perceived and selected tools with affordances aligned with overcoming those challenges. The teacher emphases may have interacted with student needs to produce differing motives, and that this in turn led students to perceive different affordances in and use *Artemis* differently.

Shared proposition scratchpad

Scaffold description

The *Shared Proposition Scratchpad* is a domain-specific scaffold that helps high school students investigate physics problems (Gijlers and de Jong 2009). It provides building blocks (e.g., variables) with which students construct hypotheses and allows students to conduct simulations to test the hypotheses.

Differential scaffold use

Students who used the *Shared Proposition Scratchpad* varied in how they approached tasks (Gijlers and de Jong 2009). For example, members of a low prior knowledge group who used the *Shared Proposition Scratchpad* spent much time constructing each hypothesis because they were unfamiliar with needed terms, and spent less time testing the hypotheses through simulations. Thus, this group discussed fewer unique hypotheses than other groups, since they spent a lot of time researching the terms involved in the problem. A group with greater prior knowledge did not need to spend as much time researching terms and spent more time discussing how the terms fit together to form a hypothesis.

Why scaffold use varied—original authors' interpretation

Gijlers and de Jong (2009) noted evidence that differences in prior knowledge led to differences in scaffold use. However, one should not believe that the students who discussed more unique propositions (hypotheses) used the *Shared Proposition Scratchpad* "correctly," while other students used the scaffolds "incorrectly." This is because the two groups perceived the task differently based on their prior knowledge—the low prior knowledge group sought to learn the requisite vocabulary necessary to form hypotheses, while the high prior knowledge group, knowing the vocabulary, focused on creating and discussing their hypotheses (Gijlers and de Jong 2009).

Why scaffold use varied—applying the lens of motives and affordances

The low prior knowledge group can be seen as having the motive of understanding content by studying vocabulary, while the high prior knowledge group had a motive of generating hypotheses. Thus, the students sought affordances aligned to their motives and used the scaffolds accordingly.

WISE

Scaffold description

Web-based Inquiry Science Environment (*WISE*) is designed to promote knowledge integration/deep understanding of science topics. It guides students through an inquiry map, and provides evidence pages, hints, and prompts to help students monitor and reflect on their progress (Linn et al. 2003).

Differential scaffold use

Kim and Hannafin (2011) studied *WISE*'s effect on problem-solving processes during a unit on wolves in a gifted 6th grade science class. The researchers grouped students' problem-solving behaviors into four categories—inquirer, reasoner, negotiator, and trial-and-error. Students worked in self-selected groups of 2–3; criteria for self-selection included problem-solving styles and interests. The inquirers were highly interested in the subject matter and method of learning. They used the scaffolds to refine their sense-making skills and often engaged in self-assessment. They engaged with the scaffolds most deeply during inquiry activities, while relying little on the teacher and their peers.

Reasoners used the scaffolds to gather and evaluate evidence, while attempting to expand their understanding of the subject and the technology (Kim and Hannafin 2011). Their approach balanced the depth of their engagement with peer, instructor, and technology scaffolds. Like the inquirers, reasoners used scaffolds to refine their sense-making strategies.

Negotiators used a task-based approach to the problem and the scaffolds, focusing on completing specific actions in the prescribed order (Kim and Hannafin 2011). They avoided exploration and self-assessment, frequently checking their progress against that of other students. They also frequently requested formative assessment from the teacher. This approach led them to engage only superficially with the provided scaffolds, excepting the communication scaffolds.

Trial-and-error students worked quickly so they could engage in extra-curricular activities (Kim and Hannafin 2011). They frequently asked for teacher assistance, engaging as little as possible with technology scaffolds and more advanced peer scaffolds. Students frequently used *WISE* to organize assignments and resources and to save answers to revisit later. Because the class was face-to-face, chat features were rarely used to request immediate support.

Why scaffold use varied—original authors' interpretation

It would be easy to say that the inquirers engaged most productively in the unit, but Kim and Hannafin (2011) found that negotiators actually communicated more deeply. Also, reasoners engaged at least as deeply in all processes as negotiators except communication (Kim and Hannafin 2011). Rather than showing that one group used the scaffolds "correctly," the study showed that multiple scaffold use patterns can lead to project success (Kim and Hannafin 2011).

