PERvasive Learning System (PERLS) – Verification, Validation, and Experimental Testing

Learning Strategy Analysis Report

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14. ABSTRACT

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Section 1: A Heuristic Evaluative Framework for Mobile Self-Regulated Learning Design

Section 2: A Learning Strategy Heuristic Evaluation for PERvasive Learning System (PERLS) v 2.0 Alpha

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Contents

Executive Summary

The PERvasive Learning System (PERLS) is a mobile, personalized system for delivering content and recommendations to learners in the workplace or informal settings. PERLS serves as a portal for aggregating and managing micro-learning resources, is xAPI-enabled, and connects to the Total Learning Architecture. PERLS can be used to guide and mentor the learner with recommended micro-content according to a self-regulated micro-learning model. These recommendations are based on several factors including the learner's goals and expressed interests, expertise, schedule, media preferences, and behaviors.

Description of Report

PERLS was designed as a platform for Self-Regulated Learning (SRL)—a means for employees in office settings or persons serving in the military to advance their education in a self-determined manner. In addition, PERLS was created to support the user's self-regulation process using functions, interfaces, and prompts to guide attention and interest. The current report summarizes a heuristic evaluation of self-regulation strategies within PERLS 1.0 and 2.0 Alpha. A self-regulated learning heuristic evaluation rubric was developed for this process. For PERLS 1.0, the heuristic evaluation was conducted with all identified publications on PERLS as well as reports on PERLS and PowerPoint files with initial training provided by DoD Advanced Distributed Learning Initiative. The PERLS 2.0 evaluation was conducted using the Alpha version of PERLS 2.0. It should be noted that this version was a preliminary version of the system missing some of the features and supporting documentation, which will be include in the final version of PERLS 2.0.

Based on the SRL literature, there are four "phases" that characterize self-regulation: Planning (e.g., analyzing tasks and setting goals), enacting (e.g., reading, writing, and problem-solving), monitoring (e.g., self-evaluations of progress and performance), and adapting (e.g., using self-assessments or feedback to modify behavior). There are also factors that affect SRL, including strategies, metacognitive skill, motivation and independence. Based on the SRL literature, two overarching design principles were developed: the platform principle and the support principle. The platform principle states that SRL-promoting technologies should include functions and tools that enable planning, enacting, monitoring, and adapting phases of SRL. Learners should be able to use the system to "complete the loop" of SRL—getting ready to learn, doing the work, evaluating the results, and trying to improve. The support principle states that SRL-promoting technologies should include scaffolds for strategies, metacognition, motivation, and independence. The information provided on the two versions of PERLS was evaluated for support of the four SRL phases at both the platform and support levels.

Conclusions

The current system has strong potential for supporting self-regulated learning. Our review found that the current system learning model (i.e., exploring, studying, and sharpening) does not directly align with SRL concepts in terms of labels. However, the features in the alpha version of PERLS 2.0 support basic elements of planning (e.g., searching, bookmarking, and choosing interests), enacting (learning the content), and monitoring (e.g., quizzes). Several features (e.g., tips and flash

cards) have high potential to be leveraged as diverse supports in future version. Additionally, PERLS 2.0 will include many tools for instructors or content creators to develop learning materials (e.g., tip cards, content cards, and quiz cards). These "authorware" features were not apparent in PERLS 1.0 documentation and represent enormous potential for customized and useful training via PERLS 2.0. Two recommendations for continued PERLS 2.0 development include updating the learning model so that it is inline with SRL models and explore how the features of PERLS 2.0 can be applied across many phases of SRL. Additional suggestions for learning strategy improvements are provided throughout the report.

Recommended reading on Self-Regulated Learning

Azevedo, R. (2009). Theoretical, conceptual, methodological, and instructional issues in research on metacognition and self-regulated learning: A discussion. *Metacognition and Learning*, *4*(1), 87-95. https://link.springer.com/article/10.1007/s11409-009-9035-7

Broadbent, J., & Poon, W. L. (2015). Self-regulated learning strategies and academic achievement in online higher education learning environments: A systematic review. *Internet and Higher Education*, *27*, 1-13. https://www.sciencedirect.com/science/article/pii/S1096751615000251

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Devolder, A., van Braak, J., & Tondeur, J. (2012). Supporting self-regulated learning in computer-based learning environments: Systematic review of effects of scaffolding in the domain of science education. *Journal of Computer-Assisted Learning*, *28*, 557-573. https://onlinelibrary.wiley.com/doi/full/10.1111/j.1365-2729.2011.00476.x

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Nielsen, J. & Budiu, R. (2013). *Mobile usability*. San Francisco, CA: New Riders Press. https://www.nngroup.com/books/mobile-usability/

Panadero, E. (2017). A review of self-regulated learning: Six models and four directions for research. *Frontiers in Psychology*, *8*, Article 422. https://www.frontiersin.org/articles/10.3389/fpsyg.2017.00422/full

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Winters, F. I., Greene, J. A., & Costich, C. M. (2008). Self-regulation of learning within computer-based learning environments: A critical analysis. *Educational Psychology Review*, *20,* 429-444. https://link.springer.com/article/10.1007/s10648-008-9080-9

