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Scaffolding and supporting use of information for ambitious learning practices

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Abstract

Purpose – This paper aims to lay out the goals and challenges in using information for ambitious learning practices.

Design/methodology/approach – Through a review of the literature, the authors integrate across learning, information sciences and instructional design to identify challenges and possibilities for information searching and sense-making in ambitious learning practices (ALPs).

Findings – Learners face a number of challenges in using information in ALPs such as a problem-based learning. These include searching and sourcing, selecting information and sense-making. Although ALPs can be effective, providing appropriate scaffolding, supports and resources is essential.

Originality/value – To make complex ALPs available to a wide range of learners requires considering the information literacy demands and how these can be supported. This requires deep understanding and integration across different research literature areas to move toward solutions.

Keywords Problem-based learning, Information seeking, Resource integration, Sense-making, Scaffolding, Ambitious learning practices, Complex problem solving, Problems of practice

Paper type Conceptual paper

> True knowledge – understanding – develops through exploration, rumination, interpretation, judgment, and the application of information. Thoughtful work on projects and problems requires roaming through complex resources, seeking inspiration, messing around, making missteps and mistakes, and experiencing serendipitous discoveries. This kind of student learning and the in-depth interactions with teachers that it entails requires time. (Hawkins, 1997).

Meaningful information problem solving in the classroom involves specific and intentional pedagogies, requiring of instructors and facilitators the type of classroom practices that are ambitious in goal, scope, and enactment. As Hawkins (1997) asserted, deep meaning-making and learner agency are critical to learning and knowledge building. We argue that such classroom pedagogies are ambitious in scope and substance and here use the term *ambitious learning practices* (ALPs) to reflect these substantial goals. Furthermore, we use problem-based learning (PBL) as an example of ALP, which involves scaffolded inquiry as students engage collaboratively in a meaningful task. PBL tasks with scaffolding support are intentionally designed as part of a well-established signature pedagogy (Hmelo-Silver *et al.*, 2018b). PBL is particularly apt as an ALP example because learners rely on successful information seeking to address the inquiry task. Thus, there is value in what can be learned from

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research that explores these different aspects from the perspectives of learning sciences, instructional design, and the information sciences.

Although ALP, PBL and information seeking have been explored in disparate literatures, the time is ripe to bring them together and explore their conceptual intersections. For example, although some information scientists have considered scaffolding (Kuhlthau *et al.*, 2015), this concept, which is long inherent to learning sciences work, has been less of a focus in information science where scholarship has been more about free and open search. In contrast, learning sciences and instructional design have prioritized understanding a range of practices, processes, and outcomes of learning in designed environments, without special consideration for how to integrate critical information literacies. When considering this interdisciplinary scholarly nexus, it is important for those in the information sciences to learn more about ALPs, PBL and scaffolding, and it is important for LS researchers to learn from information scientists about search research. One aim of this article is to invite these interdisciplinary conversations and conceptual explorations.

In classroom applications, ALPs represent a range of approaches that are inherently collaborative and engage learners in authentic, meaningful work coupled with:

- an enabling context that fosters disciplinary grounding;
- the ability to make meaning from resources; and
- guidance in the form of scaffolds along with other support systems (Hmelo-Silver *et al.*, 2018b; Knight and Mercer, 2017; Puntambekar and Kolodner, 2005; Tabak, 2004).

In this authentic, meaningful context, learners are meant to take an active role, one that involves enacting agency toward pursuing learning goals and deep information seeking (Bridges *et al.*, 2012). Thus, in defining features of ALPs, it is important to look across different research domains to surface common problems and solutions associated with creating the conditions for ambitious learning to occur in the classroom. For example, when presented with a problem or issue to consider, learners may not know how to what they need to learn. This poses significant challenges because they have to operate without relevant contextual knowledge, and it is difficult for learners to know where to start (Derry *et al.*, 2006). However, one important key to successful learner engagement in ALP is being able to initiate and sustain information seeking, and integrate across multiple forms of information (Reynolds, 2016). To explore these issues further, we draw primarily from illustrative PBL examples focusing on features common across ALPs: enabling contexts, making meaning from resources, and scaffolding support for the learner.

Ambitious learning practices: an overview

Enabling contexts

The enabling context is a critical feature of ALPs serving to organize, motivate and frame the learning experience. More specifically, the enabling context is composed of practices, situations, and processes, and offers learners opportunity to develop and apply deep understanding in the discipline (Hmelo-Silver *et al.*, 2007; Hannafin *et al.*, 2014). For example, an instructor of medieval history engaged undergraduate learners in a complex experience that began with a close reading of a biographical text of a military leader during the Third Crusade (Craig, 2017). Through text, document analysis, geographic information systems and other digital tools, teams of students created maps to depict travel times based on medieval travel methods, scale, or relative importance of a geographic location that reflected emotional experience from the texts. Students relied on a variety of resources to construct

their maps toward the overarching goal of understanding that agency is impacted by geographic context and conveying that meaning graphically. One key outcome was a shift in student understanding of the region as being both temporally and spatially bound in categorically different ways than we know today. For example, student views shifted away from perceiving Jerusalem as centrally important during this period toward understanding that the more dominant role was occupied by a small fortress of Acre on the Mediterranean coast (Craig, 2017). In this way, the context and the task provided opportunity for students to gain new perspectives, engage in deep collaboration, and convey their understanding. However, critical to this endeavor is the student ability to make meaning from resources.