Why scaffold use varied—applying the lens of motives and affordances

Each group's motives were shaped by members' needs. The inquirers' motive appeared to be to learn technological and content knowledge on their own. The negotiators' motives were to socially construct knowledge. Each group perceived affordances and used the scaffolds accordingly.

ExplanationConstructor

Scaffold description

Sandoval and Reiser (2004) developed *ExplanationConstructor* to help 9th-grade biology students organize investigations in data-rich inquiry environments. Within it, students can pose questions, propose hypothetical answers, select answers, and gather evidence either proving or disproving the explanation (Sandoval and Reiser 2004).

Differential scaffold use

Students frequently referred to *ExplanationConstructor* to monitor their progress as they examined evidence of evolution. Many discussions focused on questions to answer, boxes to fill, and questions to write. Planning was an iterative process based on results of browsing through data and the desire to explain or understand them. The software supported student planning dialogues to the extent that representations in the tool were consistent with students' understanding of the task. While an example was presented of students discussing how to use an explanation prompt, the most typical result was a decision on the prompt to use without discussion. The level of discussion in general was dependent on the dominance of the student in charge of the keyboard and the engagement of other students. Students spent much time discussing how to interpret their data but rarely linked it to their explanations.

Why scaffold use varied—original authors' interpretation

Not all students engaged with the scaffolds in the same way as the case study group (Sandoval and Reiser 2004). Often, dominant students would decide which scaffold to use. Groups also varied in the extent to which they monitored the progress of their investigations.

Why scaffold use varied—applying the lens of motives and affordances

As in Kim and Hannafin (2011), these differences may have been due to students' level of engagement with the material, their understanding of the scaffold environment, their problem-solving approach, or a combination of the three. While Sandoval and Reiser (2004) noted these differences, their analysis focused on finding epistemic practices rather than explaining why there were differences in students' engagement in these practices. However, there did appear to be different affordances of the scaffold. One intended affordance seems to be that of monitoring progress. However, since some students did not use these scaffolds as extensively as the designers may have desired, it would appear that this particular affordance was not perceived as salient to fulfilling their motives.

Galapagos finches

Scaffold description

Galapagos Finches helps middle school students investigate influences on natural selection of ground finches in the Galapagos Islands (Kyza 2009). Its scaffolds (a) make explicit the mode of inquiry of evolutionary biology, (b) allow students to engage in inquiry in a manner similar to that of evolutionary biologists, and (c) provide information on which students can base their inquiry (Kyza 2009). Kyza (2009) examined how six pairs of higher-, average-, and lower-achieving middle school students used the scaffolds.

Differential scaffold use

One higher-achieving pair generated nine hypotheses (Kyza 2009). They often summarized their thinking by talking or writing it in their journal. Their solution agreed with the expert solution at a high level. They first used previous knowledge to generate hypotheses. They then chose data, made predictions, and interpreted data.

The other higher-achieving group generated three hypotheses, all based on options available in the software (Kyza 2009). Despite collecting data for these hypotheses for most of 5 days, they still had incomplete supporting data. They approached investigation as a comparison task and did not state any hypotheses not supported by the scaffold search features. After not finding refuting evidence for their third hypothesis, they gathered evidence in support of it.

One average-achieving pair generated four hypotheses, including one that was simply announced as the "right" answer (Kyza 2009). Thereafter, they were more focused and coordinated evidence and theory more than on the previous three days combined. They used a data-driven approach and did not discuss hypotheses relative to data seeking. They struggled moving beyond the initial comparison in a way that helped the inquiry progress.

The other average-achieving pair discussed the need to provide evidence but had trouble finding supporting evidence (Kyza 2009). They began with data-driven exploration. They correctly identified the cause but did not provide evidence for their hypothesis. They then generated four hypotheses, none of which mentioned the correct cause. The students worked to support their hypotheses and modified them as necessary. They had trouble generating new hypotheses after dropping unsupported ones. The teacher helped by suggesting strategies to employ, paths to take, and connections to make.