Overview

This report provides a summary of a review of the learning strategy of the PERvasive Learning System (PERLS). PERLS is a mobile, personalized system for delivering content and recommendations to learners in the workplace or informal settings. The system was designed as a platform for SRL—a means for employees in office settings or persons serving in the military to advance their education in a self-determined manner. In addition, PERLS was created to support self-regulation using functions, interfaces, and prompts to guide attention and interest. This analyses in the current report were conducted initially on version 1.0 and on a working Alpha version 2.0 of PERLS. While a new version of PERLS was in development, a method for performing a heuristic evaluation of self-regulated learning was developed. The purpose of this new heuristic rubric was to provide a quick generalized framework for evaluation self-regulated learning support within a system. The SRL Heuristic Evaluation Framework was created to be flexible, so a fully developed system was not needed to conduct evaluation, so the evaluation could be conducted quickly during the development process. As an initial use case of the rubric, materials on PERLS version 1.0, which was no longer functioning system at the time of the review, were evaluated. This evaluation included all identified publications on PERLS, reports on PERLS provided by DoD Advanced Distributed Learning Initiative, and initial training ppts. Results from this analysis can be found in section IV (PERLS 1.0: Application of the Heuristic Evaluative Framework). Section 2 of the report summarizes a review of the alpha version of PERLS 2.0 using the SRL heuristic evaluation framework. Section 2 of this report shows how this framework can be used to evaluation SRL and succinctly report problems.

Section 1. A Heuristic Evaluative Framework for Mobile Self-Regulated Learning Design

To promote meaningful self-regulated learning (SRL), researchers and educators have explored a variety of computer-based learning environments and technologies (Azevedo 2005; Devolder, van Braak, & Tondeur, 2012; Winters, Greene, & Costich, 2008)—such as *MetaTutor* (Duffy & Azevedo, 2015; Trevors, Duffy, & Azevedo, 2014; Taub et al., 2019) and *gStudy* (Hadwin, Oshige, Gress, & Winne, 2010; Winne, Hadwin, & Gress, 2010)—to teach SRL strategies or provide a platform for self-regulation. Well-designed systems allow learners to engage in one or more SRL activities (e.g., planning, enacting, monitoring, and adapting) while also facilitating effective engagement. Many technologies now track learners' inputs, behaviors, emotions, and performance (Roll & Winne, 2015; Tabuenca, Kalz, Drachsler, & Specht, 2015; Winne, 2019) to offer feedback and personalization. And, SRL-promoting technologies are increasingly mobile—leveraging the portability of cellphones, tablets, or wearables to afford self-regulation "on the go," anywhere, and at any time (Churchill, Lu, Chiu, & Fox, 2016; Dabbagh & Kitsantas, 2005; 2012; Sharples, 2000; Shaw, Looi, & Zhang, 2012; Tabuenca et al., 2015).

The efficacy of SRL-supportive tools depends on the quality of their design (Azevedo & Hadwin, 2005; Churchill et al., 2016; Roscoe, Craig, & Douglas, 2017). These technologies must satisfy (at minimum) a double bottom-line: adhering to defensible instructional design principles possessing functional and usable interfaces guided by user-centered design) (see Dumas & Redish, 1999; Kortum & Sorber, 2015; Rubin & Chisnell, 2008; Zhang & Adipat, 2005). Indeed, several researchers have offered adaptations of usability assessment for e-learning (e.g., Mehlenbacher et al., 2005; Reeves et al., 2002; Zaharias & Koutsabasis, 2012; Zaharias & Poylymenakou, 2009). For instance, researchers have expanded Nielsen's (1992; Nielsen & Molich, 1990) heuristics (e.g., visible system status, consistency, and real-world congruence) based on instructional design concepts (e.g., prior knowledge, use of examples, and readability) (Zaharias & Koutsabasis, 2012) and instructor roles (Nacu, Martin, & Pinkard, 2018).

The novel contribution of this report is to provide a concrete *heuristic evaluative framework for designing SRL-supportive learning technologies*. Specifically, we aim to help developers quickly evaluate their technologies to make strategic (re)design and implementation decisions that align with the demands of self-regulated learning. We briefly summarize foundational and contemporary views of SRL to outline key activities that should be enabled by the software and how they might be supported. Second, we briefly consult foundational and contemporary perspectives on usability inspection to describe methods (e.g., heuristic evaluations and walkthroughs) to ensure that instructional and interface needs are met. This report then considers how a synthesis of SRL and usability inspection principles can offer guidance on evaluating and designing SRL technologies. To demonstrate, we will implement this framework using an example case: the PERvasive Learning System (PERLS) offered by the Advanced Distributed Learning (ADL) Initiative (Freed, Folsom-Kovarik, & Schatz, 2017; Freed, Gervasio, Spaulding, & Yarnall, 2018; Freed et al., 2014; Freed, Yarnall, Spaulding, & Gervasio, 2017; Suvorov, 2017).