Making meaning from resources

While students have prevalent and generally dependable access to a wide range resources given the learning issues they are pursuing, it is critical for learners to engage strategies for making meaning. These involve being able to examine the information, determining which information is most relevant, and evaluating the quality of that information (Goldman and Brand-Gruwel, 2018; Kuhlthau *et al.*, 2015). However, novice problem-solvers have difficulty critically evaluating the information they encounter with relation to the problem (Limberg *et al.*, 2008). For example, Knight and Mercer (2017) engaged learners in a problem about role models, and asked learners age 11-12 to make judgments about why high profile individuals represented good role models. One outcome was that success in the information seeking task was linked to the quality of epistemic talk within the team, suggesting that there was considerable variability within and across groups as many teams struggled to locate and evaluate information. Thus, the ability to manage information, determine its relevance, and make evaluative judgments is critical when engaged in any type of ALP generally (or PBL specifically) (Dodd *et al.*, 2010), which implies a need for targeted interventions and guidance to support learner efforts.

Guidance and scaffolding

Resources and context are not complete without guidance, or scaffolding, and this can be available in many forms in ALPs. Scaffolding as guidance reflects a metaphorical use of the term – a temporary support that assists until the learner can internalize strategies and processes to reach independent proficiency (Wood *et al.*, 1976). More specifically, scaffolding allows learners to accomplish tasks with assistance that they could not accomplish independently. Initially scaffolds were conceptualized as just-in-time support, though over time more diverse elements emerged in forms both pre-planned or adaptive (Ertmer and Glazewski, 2018). Preplanned scaffolds have been referenced as fixed (Azevedo *et al.*, 2004), material (Tabak, 2004) or hard (Brush and Saye, 2002), and represent static supports based on known or anticipated task difficulties. In contrast, just-in-time scaffolds reflect the original conceptualization – support that is provided in the moment of need. These have been referred to as soft (Brush and Saye, 2002), dynamic (Greene and Land, 2000), or adaptive scaffolds (Azevedo *et al.*, 2004). One critical contour, however, is the assumption that scaffolding should be conceived as a blended and distributed system that features both fixed and adaptive approaches to ensure learner success (Saye and Brush, 2004; Puntambekar and Kolodner, 2005). Pea (2004, p. 444) further asserted:

> It seems possible to imagine "mixed initiative" designs of scaffolding processes in which people and machines join together in helping someone learn something in the sense that certain scaffolding activities can be the responsibility of the teacher [. . .] and other scaffolding activities provided by the software.

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One approach to scaffolding draws from cognitive apprenticeship framework and may include such techniques as modeling, coaching, communicating process, and eliciting articulation (Collins and Kapur, 2015; Eberle, 2018; Hmelo-Silver and Barrows, 2006). Other scaffolding strategies including structuring, which is a form of expert modeling and/or communicating process embedded in a fixed scaffold (Reiser, 2004).

In one study of blended scaffolding, a high school biology teacher engaged students with the following PBL question: "What laws should we have to govern the use of genetic information in health insurance, employment, life insurance, and long term care insurance?" (Shin *et al.*, 2017, p. 4). The teacher used an application, known as SSI-Net, to organize and annotate resources, integrate team white boards and provide graphic organizers. The researchers observed the teacher engaging with significant adaptive, soft scaffolding techniques, and drew the conclusion that the hard scaffolding enabled more time and space for the soft scaffolding to occur.

Together, these three different features of ALPs – enabling contexts, making meaning from resources and scaffolding – may help foster the authenticity and meaning that drives the learning process. That is, although the features represent specific design and implementation choices made by the educator, one intention should be for learners to experience the environment as authentic and meaningful.

Toward authenticity and meaning

Authenticity originates from real or realistic experiences and tasks that have value beyond school, while meaning is triggered when a student jointly perceives the value and connects to the work professionally or personally (Newmann *et al.*, 2001). For example, in Gomoll *et al.* (2018b), middle school learners built robots to accomplish tasks that were important in their classroom or school such as a robot that would help the nurse carry supplies or help the teacher collect papers. In addition to the robots instrumental function, they also tended to make the robots personal, such as decorating the teacher assistant robot with the logo and colors of a local university. One important outcome of this study was a broadened notion of science, technology, engineering and mathematics among the students in ways that connected the social and the technical.

To foster authentic, meaningful experiences in the ALP classroom, the instructor or facilitator uses a range of orchestration strategies. These are driven by an enabling context to establish disciplinary grounding. However, authenticity and meaning create a great of complexity which requires the guidance and scaffolding that support student to successfully engage in ALPs. Throughout this article, we use PBL as an example to show how these features are enacted, though as we have noted, ALPs comprise more than PBL.

Problem-based learning: one form of ambitious learning

PBL is a student-centered inquiry approach to learning that begins with a dilemma to be addressed as students work in small collaborative groups with the teacher serving as a facilitator of learning. For example, students may work in small groups to determine the cause of fish death in a pond (Saleh *et al.*, 2018; Sinha *et al.*, 2015) or explaining the cause of a patient's illness (Hmelo-Silver and Barrows, 2008). The heart of PBL is a rich problem context that enables generative discussions but also includes various information resources and scaffolding (Ertmer and Glazewski, 2018). We consider this an ALP because PBL provides opportunities for student agency as they engage with meaningful inquiry tasks.