The first lower-achieving group articulated ideas less than the typical group and avoided comparing physical characteristics (Kyza 2009). They provided evidence for only part of their explanation. Additionally, they had trouble testing hypotheses but did not express awareness of the problem. They investigated without trying to connect their search to their hypotheses. They emphasized quantity of evidence over quality. Fundamentally, they understood the purpose of the hypothesis testing to be guessing.

The other lower-achieving pair generated five hypotheses, each of which was influenced by choices in the software (Kyza 2009). They compared data but did not investigate all avenues. They also did not identify disconfirming evidence. One student explored and the other documented findings. They discounted the "right" answer after looking at the wrong data set and expressed confusion at having multiple hypotheses. The teacher asked them to collect data on alternative explanations. This led them to examine several alternative explanations, but such alternative explanations were not included in their final explanation.

Why scaffold use varied—original author's interpretation

There were clear differences in scaffold use between and within achievement levels (Kyza 2009). Differences between achievement levels may likely be attributed to differing levels of applicable prior knowledge and higher-order thinking skills. This would cause hypothesis generation to be more (in the case of low prior knowledge) or less (in the case of high prior knowledge) difficult. The lower-achieving groups appeared to engage with the scaffolds in a less effective manner than the higher- and average-achieving students (Kyza 2009). But there were some positive aspects to the approaches of the average-achieving groups, especially in that they employed a data-driven approach. The current authors note that this is an expert problem solving approach (Gick 1986; Jonassen and Hernandez-Serrano 2002; Weisburg 1993). Differences within achievement levels are more difficult to explain (Kyza 2009). These differences may be due to students' various understandings of the nature of the task and the actions required to complete it (Kyza 2009).

Why scaffold use varied—applying the lens of motives and affordances

If the students' actions were indeed driven by their differential understanding of the actions needed to complete the task, their motives for engaging with the scaffolds would, in turn, be shaped by these understandings. For example, the first lower-achieving group's focus on collecting large amounts of information could be driven by a motive to prove their hypothesis. The students could then perceive the rich data environment of the scaffold as having the affordance of providing only relevant information. Because not all students used the scaffolds in this way, we can say that the scaffolds presented different affordances and were used accordingly by different student groups. Such use may be attributed to differing student motives.

Discussion

Implications for scaffold design

Thus far, we (a) described how previous research on differential instructional support use, research on affordances, and activity theory can combine to form a framework for explaining how and why K-12 students use scaffolds, and (b) reviewed evidence of how and why K-12 students use scaffolds. Ultimately, we want to not only propose these ideas, but also discuss how designers can use this information to design scaffolds that students really need.

Akhras and Self (2002) explored how to build multiple affordances into scaffolds. Rather than only constructing theories of the task and the tutee, designers should construct process, situation, and affordance models. Process models pertain to how interactions develop. Situation models refer to the types of situations in which the resource could be used, and consist of "objects, relations between objects, properties of objects, potential states of objects and possible transitions of state between them" (Akhras and Self 2002, pp. 12–13). Affordance models contain a scaffold's possible uses. As this paper indicates, designers should also construct a motives model.

Constructing process and situation models

Constructing process, situation, and affordance models and traditional instructional design differ in that in the former, the focus is on the situations in which the scaffold will be used, and on groups rather than individual students (Akhras and Self 2002). As such, it is crucial to consider the system in which the scaffold will be used—individual students and their groupmates, their challenges, their motives, and tools.

Process model Constructing a process model is akin to step 2 of the Jonassen and Rohrer-Murphy (1999) model for designing constructivist learning environments—analyze the activity system. In this step, designers describe the social interactions among participants and how labor may be divided. Knowing the nature of possible social interactions among students is central to determining how tools can be used. Furthermore, within authentic problems, there may be multiple feasible divisions of labor, and designers should predict most such divisions.