Self-Regulated Learning: Platforms and Supports

SRL refers to iterative learning processes in which individuals make plans, set goals, take action to complete tasks, monitor their progress and outcomes, and adapt their efforts to improve future performance (Azevedo, 2009; Boekaerts & Corno, 2005; Butler & Winne, 1995; Greene & Azevedo, 2007; Panadero, 2017; Pintrich, 2004; Schraw, Crippen, & Hartley, 2006; Winne, 2018; Winne & Hadwin, 1998; Zimmerman & Schunk, 2001). This highly metacognitive and self-directed approach has been cited extensively as a key element of success in K-12 education (e.g., Ben-Eliyahu & Linnenbrink-Garcia, 2015; Cleary & Kitsantas, 2017; Cleary, Velardi, & Schnaidman, 2017; Dent & Koenka, 2016; Kitsantas, Steen, & Huie, 2009), higher education (e.g., Ben-Eliyahu & Linnenbrink-Garcia, 2015; Greene, Costa, Robertson, Pan, & Deekens, 2010; Mega, Ronconi, & De Beni, 2014; Pintrich, 2004), online learning (e.g., Broadbent, 2017; Broadbent & Poon, 2015; Littlejohn, Hood, Milligan, & Mustain, 2016; Kizilcec, Pérez-Sanagustín, Maldonado, 2017; Wan, Compeau, & Haggerty, 2012; Wang, Shannon, & Ross, 2013; Wong et al., 2018), and workplace learning (e.g., Fontana, Milligan, Littlejohn, & Margaryan, 2015; Margaryan, Littlejohn, & Milligan, 2013; Siadaty, Gašević, & Hatala, 2016a, 2016b; Sitzmann & Ely, 2011; Wan et al., 2012). Such studies and reviews have established that youth and adults who engage in SRL tend to learn more effectively than those who do not.

Although SRL has been characterized in myriad ways, unifying themes have emerged (e.g., Panadero, 2017). SRL typically occurs across several iterative and related "phases" of activities, and successful coordination of these phases requires strategies and strategy knowledge. Second, external supports are often necessary to promote SRL. In the sections below, we summarize these key elements, which in turn informs design principles for SRL-promoting technologies.

The Platform Principle: Enabling Strategic Self-Regulation

Many conceptualizations of SRL describe "phases" of *planning*, *enacting*, *monitoring*, and *adapting* activities. Importantly, these phases unfold iteratively, interdependently, and recursively. Progress through the phase is not necessarily linear, and the inputs and products of each phase can influence each other via feedback and feed-forward mechanisms. Likewise, learners do not simply move through the phases until learning is "complete," but may revisit phases repeatedly as they gain mastery. Thus, the terminology of "phases" is a partial misnomer, yet is nonetheless useful for describing collections of dynamic processes of getting ready to learn, doing the work, evaluating the results, and trying to improve.

Strategies and strategy knowledge are fundamental to SRL. Strategies are step-by-step procedures that are intentionally employed to achieve desired outcomes, improve performance, optimize resources, and overcome obstacles (Alexander, Graham, & Harris, 1998; Broadbent & Poon, 2015; Donker, de Boer, Kostons, Dignath va Ewijk, & van der Werf, 2014; Zimmerman & Schunk, 2001)—strategies are the operations that learners employ to accomplish each SRL phase.

First, successful performance of most tasks—such as reading (McNamara, 2007), writing (MacArthur et al., 2016), and problem-solving (Jonassen, 2010)—is facilitated by general and task-specific strategies that impose structure, guide attention, promote deeper reasoning, or otherwise improve accuracy and efficiency. In many cases, strategies go beyond the minimum required for the task, but this additional effort (Winne, 2018) results in better learning. For example, the basic activity of reading entails scanning words and sentences to create a mental representation. However, to facilitate retention and comprehension, learners might engage in self-explaining strategies such as bridging (i.e., linking ideas), predicting (i.e., anticipating upcoming knowledge), and elaborating (i.e., connecting new and prior knowledge) (e.g., McNamara, 2017; McNamara, Leveinstein, & Boonthum, 2004; Snow, Jacovina, Jackson, & McNamara, 2016). Self-explaining is more demanding than basic reading, but results in better understanding.

Second, SRL itself comprises activities that benefit from strategies. For instance, planning involves assessing time constraints and scheduling tasks. Thus, self-regulation may benefit from learning time management strategies (e.g., Dunlosky & Ariel, 2011; Hartwig & Dunlosky, 2012; Rodriguez et al., 2018). Similarly, self-questioning strategies (e.g., Wong, 1985; Joseph, Alber-Morgan, Cullen, & Rouse, 2016) and self-testing strategies (e.g., Hartwig & Dunlosky, 2012; Rodriguez et al., 2018) can provide methods for students to monitor and assess their own learning. Students also have a variety of methods available to adapt to problems, such as information-seeking (e.g., Walraven et al., 2013) and help-seeking (e.g., Roll et al., 2014). Finally, many SRL strategies can also be embedded within learning tasks, such as using self-questioning to both monitor and improve text comprehension (e.g., Joseph et al, 2016; Snow et al., 2016).

Phases of Self-Regulation. In the *planning and preparing phase*, self-regulated learners analyze or define their tasks, review instructions, gather resources, choose strategies, set goals, and establish evaluation criteria (e.g., Eilam & Aharon, 2003; Kostons, van Gog, & Paas, 2012;

McCardle, Webster, Haffey, & Hadwin, 2017). Good plans allow learners to be more efficient and less likely to waste time. Learning strategies can be identified and practiced in advance to avoid later trial-and-error, and plans can prepare learners to attend to signals of success (e.g., Panadero, Jonsson, & Botella, 2017; Panadero & Romero, 2014) and craft contingency plans for when failures, errors, or obstacles arise.