In considering the ways in which teachers achieve ambitious practices in the classroom, we propose, in part, that a requirement for learner success is the ability to meaningfully

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access, use, and apply information from a range of sources. ALPs present some unique and persistent challenges for learners. Here we cite from the learning sciences, instructional systems, and a sampling of highly cited literature in the information and learning sciences that synthesize how students find and use information as they engage in meaningful tasks. Thus, we argue that pursuing practices to scaffold and support learners can help address the challenges and potentially foster learner success in PBL specifically and ALPs more broadly.

Working in a problem-based learning space

PBL is a student-centered inquiry approach to learning that begins with a dilemma or problem that drives the process as students work in small collaborative groups with the teacher serving as a facilitator of learning. As such, scaffolding has long been the terrain of PBL scholars in the learning and instructional design sciences, who have crafted definitions and processes of scaffolding in the research corpus over decades (Tabak and Kyza, 2018; Belland *et al.*, 2008). As in most ALPs, PBL changes the role of teacher and students, as the teacher's role is to support and scaffold student learning rather than deliver content, while students become responsible for the learning. These changes in roles are demanding for both the teacher and the learner (Hmelo-Silver, 2000; Hmelo-Silver *et al.*, 2018a). Here, we use PBL as an example to show how these features are enacted, though as we have noted, ALPs comprise more than PBL.

Meaningful learning in PBL is complex, as it requires exposure and integration of new content, skills, and/or practices for students to address the problem (Hmelo-Silver *et al.*, 2018b). For example, if wanting to target content on related to bacteria, viruses, DNA, evolution, cell theory, and the human immune system that also connects to current events, a microbiology teacher might pose the following question: "How do I know if my food is safe?" Student teams can begin by researching outbreaks of foodborne illnesses and building knowledge toward making judgments about likely causes. One culminating activity to directly address the question could be to have students convey what they know about food, sources of foodborne illnesses along with impacts, food production, and safe handling practices. However, it is not enough to give students resources without guidance and scaffolding, as marshaling information to make contextually relevant judgments and evidence-based arguments places a high demand on the learner. In addition to scaffolding relevant disciplinary and problem-solving skills and practices, we need to support learners to develop critical information literacy practices.

Critical information literacy demands on the learner

In a typical cycle, PBL requires that learners engage both broadly and deeply with a wide range of content (Hmelo-Silver, 2015; Saye and Brush, 2017). At the beginning, learners are introduced to the problem and general parameters. They then work collaboratively to frame the problem, identify learning goals and needs, pursue learning issues, and construct an argument or solution (Belland *et al.*, 2008). This requires learners to build a knowledge base through successful access, management, and use of information, all of which requires targeting learner agency through specific skills and strategies, discussed in more detail below.

Building a knowledge base

The process of conducting meaningful investigations and determining what information is relevant in a given situation requires domain specific knowledge (Reimann and Markauskaite, 2018; Quintana *et al.*, 2004). Furthermore, learners tend to struggle when they

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face complex material, tasks, and questions (Evensen *et al.*, 2001; English and Kitsantas, 2013). Such knowledge work requires constructive use of authoritative sources (Scardamalia, 2002). Research has documented learners feeling at a loss for even knowing how to and where to start when they reach the limits of prior knowledge (Krajcik *et al.*, 1998; Polman, 2000; Saye and Brush, 2017). For example, in an advanced undergraduate engineering course, teams were tasked with designing, programming, simulating, and testing a heart rate monitor. Students experienced difficulty troubleshooting their designs, which every team highlighted as the most troublesome and time-consuming aspect to their work. Both the instructor and students acknowledged they would not have been successful without assistance (Gomoll *et al.*, 2018a).

Managing information and determining relevance

When encountering a large amount of information related to a given problem, it is critical for learners to be able to examine the information and determine which information is more (or less) relevant to the given problem, and to evaluate the quality of that information. However, novice problem-solvers have difficulty critically evaluating the information they encounter with relation to the problem they are attempting to solve. In a study of undergraduate dental students, Jin *et al.* (2015, p. 102) found that although students were able to use a range of online sources, they faced challenges in selecting relevant and high quality information. These students noted the challenges in managing time for search, selecting among the vast quantity of information, and sometimes feeling "lost in the woods." One example quote included a desired for more teacher guidelines to help them manage the complexity of information.

Constructing evidence-based arguments

Essential problem-solving involves constructing arguments based on evidence, considering alternative arguments, and evaluating the strength of those arguments (Chinn and Clark, 2013; Duschl and Osborne, 2002; Zeidler *et al.*, 2009). However, researchers have found that simply "experiencing" PBL does not necessarily guarantee that students construct strong arguments supported with evidence as they progress through the process (Walker and Zeidler, 2007). Learners often fail to support potential solutions to problems by linking relevant resource and data while constructing their solutions (Krajcik *et al.*, 1994). Reiser (2004) discussed the need to "problematize," or make some aspects more problematic for the learner to support links between information, complexity, and arguments. In other words, the idea is to add complexity (at least in the short term) so that learners are not satisfied with surface-level understanding. In one study of middle school students, Belland (2010) investigated teams of students in PBL, and found wide-ranging entry levels for argumentation ability prior to the teams' inquiry into a problem about how genetic information can best be used to improve lives and society. However, one important outcome of Belland's research is that lower-achieving students attained higher performance on the ability to evaluate arguments when given targeted scaffolding support, a critical first step in supporting overall argumentation skill.