A key factor influencing social interactions and, thus, problem solving is communication (Rojas-Drummond et al. 2008). Communication is not a simple binary construct. The designer needs to go beyond just whether or not students will communicate: s/he should know communication patterns among target students. What do they talk about, and how? What communication problems might students encounter? One way to assess this is through discourse analysis among target students (Collins 2008; Ten Have 1999). Discourse analysts describe micro-cultures through examination of discourse passages to see what they tell about social and cultural influences on communication (Bloome et al. 2005). One could videotape target students engaging in learning processes similar to those to be supported by the scaffold, select brief discourse units, and consider how the form of the language used in the discourse unit and turn taking indicate "identities, roles, and/or relationships for the" students (Ten Have 1999, p. 106). Designers may learn that when discussing target content, students gravitate toward non-productive interaction styles (e.g., dominant group member). Students engage in collaborative problem solving to benefit from the diverse perspectives and talents that multiple individuals can bring to a group task. If target students gravitated toward unproductive interaction, this would be important to consider both in the design of the scaffold, but also in a consideration of potential motives that students could have.

Designers also should consider division of labor. Unfortunately, this is not as easy as doing a traditional task analysis and saying that if there are three students, each can take one major component of the task. This is because authentic problems have many possible solutions and solution paths (Jonassen 2000). Rather, the simplest way may be to consult the literature for reports of similar students solving similar problems. What division of labor did students in these reports assume? Not all such reports will include such information, but it is likely that much case study work will. Such information can be considered both in the design of the scaffolds, and in a consideration of what motives students will face when engaged in the target learning task.

Situation model Constructing a situation model can be related to step 3 in the Jonassen and Rohrer-Murphy (1999) model for designing constructivist learning environments—analyze the activity structure. In this step, designers focus on (a) the motives of the task, (b) "the planning and problem solving actions" required to complete the task (Jonassen and Rohrer-Murphy 1999, p. 73), and (c) the automatized, nonconscious activities required to perform actions. However, motives will be considered in their own category.

Constructing a situation model involves thinking about how students plan and approach problem solving in the target activity. This is easier with context-specific than with generic scaffolds. For example, in *Galapagos Finches*, students will always be approaching the same problem (Kyza 2009). While there are different ways to solve it, the types of considerations that students will need to make and approaches to solving the problem will be similar across students. Designers will need to consider the scope of the activity to outline how students will approach problem solving. It is more complicated with generic scaffolds because designers need to think about all possible problems with which the scaffold could be used. Different problem solving approaches may be needed with different problems. Empirical evidence from target students who outline how they would approach solving the possible problems would be useful here.

Considering non-conscious, automated activities required to perform actions is also useful because some students may not have the skills needed to perform such activities. In that case, designers would do well to support such activities in the scaffolds. To consider such, data could be collected through close observation of students engaged in solving similar problems, or relevant empirical literature could be consulted.

Constructing motives and affordances models

After constructing process and situation models, designers may have a preliminary understanding of what affordances are needed. For example, by understanding the division of labor, designers may know what tasks individual students may perform, and what associated challenges they may face. They may also understand the planning steps students need to take. But this does not entirely explain what affordances should be embedded in the scaffolds. This is because affordances are not properties of the scaffold, the situation, or the student individually; rather affordances result from the confluence of the three (Akhras and Self 2002; Osiurak et al. 2010). Furthermore, affordances cannot be acted upon if they are not perceived (Akhras and Self 2002; Osiurak et al. 2010; Scarantino 2003). The critical factor is the student's motives.

Motives model Viewed from the activity theory perspective, motives are clearly influenced by interactions with others and the situation in which those interactions are experienced (Leont'ev, 1974; Roth and Lee 2007). But, at the same time, one cannot know with certainty what motives individual students will hold if one knows simply the type of interactions they will experience, and in what situations (Leont'ev 2009).