In the *enacting and performing* phase, learners attempt to complete (or make progress) on their tasks, which may require demonstrating knowledge, acquiring new, solving problems, making decisions, and more. To do so, learners engage in a variety of task-specific procedures, such as reading and using comprehension strategies (e.g., McNamara, 2007). In this stage, learners also enact their plans. Consequently, learners who lack clear plans are disadvantaged because they have less direction, fewer steps to follow, and may be ill-prepared to recognize when they err.

In the *monitoring and evaluating* phase, learners assess their own knowledge and performance (e.g., accuracy and understanding), evaluate outcomes (e.g., quality of products), predict outcomes, and diagnose errors (e.g., Deekens, Greene, & Lobczowski, 2018; Kostons et al., 2012). Such judgments can be prospective, concurrent, or retrospective, and may occur before, during, or after task completion (e.g., Baars, Vink, van Gog, & Paas, 2014; Mihalca, Mengelkamp, & Schnotz, 2017). For instance, before solving a problem, learners may retrospectively reflect on past successes with similar problems and then make prospective predictions about upcoming problems. Once students begin working, they may concurrently evaluate how well they are doing. Finally, after solving the problem, students might retrospectively assess the accuracy of their solution and diagnose any incorrect answers or steps. Such self-evaluations are essential because learning and task performance rarely unfold smoothly or without error (Bjork et al., 2013; Panadero et al., 2017), and mistakes can halt further progress and lead to poor solutions, harmful decisions, or misconceptions.

In the "final" *adapting and regulating* phase, learners "close the loop." The results of self-monitoring and self-assessment ideally reveal learners' successes and failures, strengths and weaknesses, knowledge gains and gaps, and so on. A fundamental assumption of most SRL models and publications is that self-regulated learners *use* this information to adapt and improve. If learners realize that they are missing critical knowledge, they set goals and take action to fill that knowledge gap (e.g., searching online for more information, Walraven, Brand-Gruwel, & Boshuizen, 2008, 2013; or seeking help, Aleven, Roll, McClaren, & Koedinger, 2016; Roll, Baker, Aleven, & Koedinger, 2014). Similarly, if learners realize that their plans were too ambitious, they might change their plans to better suit their resources or abilities. Any aspect of planning, enacting, or monitoring is potentially open to inspection and modification.

The Platform Principle. In the design of computer-based learning environments, *the platform principle states that SRL-promoting technologies should offer platforms for planning, enacting, monitoring, and adapting*. That is, technologies that seek to promote SRL must enable learners to accomplish self-regulatory tasks via the software. Such platforms can be instantiated based on specific strategies. For example, "creating a calendar" and "making to-do lists" are both planning strategies, and thus software might include "calendar tools" for learners to plan their studying or assignments, or "to-do list tools" for setting goals and tracking completion. Similarly, software may offer direct access to subject matter content (e.g., e-textbooks) for students to read, along with “drawing” or “quiz” platforms for diagramming or self-assessment strategies.

There are countless ways to implement these platforms and we not endorse any particular methods. Similarly, it is an empirical question whether a technology must include platforms for *all* phases or whether certain phases are more crucial. However, we assume that technologies that offer more and diverse platforms will be more effective than technologies that offer fewer platforms—a “fully-featured” SRL-promoting might allow learners to engage in all phases (i.e., “close the loop”) without needing to exit the technology.

The Support Principle: Scaffolding Strategic Self-Regulation

Research has revealed myriad caveats and constraints that can limit whether, how, and to what extent effective SRL occurs (e.g., Aleven et al., 2016; Azevedo, Moos, Greene, Winters, & Cromley, 2008; Bjork, Dunlosky, & Kornell, 2013; Kornell & Bjork, 2007; van Meeuwen, Brand-Gruwel, Kirschner, de Bock, & van Merriënboer, 2018; Walraven et al., 2008; Zheng, 2016) Although SRL is “self” driven by definition, learners often need external guidance, feedback, and encouragement to acquire SRL proficiency (e.g., Azevedo et al., 2008; Cleary et al., 2017; Devolder et al., 2012; Dignath & Büttner, 2008; Lee, Lim, & Grabowski, 2010; Nicol & Macfarlane-Dick, 2006; Roll, Aleven, McClaren, & Koedinger, 2011; Zheng, 2016; Zumbrunn, Tadlock, & Roberts, 2011).

Scaffolding for SRL can take many forms, including instruction, prompting, feedback, and assessments. The exact manifestation of scaffolds is likely less important than whether scaffolding is provided at all—some support is better than no support, and combining multiple scaffolds may be ideal. For instance, many learners benefit from *direct instruction* about SRL and relevant strategies (e.g., techniques for setting reasonable goals and self-monitoring) and opportunities to practice these skills. *Direct and indirect prompts* can remind learners about what they should (or could) do, guide them toward optimal actions, and draw attention to important ideas and tools (e.g., Bannert, Sonnenberg, Mengelkamp, & Pieger, 2015; Berthold, Nückles, & Renkl, 2007; Devolder et al., 2012; Müller & Seufert, 2018).

Another approach is to provide *feedback* in response to learners’ inputs, behaviors, or performance (e.g., Azevedo et al., 2008; Butler & Winne, 1995; Lee et al., 2010; Nicol & Macfarlane-Dick, 2006; Roll et al., 2011; Shute, 2008). Summative feedback provides objective indicators of performance (e.g., correct vs. incorrect) whereas formative feedback offers information on how to improve. Because students’ are not always skilled at self-monitoring, external feedback can reduce the mental workload of identifying knowledge gaps, strengths and weaknesses, and so on. Feedback can also convey missing or new information, introduce or refine strategies, and guide students’ through successful self-regulation.