Integrating knowledge and evaluating solutions

Researchers have emphasized the importance of continually integrating new knowledge and evaluating progress throughout the problem-solving process (Hmelo-Silver, 2000). This form of reflection and "progress checking" provides learners with the opportunity to reflect on their investigative strategies. However, learners often do not engage in meaningful reflection. Furthermore, they typically experience difficulty with managing new knowledge

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encountered during problem-solving and integrating that new knowledge into potential problem solutions – particularly when the new knowledge suggests alternative solution paths (Reiser, 2004). For example, students building the heart rate monitor described above face considerable stress and pressure when taking their individually built components and connecting them together in the overall design (Gomoll *et al.*, 2018a). For every team, the final design simply did not work at the outset, and teams experienced considerable failure that required them to troubleshoot numerous aspects from their built to their programmed components. Teams who were the most successful were ones who had done external research across disciplines about topics related to the human biological system to understand at a deeper systemic level what needed to happen. Such deep integration represents an ultimate goal in PBL, which requires sufficient scaffolding and support to enact PBL with a wide range of students (Hmelo-Silver and Barrows, 2006; Hmelo-Silver *et al.*, 2018b).

Scaffolding and supporting critical information literacy in problem-based learning

It is important to recognize that learners need support for working in a PBL space, and the integration of problem-solving and information seeking strategies may contribute to learner success. Kuhlthau *et al.* (2015) emphasized the need for teaching and supporting strategies at a fine grained level and highlighted the fact that teachers can draw attention to and reinforce specific search strategies until learners have internalized them. In one example, Maniotes and Kuhlthau (2014) illustrated the classroom potential by beginning with a local problem of an invasive plant species taking over walls and flower beds at the school. By showing images and asking students to discuss observations, the introduction served to ground the inquiry, frame it in a way that was relevant, and motivate next steps or questions. Once teams assumed more independence toward their project, they could move through a sequence that enabled both meaningful questioning and grounded research across a variety of topics and disciplines.

As we have mentioned previously, successful performance requires adequate support and scaffolding. However, at least in some ways, it is important to distinguish between all forms of support broadly and scaffolding specifically. Scaffolds are designed to guide and foster later independent performance, and are meant to be removable toward the goal that the learner will internalize the required process, strategies and techniques (Belland, 2011). For example, when one researcher wanted to support student argumentation and use of evidence, he built a fixed scaffolding tool to help students organize information, develop claims and link evidence to claims (Belland, 2010). More broadly, other resources are meant to support a task at hand but are not necessarily characterized as scaffolds. Such resources might include making particular kinds of physical or conceptual materials available for single use. Physical resources might include construction materials, such as tanks, pumps, and tubing for building an aquaponics systems (Wallace *et al.*, 2017). Conceptual resources might include a hypermedia text for preservice teachers (Hmelo-Silver *et al.*, 2009; Jeong and Hmelo-Silver, 2010) or linked primary source articles and documents for students to study the USA Civil Rights Movement (Brush and Saye, 2002).

However, given the prevailing challenges we have previously outlined, it is important to recognize that there are numerous pedagogical strategies that educators should consider bringing to bear in the classroom. We argue that at least three forms of support are critical when it comes to helping students access and use information in productive and meaningful ways:

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(1) curating resources;
(2) scaffolding information seeking; and
(3) supporting sense-making from sources.

Curating resources

Given the challenges and opportunities in searching and seeking for information, it can be helpful to start with curated resources. In the medical school PBL model, the significant prior knowledge and interest of the students can help bootstrap the information seeking process in more relevant and focused ways. For learners with lower prior knowledge, helping narrow the search space may be important to provide access to ALPs for a broader range of students (Derry *et al.*, 2006). Hmelo-Silver *et al.* (2009) provided a learning sciences hypermedia to help students get started in in a PBL course for pre-service teachers. They developed curated resources for both presenting their case materials as video cases and texts for engaging in self-directed learning. Multiple hypertext pages were linked to other relevant concepts and to the videocase materials. Jeong and Hmelo-Silver (2010) found that more effective groups engaged more fully with appropriate resources whereas students in less effective groups tended to just briefly skim relevant materials. In K-12 settings, the *Globaloria* guided discovery program included a wiki with resources that learners can draw from (Reynolds and Caperton, 2011).

Beneficial outcomes of curation

When learners are offered a curated, more narrow set of resources, there are at least two distinct advantages. One advantage is located in minimizing task complexity. Because of the wide-ranging demands, learners may benefit from resources at hand that make the task overall more manageable. In one study with middle school students that asked learners to consider how personal genetic information should be used and protected, the teacher assigned teams to various stakeholder positions (i.e. doctor, parent, insurance company, factory owner and the like) (Brush *et al.*, 2016). In describing two iteration and implementation cycles, the researchers noted that the teacher engaged two specific strategies to foster success. The first was to be more specific and detailed with the stakeholder descriptions, and the second was to make some of the curated resources *optional*, in effect narrowing the scope and resources between the first and second implementations to help teams manage the complexity.