Each student may tend to harbor particular motives in particular subjects. It may be feasible to determine this prior to initial design through such data collection efforts as surveys conducted among target students (Veermans and Tapola 2004). But when students use scaffolds in actual units, the way they build the sign that the scaffold represents will depend on motives that stem from a number of factors—past experiences with similar tools, culture, and challenges. Many motives will not emerge until students are faced with a similar unit. Thus, designers should not stop at surveys (Veermans and Tapola 2004). Having target students engage in a unit while using the scaffolds and collecting interview and observation data from an ethnomethodological perspective can be useful to determine how challenges, culture, and other factors influence student motives and their building of signs. By applying an ethnomethodological framework, researchers seek to explain the methods by which individuals make sense of everyday experiences (Garfinkel 1967).

A drawback of the approach we suggest above is that it is very expensive. As noted by Thiagarajan (2002), instructional designers always want to do their work faster, better, and cheaper. Making scaffold development cheaper is important because there are only so many large federal grants that can be obtained to do such research. The field needs to move to a more automated design model for determining needed affordances for scaffolds and building such affordances into scaffolds. Specifying the exact form that such a model would take is beyond the scope of this paper, but it may emerge through faithful reporting of not only the results, but also the process of design research with scaffolds (Bannan-Ritland and Baek 2008; Edelson 2002).

Affordances model Affordance models reflect what students can accomplish with scaffolds (Akhras and Self 2002). Students cannot perceive affordances that a scaffold cannot support. Once designers know what motives may arise in target students and in what situations and in what type of interactions, affordances that students may seek can be considered and then built into the scaffolds. When considering how to build affordances into scaffolds, one needs to consider how students perceive affordances in the scaffold, how students can be encouraged to grasp affordances, and what affordances need to be supported by the scaffold.

Designers should ensure that affordances are indicated by the form of the tool (Faiola and Matei 2009; Pols 2012). Helping users perceive affordances can be as simple as adding a button (Hsiao et al. 2012; Pols 2012). But with scaffolds, adding buttons may not be enough. For example, if designers know that dividing up tasks can be challenging in the target task, then they can build features into the scaffold that allow for efficient division of tasks. This can be indicated by a prompt that leads students to divide up tasks, a step in which students need to divide overall tasks into smaller components, or both. Students need to know that dividing up tasks is possible and encouraged, because left to their own devices many K-12 students will either not divide up tasks or half-heartedly divide up tasks but end up duplicating efforts nonetheless (Belland et al. 2009). If designers know that oral communication is likely to be a challenge among target students, they can design scaffolds such that individual students need to articulate in writing their ideas. Text boxes that afford writing paired with instructions can encourage articulating ideas in writing. But the text that they write needs to actually be read by groupmates.

It is one thing to perceive affordances; it is yet another to actually grasp affordances. To grasp an affordance, the affordance needs to be aligned with individual students' motives, and students need to recognize this. This is easier done with something like a switch, which has the affordance of making a dark room bright (Pols 2012) than with a scaffold. This may mean that instructional messages should be added to scaffolds to help students recognize how a scaffold affordance can align with a particular motive. For example, in the case of a scaffold affordance of aiding communication, explanatory rationales (e.g., to ensure that all thoughts are voiced and heard/read) could explain why students should articulate their ideas in writing (Belland et al. 2013).

Designers should carefully assess target students' motives and think about what affordances align with those motives. This should not be an afterthought, because design decisions made early on (e.g., computer architectures and programming languages) limit what affordances can be supported. No tool can have an unlimited number of affordances. Also, no tool can be tweaked to have any desired affordance. For example, an axe cannot be tweaked to aid the discovery of cellular processes. Its underlying design is simply wrong for that.

Implications for research

In this paper, differences in scaffold use were attributed to factors such as communication challenges (Belland 2008) and differences in prior knowledge (Gijlers and de Jong 2009; Kyza 2009) and teacher emphases (Abbas 2002). These challenges led to differing motives. No one method of using a scaffold consistently led to better results.

Why do students use scaffolds differently? First, when students examine a scaffold, they may not perceive what the scaffold designer intended (Gibson 1986). Rather, they may perceive affordances in scaffolds according to their motives (Gibson 1986; Osiurak et al. 2010; Wagman and Carello 2001). They can then use the scaffold in a manner that aligns with their needs.