Self-assessment and *formative assessment* resources (e.g., rubrics and peers) can also facilitate strategies, self-monitoring, and learning (e.g., Panadero et al., 2017; Panadero, Jonsson, & Strijobos, 2016; Panadero & Romero, 2014). Learners can use rubrics to study assessment criteria and exemplars, which makes these guidelines more accessible and usable. Learners can also participate in creating these rubrics (e.g., Fraile, Panadero, & Pardo, 2017), which further promotes self-monitoring, self-efficacy, and planning. Relatedly, learning analytics and *automated assessment* tools are increasingly using student data to personalize recommendations and feedback (e.g., Azevedo & Gašević, 2019; Gašević , Jovanović, Pardo, & Dawson, 2017; Lodge, Panadero, Broadbent, & de Barba, 2018; Roll & Winne, 2015; Tabuenca et al., 2015; Winne, 2018; Winne & Baker, 2013). Learners' actions (e.g., navigation) and inputs (e.g., short-answer responses) can be analyzed by the software, and algorithms can guide responding to students' knowledge, skills, and cognitive-affective states in real-time. Similarly, these data can be communicated to students via feedback and visualizations to help them monitor their performance and adapt.

Targets for Support. *Strategies and strategy knowledge* are essential SRL. Learners need to understand how to enact each phase along with strategies for completing constituent tasks. Direct instruction can teach learners about strategies and their rationale and then provide opportunities to for practice. Once learners have begun to acquire the strategies, prompts can serve as reminders to use them. Prompts can also nudge learners to engage in productive behaviors even when they lack explicit strategy knowledge (e.g., learners can be prompted to "test your understanding" without necessarily knowing about "comprehension monitoring" strategies). Similarly, as learners work, they can receive immediate feedback on recent steps or receive delayed feedback after completing longer tasks. Feedback can thus introduce strategies, help learners monitor their strategy use, and reveal how a new or different strategy might work better.

Another impediment is that many learners lack proficiency in *metacognition and self-monitoring*. Learners may fail to assess themselves or may be poorly calibrated (e.g., Alexander, 2013; Azevedo, 2009; Dunlosky & Thiede, 2013), such as overestimating their performance. In addition, learners may rely on misleading cues to judge their recall or understanding (e.g., Bjork et al., 2013). Support for this aspect of SRL may take the form of clear guidelines, prompts, or rubrics that remind learners when and how to self-assess. Similarly, of the demands of self-assessment and self-monitoring can be "offloaded" on to others—providing external monitoring and regulation while learners are still developing their own skills. In the case of SRL-promoting technologies, learning analytics tools can perform some of these assessments automatically and communicate the results to learners via instruction, prompts, and feedback.

Numerous links between SRL *motivation*, and *affect* have also been observed (e.g., Boekaerts, 1995; Cleary & Kitsantas, 2017; Duffy & Azevedo, 2015; Littlejohn et al., 2016; Mega et al., 2014; Pintrich, 2004; Schunk & Zimmerman, 2012; Smit, de Brabander, Boekaerts, & Martens, 2017). Learners with lower intrinsic motivation or self-efficacy are less likely to engage in SRL. Technologies can support motivation by creating environments that are conducive of positive attitudes and attributions. For instance, intrinsic motivation is fostered by opportunities to feel competent, autonomous, and connected (Reeve, Ryan, Deci, & Jang, 2008; Ryan & Deci, 2000). Thus, SRL-promoting technologies should allow students to experience meaningful growth and exert control over their learning. Technologies that are too easy, too hard, or too strict may thwart intrinsic motivation. Similarly, learners form self-efficacy beliefs through experience, observation, and feedback (e.g., Ahn, Usher, Butz, & Bong, 2016; Usher & Pajares, 2008). Thus, technologies might help learner develop positive efficacy beliefs by demonstrating strategies (e.g., vicarious learning with pedagogical agents, Twyford & Craig, 2017) or giving formative feedback that highlights successes along with opportunities to grow. Finally, motivation and emotions are themselves open to strategic self-regulation (Smit et al., 2017), such as "gamifying" a boring task to make it more enjoyable or identifying personal relevance in a topic to increase interest. Researchers are exploring the use of learning analytics to detect learners' cognitive-affective states (e.g., frustration) in real-time, and which potentially enables technologies to intervene when learners exhibit disengagement (e.g., Calvo & D'Mello, 2010; Grawemeyer et al., 2017; Spann, Shute, Rahimi, & D'Mello, 2019).

A final consideration is that scaffolding and support, although necessary, should not be permanent. If the goal is to promote *self*-regulation, then external software tools cannot scaffold learners in perpetuity. Thus, a final aspect of SRL support is to *promote independence*. In educational research, "fading" refers to the gradual and adaptive removal of support until learners can perform tasks on their own (Azevedo & Hadwin, 2005; Belland, 2014; Devolder et al., 2012; Lajoie, 2005; Pea, 2004). Importantly, fading does not necessarily require the removal of *all* assistance, but learners should not need to be (re)taught strategies repeatedly, or prompted to self-monitor on every problem-solving step, or require constant encouragement. Ideally, if learners receive adequate instruction and practice, then the mere presence of the platforms may serve as sufficient SRL cues. For example, once learners understand and internalize the value of "self-questioning tools," they may no longer need explicit reminders to "test your understanding."