A second possible advantage that may result when resources are curated is that teams attain a common starting point for building shared knowledge. It is difficult for learners to know where to begin if they have limited prior knowledge and language in the domain. For example, students initiating research in DNA and genetics may not know or recognize they are linking into topics within microbiology that include Darwinism, cell theory, the theory of evolution, genomics, phylogeny and the tree of life, to name a few. Initially, groups may do a lot of wheel-spinning before they land on a productive course, which is why curation and a common starting point can be effective. For example, Brush and Saye (2002) structured *Decision Point!* to help learners build knowledge about the US Civil Rights movement. In their multimedia database of collected video, images, newspaper articles, essays, speeches, and other historic documents, the researchers included the ability for students to access multiple views in their exploration. This included an organizing structure for helping learners to see the three strategies of Civil Rights leaders (legal system, non-violent direct action, and Black Power). Furthermore, an interactive timeline helped learners locate events

and associated material in context to other events. For each event students accessed, an interactive essay provided an overview to help learners see what was going on and why it was important. Such resources and organizational schemes are critical for introducing novices to both the structure and critical entry readings.

Although it may not be overtly obvious to educators how many resources to begin with or where learners should start, the important thing is to begin with something that gives learners a common starting place and enough information to initiate their inquiry. Resources should be purposefully selected and varied enough to at least partially cover the scope of the problem space. However, curated resources are not enough, and more intentional scaffolding is generally required to help learners meet success.

Designing for information seeking in the context of ambitious learning practices

A key strength of PBL and other ALPs is the focus on searching for, synthesizing, and applying new knowledge. Being able to work with information is an important twenty-first-century skill (Chu *et al.*, 2017). However, searching for information can prove to be quite challenging (Kuhlthau *et al.*, 2008). In this day and age, information literacy is digital literacy.

> The digital literacies required for sustained idea improvement in knowledge building communities additionally involve finding and citing relevant information, dealing with information resources beyond grade level, exploring simulations and models, assessing the adequacy of the information resources – including what information might be missing, and selecting information to enter into the class discourse environment for further analyses and improvement (Goldman and Scardamalia, 2013, p. 257).

According to the Kuhlthau *et al.* (2008) model, information searching can occur across six stages: initiation, selection, exploration, formulation, collection, and presentation. Such a model complements PBL inquiry cycles by considering how learning issues are determined, explored during self-directed learning (SDL) and integrated into collaborative learning processes as learners revisit a problem after SDL. As Kuhlthau *et al.* (2015) noted, information literacy is part of this search process and entails using a range of strategies and understanding that:

- is organized provides access to facts, ideas and multiple perspectives;
- includes strategies for systematically keeping track of sources of information;
- provides support for choosing the highest quality and most useful sources for the task-at-hand; and
- helps learners see that sources have characteristics that help in evaluating the quality of their information (e.g., expertise, perspective, up-to-date, and quality).

This critical information literacy points to a need for support in PBL as teams research learning issues. From a learning sciences perspective, Goldman and Scardamalia (2013, p. 256) argue that a key challenge is "that the information age brings with it the need for citizens to create coherence from multiple sources of information that are as likely to contain conflicting as complementary information." However, typical information searching strategies are often not critical but, rather, focused on collecting facts (Limberg *et al.*, 2008). In research focused on individual learners, Limberg *et al.* found that more critical information literacy required a meaningful task, a critical approach to sources, and interactions with teachers and librarians and was embedded in discursive practices. The challenges of using information appropriately are discussed in the learning sciences literature on digital literacy and multiple document comprehension.

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A goal for scaffolding information search is to eventually have the learner assume responsibility for finding and evaluating information, recognizing that most learners are not inherently successful without planned, intentional support. For example, Reynolds (2016) discussed the challenges middle school students encounter when attempting to use information resources to learn programming in the Globaloria computer science education initiative. This was due to cognitive load and novice status, during less structured early curricular iterations. The program later shifted to a heavier emphasis on worked examples, designed exercises and reduced emphasis on searching to better scaffold student programming knowledge building. This indicates there is value in phasing in the complexity and gradually handing responsibility to the learners. In addition to the support in the immediate problem context, this is important for meaningful lifelong learning and the development of self-regulation strategies more broadly. In this section we consider both searching for information and then evaluating it once it is found. For both searching and evaluating, we detail examples of strategies and processes that are potential targets of scaffolds.

Search strategies in ambitious learning practices

Different approaches to searching are appropriate at different phases of the PBL cycle and will depend on the students' prior knowledge. Kuhlthau *et al.* (2015) identified a variety of search strategies that may be used to locate diverse resources. Most important for ALPs, these strategies include *browsing, chaining, differentiating* and *extracting*. Initial exploration of resources may involve browsing.