Central to the concept of differential use of scaffolds are users' motives. Student motives were of utmost concern to the earliest formulators of the instructional scaffolding idea (Belland et al. 2013). Wood et al. (1976) noted that the first step of scaffolding was to enlist students' interest in the task. Intentions/motives are a central concept in activity theory (Engeström 2009; Leont'ev 1974, 2009), which forms one of the conceptual foundations of scaffolding.

One might ask if it is desirable to allow students to recognize affordances of scaffolds and use them accordingly. In the original scaffolding metaphor, teachers determined the support students needed at any given time and provided exactly that (Collins et al. 1989; Wood et al. 1976). However, that is not realistic with authentic problem solving scaffolds. The affordances need to be determined, and the only feasible way with current technologies is for the student to do so (Gibson 1986). Through a process of perceiving affordances in scaffolds, students may be able to use a scaffold in ways that align with their motives.

The idea of users perceiving affordances begs a few questions. First, what is the mechanism by which this perception emerges? Is it best explained by the ideas of Gestalt psychology, i.e., potential uses are perceived when the user perceives the whole activity system—motive, individual, and sign (Helson 1933)? But this seems to imply a conscious awareness of motive, which may not always be the case (Roth and Lee 2007). Second, are there specific cues built into signs that some individuals pick up on, while other individuals pay attention to other cues? Do they see those cues (e.g., a prompt telling them to come to consensus with their groupmates), compare that to their motive (e.g., engage in more productive group work), and then perceive the affordance of the scaffold to aid in group work? If so, can these cues be manipulated by designers to promote certain affordances over others?

Dialectics may help one consider the mechanism by which affordances of scaffolds are perceived and adopted by students. Students may perceive several possible uses of a scaffold, but this does not mean that the scaffold will be used in all those ways. Rather, students may engage in a dialectical debate of the possible uses of the scaffolds. All dialectical systems have an organizing principle (Lunenfeld 1999). In this case, the organizing principle is the student's motive. This motive may help the student arrive at his/her best use of the scaffold.

Limitations, remaining questions, and suggestions for future research

A limitation of this paper is that the authors of the included studies did not collect data on differential scaffold use through systematic measurement of motives. Thus, we carefully culled information from research reports that may imply particular motives, or suggest that motives may be at play. In doing so, we had to rely on what was presented in the included studies. What we found when examining the included research reports was undoubtedly influenced by the corresponding authors' viewpoints, as researchers' theoretical perspectives influence study design, analysis, and writing of research reports (Eisner 1992; Lather 2012). There is a need for systematic measurement of individual and group motives to fully understand if motives and perceived affordances of scaffolds explain how and why scaffolds are used.

There is a need for empirical validation of the models—process, situation, motives, and affordance—that we proposed to develop scaffolds. It is beyond the scope of this paper to do so. But such empirical validation would be a great avenue for future research.

Authentic problem solving scaffolds may hold multiple affordances for the same individuals. This may happen when individuals have multiple motives in an inquiry-learning task (Simons et al. 2004). However, this leaves some important questions. Is it possible to have multiple affordances that are of equal importance? Or is one clearly a more important function for a given individual? If so, is it important for researchers to find out which?

There is a need for more research examining the extent to which students use authentic problem solving scaffolds differently. For example, does differential use depend on scaffold form? For example, are scaffolds in the form of question prompts more likely to be used differently than scaffolds in the form of expert modeling? Or vice versa? What about between generic and context-specific scaffolds? Also, there is not enough information regarding the best methods to discover student motives during inquiry units. When students work together during inquiry units, it seems possible that different students would have different motives. Is it reasonable to consider each student's motive separately? According to activity theory, it does not seem appropriate. However, it would be challenging to consider motives from the group level. First, group members may have differing individual motives. These individual motives may not be entirely displaced by a group motive. Second, determining a group motive is challenging from a measurement perspective. One could conduct a focus group interview, but the focus group methodology does have limitations. For example, in a focus group interview, participants are talking from their own experience but also in a particular context, so results may be indicative of individual viewpoints or viewpoints skewed towards that of other participants (Gibbs 1997).

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