The Support Principle. In the design of computer-based learning environments, *the support principle states that SRL-promoting technologies should include scaffolds for strategies, metacognition, motivation, and independence*. These supports can take a variety of forms such as direct instruction, prompting, feedback, and evaluations. As with platform design, we do not endorse any specific method. However, more robust systems will likely offer support for every included platform (i.e., if the technology includes note-taking tools, it should also include note-taking assistance), and might have multiple forms of support (e.g., hints for note-taking strategies, prompts to take notes, and automated feedback on the quality of notes). These supports should encourage learners to be proactive and independent, including the ability to deactivate external hints, prompts, and feedback functions as learners become more self-directed.

Evaluating Self-Regulated Learning Technology Design

This report has articulated two overarching, multifaceted design principles for SRL-promoting technologies: the *platform principle* and the *support principle*. Educational technologies that aim to promote SRL must include (a) *platforms* (i.e., functions, features, and tools) for engaging in planning, enacting, monitoring, and adapting activities, and (b) *supports* (e.g., instruction, prompts, feedback, and assessments) that facilitate strategic behavior, metacognition, motivation, and independence. These dual demands result in potentially complex system requirements and designs—there are myriad ways to implement SRL. When (re)designing, (re)developing, or evaluating such systems, it may be useful to employ a *heuristic evaluative framework* to map out whether and how these design principles are addressed.

The idea of a heuristic evaluative framework borrows from work on usability assessment (e.g., Bastien, 2010; Dumas & Fox, 2009; Dumas & Redish, 1999; Kortum, 2016; Rubin & Chisnell, 2008; Wichansky, 2000; Zhang & Adipat, 2005). The International Organization for

Standardization (ISO) defines *usability* as the extent to which products, devices, or systems can be used by their intended audience to complete desired tasks with accuracy, ease, speed, and satisfaction (ISO 9241, ISO 2018). Similar formulations (e.g., Nielsen & Budiu, 2013) consider dimensions such as learnability, efficiency, memorability, errors, and satisfaction. Collectively, a system is considered "more usable" when using the system (a) improves users' performance; (b) reduces rather than exacerbates users' physical or mental burdens; and (c) prevents user error or facilitates error recovery; and when the users themselves (d) make fewer errors, (e) can learn how to use the system smoothly; and (e) report positive perceptions of their experiences.

Usability assessments evaluate the above factors to identify and remove usability threats. For example, user testing recruits end-users to complete tasks within the system while collecting data on completion, timing, errors, interactions with system features, and attitudes. Such testing is ideal and necessary once a working prototype or functional system has been developed. However, informative usability assessments can (and should) begin far earlier in the design process. Specifically, *usability inspection* methods offer a principled means for developers to explore usability via *heuristic evaluations* (e.g., Hvannberg, Law, & Lárusdóttir, 2007; Nielsen, 1993; Nielsen & Budiu, 2013; Nielsen & Molich, 1990), *cognitive walkthroughs* (Huart, Kolski, & Sagar, 2004; Karat, Campbell, & Fiegel, 1992; Khajouei. Esfahani, & Jahani, 2017; Mahatody, Sagar, & Kolski, 2010; Polson, Lewis, Rieman, & Wharton, 1992), and related methods. Throughout development (i.e., from the earliest stages of ideation onward), these approaches (see Khajouei et al., 2017) can be used to inspect systems, identify strengths and weaknesses, and update designs.

Notably, there are strong parallels between self-regulation, iterative design (e.g., Jonassen, 2008; Nielsen, 1993), and design thinking (e.g., Adams & Atman, 1999; Dym, Agogino, Eris, Frey, & Leifer, 2005; Razzouk & Shute, 2012). In this sense, our heuristic framework is akin to a rubric (e.g., Fraile et al., 2017; Panadero & Romero, 2014) that specifies goals and criteria for SRL-promoting technology design. Beyond typical usability inspections for interface design and navigation, this framework specifies heuristics for SRL design (i.e., documenting the presence or absence of key platforms and supports) and cognitive walkthroughs based on SRL tasks.

Heuristic Evaluation

Heuristic evaluations allow developers to systematically inspect their designs (e.g., wireframe mockups and prototypes) to identify threats to usability and user experience based on pre-defined parameters (e.g., Gómez, Caballero, & Sevillano, 2014; Hvannberg et al., 2007; Nielsen & Budiu, 2013; Zaharias & Koutsabasis, 2012). Specifically, these evaluations aim to reveal violations of design principles, the severity or likelihood of usability problems, and potential causes and remedies of these threats.

These evaluations can be conducted "in house" by developers before end users ever interact with the system. Thus, there is no risk of users accessing a system that might be harmful (e.g., promoting misconceptions). Similarly, by conducting heuristic evaluations *early* in the design process, usability threats can be identified and removed before time or money are wasted. Finally, the speed and low cost of heuristic evaluations facilitates iteration. Each inspection can reveal issues to be fixed in subsequent designs, and every iteration may reveal new or overlooked threats. Subtle problems may only become apparent after more blatant problems are removed.