Browsing involves exploring the affordances of a resource space in the area of interest. In PBL, this might involve first scanning resources that have been curated to get a sense of possible keywords that might lead to a more focused search. It helps the learner see what resources are available, of interest, and perplexing (Kuhlthau *et al.*, 2015). For example, in Hmelo-Silver (2000), students were assigned a textbook to use as a resource but with no readings assigned. The instructor observed students using the book's table of contents and index to help identify keywords for learning issues. An important aspect of browsing is also being able to use different search engines as (Laxman, 2010, p. 514) reports "consist of six different types of search engine strategies: Keyword search, wide search definition, complex search, use of general knowledge, computer convention and Boolean search." Goldman and Brand-Gruwel, however, note that learners have often have difficulty selecting appropriate resources when doing internet searches, tending to rely on their position in the search results.

One approach to dealing with the challenges in searching is embedded instruction. Laxman (2010) developed an explicit information search strategy training (much of which seemed focused on browsing) that was tested with Polytechnic students in a PBL class and demonstrated that these skills can be taught; when tailored to the type of problem being addressed outcomes were associated with enhanced problem solving. Scaffolds for browsing might include discussion to elicit student ideas about their plans for browsing and reflection on how they went about browsing after the information search. Structured worksheets might communicate the process of generating keywords and scaffold the formation of different Boolean searches.

Another key search strategy is *Chaining*. Chaining involves following up on references that have been cited in particular sources or identifying other sources that have cited a key reference (Kuhlthau *et al.*, 2015). Kuhlthau noted that for guided inquiry (another example ALP) in younger learners, this may involve scanning the library shelves for books with similar call numbers to a book of interest. In contrast, for older learners this might involve

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scanning reference lists or tracking sources from footnotes. One way to scaffold and guide chaining might be to use structured guides that help communicate a process for chaining–such as a worksheet asking students to identify several sources that appear in multiple reference lists and several sources that cite references that they found particularly valuable. Discussions around these worksheets could provide opportunities for students to reflect on how chaining can be a valuable strategy.

Differentiating sources involves comparing and contrasting different sources – this may involve considerations of format, quality and difficulty (Kuhlthau *et al.*, 2015). Goldman and Scardamalia refered to this as a process of *sourcing* that involves the process of identifying and representing the metadata about the information source. Such cognitive work involves multiple document comprehension, which also involves detection of conflicting information that the learner subsequently evaluates and decides which sources to use. Goldman and Scardamalia (2013) suggest that it is important to have norms for discussions of sourcing processes students discuss where they found the information, whether they were using direct quotes or paraphrasing, how they knew the information was reliable or what type of expertise the author had. Differentiating processes may be dependent on prior knowledge and the stage of the PBL process (or other learning cycles in ALPs). A labeled table could serve as a scaffold that helps student organize their information sources for their PBL endeavors that might allow them to better understand the differences between, for example, peer-reviewed articles and popular press, or how particular kinds of sources might be useful at different phases of their inquiry. For example, an encyclopedia or review article might be important when beginning inquiry whereas a deep dive into particular content might be key as learners are narrowing in on their PBL problem. Jin *et al.* (2015) noted that dental students' online information seeking was a social practice, and they also recognized the complexity of extracting reliable information that posed a high cognitive load. The findings in this study highlighted the need for facilitators to scaffold development of skills for mapping information from sources to problem scenarios. This initial extracting is an important step toward the sense-making needed for meaningful learning through ALPs.

In an intervention study of sourcing behavior, fourth and fifth grade students participating in discussion-oriented intervention that emphasized evaluating sources when studying texts about climate change (Macedo-Rouet *et al.*, 2013). This was an experimental study rather than an example of ALPs; however, these results suggest that even a short intervention helped less skilled students achieve greater learning and comprehension than students in a control condition.

An example of scaffolding information use in a more open environment is found in Reynolds *et al.* (2013). They studied collective information behavior among middle school students engaged in game design as a PBL context. They found that students would often start with browsing the curriculum-supplied wiki for help. Peer scaffolding was an important part of the search process as the norms for help seeking involved first consulting the wiki followed by peers before asking the teacher for help.

Along with the specific strategies for information seeking, keeping track of sources remains vital for managing both information itself and connecting it to the problem at hand. Bae *et al.* (2018) reported on using PBL in a large undergraduate history class. In this class, the PBL whiteboard was structured into quadrants to support citation and sourcing as students looked for evidence to support and refute their hypotheses. The structure of the whiteboard made students' thinking visible, thus allowing the facilitator to navigate a large classroom and be able to dynamically scaffold these disciplinary sourcing, citation, and argumentation practices as she walked among the small groups.

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In summary, scaffolding information search, evaluation, and management are critical to supporting students in the productive success of PBL (Kapur, 2016). Scaffolds can be fixed in the form of structured worksheets that guide students in information seeking and evaluation or rubrics that help students understand what high quality information search strategies look like. They can also be more fluid in the form of prompts for discussion and reflection on search processes. Collaborative reflection allows students to make their thinking visible and open for revision (see also below). Finally, modeling and coaching from both teachers and peers has a role, which we discuss in more detail below. Quintana *et al.* (2004) also argued for the importance of scaffolding learners to organize work products that would otherwise distract from effective learning and doing. We suggest that researchers should focus more specifically on *how* learners can be supported in information seeking, particularly within and across various disciplines, which represents a key step in helping learners arrive at sense-making.