Heuristic evaluations have been used to improve e-learning and online instruction, such as web-based writing courses (Miller-Cochran & Rodrigo, 2006), web-based tools for knowledge-sharing and collaboration (Hvannberg et al., 2007), web-based support for competence maps (Stoof, Martens, & van Merriënboer, 2007), online employee training (Zaharias & Poylymenakou, 2009), MOOC-like online courses (Zaharias & Koutsabasis, 2012), virtual laboratories (Davids, Chikte, & Halperin, 2013), game-based social skills training (Tan, Goh, Ang, & Huan, 2013), peer communication (Carmichael & MacEachen, 2017), and educator roles (Nacu et al., 2018). These evaluations were able to reveal superficial and substantive issues related to system design and instruction (e.g., access, navigation, locating resources, and clarity of instructions and tasks), which empowered the developers to repair or prevent problems in future studies or interventions.

Methodologically, the parameters assessed in heuristic evaluation can be established based on knowledge of best practices and/or the features of specific tasks and domains. Many researchers begin with Nielsen and colleagues' widely-used heuristics (Nielsen, 1993; Nielsen & Budiu, 2013; Nielsen & Molich, 1990). Indeed, evaluation of SRL-promoting technologies should address heuristics for interface design (e.g., Nielsen & Molich, 1990), such as communicating the status of the system (e.g., wireless connectivity), using consistent terms and symbols that are familiar to intended users (e.g., "play," "pause," and "stop" navigation), minimize memory demands (e.g., saving key settings and outputs for later use), using minimalist design (e.g., avoiding distracting colors and unnecessary pop-ups), and preventing errors while also enabling efficient recovery (e.g., clear documentation, confirmation requests for substantive actions, and "undo" functions). In other words, any educational technology should conform to principles of user-centered design.

However, by considering these checklists in conjunction with heutagogical and instructional concerns, these principles can be tailored to learning contexts (e.g., Zaharias & Koutsabasis, 2012; Nacu et al, 2018; Reeves et al., 2002; Tan et al., 2013). For instance, one heuristic argues that system status should be communicated clearly and visibly—if a system relies upon a network connection to send and receive data, the interface might include a network "signal strength" indicator so users know when and if they are connected. In an educational technology, status indicators might also convey the availability of learning or assessment resources. If learners submit inputs to be scored (e.g., a quiz), status indicators might report when the "grading" is finished and feedback is available. Likewise, if a learning module has multiple steps, status indicators could inform learners of their current position in those steps, how many steps remain, and the anticipated duration of those steps.

Another heuristic recommends that interfaces should contain familiar concepts and symbols that correspond to users' expectations. In a multimedia lesson, learners might reasonably expect to navigate using "play," "pause," "forward," and "back" buttons common to many devices. However, in some cases, new and unfamiliar interfaces may be specifically designed to transform students' "familiar" behaviors—the purpose is to introduce an unfamiliar learning activity (e.g., teaching a computer agent via concept-mapping; Roscoe, Segedy, Sulcer, Jeong, & Biswas, 2013). In these cases—a potentially conflict between interface heuristics and instructional processes—new concepts, interfaces, and controls must be carefully explained beforehand. Thoughtful use of system documentation (i.e., another heuristic) may offset such "design violations."

Heuristic Evaluation of SRL Design. This report offers evaluative heuristics for SRL design based on the platform principle and support principle (Appendix A). SRL-promoting technologies should incorporate one or more platforms for *planning*, *enacting*, *monitoring*, and *adapting*. Heuristically, developers can document (a) whether and (b) how such tools are implemented within a system. The former can be implemented as a binary evaluation: "Does the system incorporate tools, functions, or features for planning?" The latter entails summaries of the actual tools: "If 'yes,' describe the specific tools, functions, or features are implemented to enable planning." Similarly, SRL activities should be scaffolded with regard to *strategies*, *metacognition*, and *motivation*, whole also encouraging eventual *independence*. As above, the presence or absence of supports is a binary evaluation: "Does the system incorporate strategy support for planning? When supports are identified, evaluators can document the specific implementation: "If 'yes', describe the specific tools, functions, or features that provide strategy support for planning." Appendix A provides a template for documenting these evaluations.

Cognitive Walkthrough

In a cognitive walkthrough, developers take on the role of users to complete key tasks while documenting the effects of possible actions, clarity and salience of features, available resources, potential sources of confusion, and how the system communicates with users (e.g., Mahatody et al., 2010; Polson et al., 1992; Wharton, Bradford, Jeffries, & Franzke, 1992). These tests can be performed with paper prototypes, wireframes, functional prototypes, and other early or incomplete products—missing components may be simulated using mockups (similar to Wizard of Oz designs; e.g., Mavrikis & Gutierrez-Santos, 2010; Schlögl, Doherty, & Luz, 2015). Walkthroughs can also be performed frequently, iteratively, inexpensively, and "in house" without recruiting end users. However, whereas heuristic evaluations focus on the presence, absence, or implementation of design parameters, walkthroughs further reveal how users might interact with the system or how designs interfere with task completion. Although a valuable function might be offered, threats may not be revealed until someone attempts to *use* it. Walkthroughs thus attempt to anticipate actions, thoughts, feelings, and needs from the user perspective.