Sense-making from sources in ambitious learning practices

In any PBL investigation, students are responsible for simultaneously investigating goals and managing information. In this context, possibly the most challenging and difficult task for students is one of sense-making, which is internal and socially constructed (Ertmer and Glazewski, 2018; Hmelo-Silver and Barrows, 2006, 2008). Nonetheless, there are facilitation strategies for scaffolding internal sense-making that may help learners. These include *making judgments about information relevance; sharing and comparing to refine understanding;* and *making connections toward integrated knowledge*.

Scaffolding judgments about information relevance

When students are working through material, they are responsible for making judgments about relevance. Students can encounter difficulties when they do not know *how* to determine relevance and priority. Furthermore, students often do not typically engage productive strategies. One scaffolding strategy is modeling how to think about a problem and information that may or may not fit. Pedersen and Liu (2002) addressed this through video-modeling of expert behaviors embedded in *Alien Rescue*, a PBL game for middle school learners. An expert agent used available tools to demonstrate how he was thinking about the problem. The agent's actions were overt as he spoke about how to find information, determine if it was relevant, and record it in a notebook. In one study with three conditions (agent modeling, hints and tips without modeling and generic help for tool functionality) the researchers looked at student in game actions along with performance on a transfer task. Students in the modeling condition asked more questions that were coded to elicit useful information. Furthermore, students who experienced the agent modeling exhibited higher performance on the transfer task than those in the other two groups, suggesting more than one beneficial outcome of targeted modeling.

In addition to modeling, there are structures educators can put into place that may help learners overcome some non-productive behaviors, such as working close to deadlines rather than working toward deep understanding (Goldman and Brand-Gruwel, 2018). In one study of student behaviors and strategies in PBL, researchers looked at how preservice science educators worked across a semester, and found that given a three-week milestone, students waited until the final week to begin work (Ruiz-Gallardo *et al.*, 2016). Students tended to focus on assignment requirements rather than pursue learning issues, ask questions, locate evidence, and refine their understanding. In the second implementation, they suggested strategies for group organization and required peer review prior to assignment submission. Both strategies had an impact on student workflow in the problem,

and helped even out their productive work time as opposed to seeing it spike just before a deadline. This research demonstrates that students may need both time to think and strategy assistance to be able to meaningfully determine relevance of resources in PBL. However, it is important to recognize that these are not skills that typically happen in isolation, and students can rely on peers for information sharing and comparing.

Sharing and comparing information

In a complex problem-solving endeavor, teams need space and strategies for sharing and comparing information. One specific aim is to correct alternative conceptions and naive ideas, which generally requires group input (Hmelo-Silver and Barrows, 2008). Researchers and developers alike have leveraged strategies for making thinking visible to give individuals active reflection space to voice and vet ideas (English and Kitsantas, 2013; Ertmer and Simons, 2006). Making thinking visible reflects the fact that learners' internal thinking and dialogue typically remains unseen during learning activity, which require specific strategies to surface (Collins *et al.*, 1991). This process involves reciprocity toward making both teacher thinking and student thinking visible in the environment so that "[. . .] students can observe, enact, and practice [tacit processes] with help from the teacher and from other students" (Collins *et al.*, 1991, p. 3). Student thinking can be made visible through assignments, assessments, discussions, artifacts, and other collaborative tasks.

A wide range of strategies has been used to make student thinking visible, including structures for organization of resources, information, and ideas. In an inquiry learning context, Causal Mapper was built as a tool for helping students establish visual representations of causal relationships between observations, ideas, or other phenomena (Baumgartner, 2004). During one initial use, students created a representation of the forces that may be acting on water quality of a nearby creek. One important research outcome was that students exhibited change between their entry level and their post-investigation maps, but were reluctant to remove or correct initial ideas. Furthermore, students tended to represent possible relationships as direct, and had difficulty with intermediary relationships. In response, the author suggested numerous ways to customize tool use for classroom implementation and facilitation, providing some insight regarding the interplay between scaffolding strategies that can be handed off to technology and those that should be handled by the teacher.

Currently, there is some emerging evidence to suggest that interdisciplinary teams benefit when given space to make their thinking visible. In one investigation of teams composed of students drawn from medicine, dentistry, pharmaceutical sciences, occupational therapy, and nursing, the interdisciplinary teams engaged a problem of a patient experiencing joint pain and having trouble swallowing (Imafuku *et al.*, 2014). The researchers looked across the student teams to ask about how students worked within and across disciplines, which resulted in mixed outcomes. On one hand, a number of students engaged strategies for elaboration and communication across disciplines to bridge the divides between disciplines, and they displayed strategies for trying to understand the needs and priorities of their peers. Furthermore, they discovered different approaches to patient care. However, some students found it difficult to communicate across disciplines, and others were afraid of making mistakes. More overt facilitation needs to help all students in a situation such as this to realize value in cross-disciplinary teaming, with specific aims to make thinking visible and normalizing any communication difficulties. Furthermore, we argue that making thinking visible is necessary if students are going to make connections between ideas.

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Making connections toward integrated knowledge in ambitious learning practices

One of the more well-documented and consistent outcomes of PBL specifically and ALPs more broadly is reflected in what generally falls in the category of skill application or critical reasoning (Strobel and van Barneveld, 2009; Walker *et al.*, 2015). More specifically, in studies that compare PBL against lecture-based pedagogies, PBL is generally more favorable when outcomes measures include complex measures of knowledge application, explanation, and problem solving However, it is important to note that such findings are not spontaneous outcomes, but, rather, associated with intentional pedagogies that help learners to make connections across information sources and meaningfully integrate knowledge. Goldman and Scardamalia (2013) noted the challenges in fostering meaningful knowledge building, articulating some of the problems that arise because specifically and especially because we are asking learners to make sense of large amounts of information from multiple sources by multiple authors, much of it conflicting or inconsistent.

One specific strategy for supporting learners' ability to handle information is *embedding expertise*, which can take a variety of forms and offers a number of potential benefits. This can include embedding expert views, overview, or hints directly within digital material, both to help frame the context and to call out key information. For example, in the *Decision Point!* Civil Rights Project described earlier, Brush and Saye (2002) offered linked, interactive essays to help students access and acquire critical contextual overview. Each overview essay surfaced conflicting perspectives, contextual information, and competing priorities as students made sense of major events such as Brown vs. the Board of Education, Little Rock, the Freedom Rides, March on Washington, and the Voting Rights Acts. Expertise can also be embedded within documents themselves, which Shin *et al.* (2017) documented when a teacher annotated specific online articles and resources with highlighted information directed as his specific students based on his knowledge of student prior knowledge and likely difficulties.

However, it is not possible to anticipate every likely difficulty, which is where adaptive scaffolding comes into play. That is, not all forms of expert support need to be pre-planned, nor should they be. The static supports should simultaneously serve learners and free up the facilitator's time to be able to provide dynamic support on the fly (Brush and Saye, 2002; Simons and Klein, 2007). By addressing some of the more common difficulties, teachers are free to some extent to address learner needs as they arise, and push for deeper thinking and integration of knowledge.

Moving forward with advanced learning practices

In our own search for preparation of this article, it seems that information searching, sourcing, and management represent critical efforts to ensure learner success in PBL specifically and ALPs more generally. Furthermore, we argue these efforts represent an area deserving of deeper investigation. Although we might know a lot about strategies for scaffolding generally, we know comparatively little about how to support learners for meaningful information integration processes. Additionally, different disciplines use different language to talk about learner actions, interactions, and needs. For the information sciences, information searching helped direct us to an appropriate literature. In the learning sciences, the same search terms for our review were not fruitful but rather appeared under the research area of multiple source comprehension. For the instructional design community, this work would be found under information problem-solving, providing challenges in creating a synthesis toward a more comprehensive and unified understanding of ALPs.

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It would be helpful for researchers studying similar phenomena in different fields to develop a common language and engage in cross-disciplinary discussion, as *Information and Learning Sciences* is aiming to accomplish. Beyond that, future researchers should look more deeply into the strategies we need to best support searching, evaluating and using information in productive ways. These strategies are critical for successful ALPs and at the same time, ALPs also have the potential to provide excellent contexts for studying these strategies and different tools for supporting them. Given the overwhelming amount of available information, critical information literacies are more important than ever as we seek to foster deep inquiry and learning.

Furthermore, we suspect that an important part of ALPs such as PBL is the felt need, which can be a mixed experience for the learner. On one hand, learners might be driven toward greater agency and self-directed learning. On the other hand, they might experience tremendous doubt and failure, which can derail a learning experience. Nonetheless, uncertainty and frustration are part of the inquiry process and it may be useful to prepare learners for this. The literature on PBL has not explicitly addressed these affective factors when it comes to student self-direction specifically or information seeking processes more broadly. However, the Kuhlthau *et al.* (2015) model of guided inquiry includes affective considerations as an explicit part of the process. It is also not clear how information seeking approaches consider the social nature of knowledge construction though Goldman and Brand-Gruwel (2018) explicitly include the socio-cultural context in the model of working with multiple sources as do Knight and Mercer (2017) in their study of collaborative information seeking tasks. These supports are critical for enabling a wide range of learners to have opportunities to engage in ALPs that support agency and the development of critical information literacy skills. Some studies as noted above have shown the additional benefit of such support on lower-achieving learners. The challenges in self-directed learning may also suggest a role for school librarians in addition to classroom teachers to help promote information literacy when creating opportunity for ambitious learning to take occur (Chu *et al.*, 2017).

To understand more deeply about how to support learners in ALPs, we ultimately need to engage comprehensive and integrated classroom interventions and research approaches that draw from multiple areas. There is tremendous opportunity for joint work and collaboration among teachers and library educators as they seek to foster meaningful problem solving given the demands placed on the learner the ALP classroom. Yet, it is simultaneously important to recognize the demands placed on educators as their roles shift. It can be tremendously difficult to orchestrate a learning environment in which all teams are productive and successful. However, teachers who partner with library educators might experience relatively greater success given the expertise generally resident within such specialists toward curating, scaffolding information seeking, and supporting sense-making. With integrated research methods and advances in the ability to capture and make sense of large amounts of data, we can inform deeper understandings of how learners engage with information toward meaningful activity in ALPs.

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