Walkthroughs begin by identifying target tasks and steps. For instance, a system might attempt to enable self-monitoring via a "quiz" function that delivers a multiple-choice question after completing a lesson. From a heuristic standpoint (Appendix A), this feature might serve as a platform for monitoring. To conduct a walkthrough, evaluators would specify the steps for accessing and completing this "quiz task," such as (1) "complete any lesson to trigger a quiz," (2) "answer the quiz question by selecting and answer," and (3) "receive feedback on correctness." Developers would attempt to perform this task while documenting sources of confusion, time-on-task, successes and failures, assumptions about users, and more. Such evaluations can also reveal the need for additional features, such as more informative feedback.

A few studies have employed cognitive walkthroughs in the evaluation of educational technologies, such as multimedia applications (Huart, Kolskim & Sagar, 2004), e-portals for history courses (Karahoca & Karahoca, 2009), learning analytics toolkits for teachers (Dyckhoff et al., 2012), digital textbooks Lim, Song, & Lee, 2012), automated writing evaluation (Roscoe, Allen, Weston, Crossley, & McNamara, 2014), and augmented reality for heart anatomy

(Kiourexidou et al., 2015). Overall, walkthroughs appear to be effective in revealing usability threats in educational systems along with misalignments between intended tasks and actual use.

Cognitive Walkthroughs of SRL Design. This report suggests two levels of walkthrough for evaluating SRL-promoting technologies. At a *technology level*, developers explore features built into the targeted system (e.g., features identified from the heuristic analysis) to complete relevant tasks. For instance, if a system includes a quiz function, calendar function, or reminder function, then walkthrough tasks should explore each function to inspect usability problems. However, more broadly, SRL is "an iterative, metacognitive processes in which learners make plans and set goals, take action to complete tasks, monitor their progress and outcomes, and adapt their plans and strategies for future performance and work" (i.e., the definition provided at the outset of this report). To engage in SRL, learners must have the opportunity to "close the loop"—to engage in all four phases. Thus, at an *SRL level*, developers should consider self-regulation itself as an overarching task. Can evaluators use the system to make plans, take action, self-monitor, and adapt (i.e., all four SRL phases)?

An important caveat is that the "ideal" state of having platforms and supports for *all* phases is not always feasible. Moreover, there is no requirement for the system to be the *only* platform or support. Some activities may be offline (e.g., paper-and-pencil worksheets) or may involve a separate technology (e.g., an organic chemistry simulation). Instructors can provide verbal instructions, discuss strategies, demonstrate methods, and provide feedback. Ample research also demonstrates the value of peers as instructors and assessors (e.g., Patchan & Schunn, 2015; Roscoe, 2014; Roscoe, Walker, & Patchan, 2018). Thus, the intended use of an SRL-promoting technology could entail external instruction or support. This blend of online and offline SRL should be explicitly indicated in system documentation and usability inspections. If one or more phases of SRL are intended to occur outside the system, developers should make users aware of these expectations and perhaps offer recommendations for how to achieve such aims.

PERLS Version 1.0: Application of the Heuristic Evaluative Framework

The heuristic evaluative framework introduced in this report is demonstrated through an analysis of the *PERvasive Learning System* (PERLS). PERLS is a mobile, personalized system for delivering content and recommendations to learners in the workplace or informal settings (e.g., Freed et al., 2017b; Freed et al., 2018). Specifically, learners can use a mobile device to access a variety of instructional "content cards" (e.g., text documents, videos, and web-based simulations) and "action cards" that enable goal-setting and quizzes. Underlying these tools is a contextually-aware recommender system that suggests learning objects based on the users' activity (e.g., topic access and navigation), location, and topic importance (Freed et al., 2018). Learners can use the system to acquire knowledge or skills in a selected domain while the software attempts to guide appropriate learning activities and trajectories. Prior versions of PERLS thus represent a fairly flexible SRL-promoting technology. The system was intentionally designed as a *platform* for SRL—a means for employees in office settings or persons serving in the military to advance their education in a self-determined manner. In addition, PERLS was created to *support* self-regulation using functions, interfaces, and prompts to guide attention and interest. A handful of usability and pilot studies (Freed et al., 2014, 2017b; Suvorov, 2017) observed positive perceptions of flexibility, portability, tracking, and motivation.

A heuristic evaluation of PERLS provides a systematic mapping of SRL features and functions to reveal design strengths and weaknesses (e.g., neglect of one or more SRL phase) and inform future development or deployment. This evaluation begins with a critical analysis of the published PERLS SRL Model (Freed et al., 2018) and then considers how PERLS incorporates both platforms and supports for SRL activities. Considerations for cognitive walkthroughs are discussed but a cognitive walkthrough is not presented due space limitations.

Evaluation of the PERLS Self-Regulated Learning Model

PERLS developers recognized the challenges of adult learning and lifelong learning that takes place outside of formal instructional environments:

> Adults routinely learn job-related knowledge for which little or no formal instruction is available, doing so through a self-assembled mixture of resources at times, places, and pace of their own choosing. Informal learning presents challenges such as discovering needs, identifying resources to address those needs, self-assessing progress, and coping with conditions that strain a learner's determination and metacognitive faculties (Freed et al., 2018, p. 1).

In acknowledgement of these complex demands, the developers articulated an SRL-inspired model of learning to guide system development. The "PERLS SRL Model" (Figure 1) conceptualized three phases of "exploring," "studying," and "sharpening" (Freed et al., 2018).

The *Explore* phase (comprising Discovery, Dabbling, and Bridging) entailed gaining awareness of topics, skimming, and choosing topics for further study. Specifically, *Discovery* was defined as a period of encountering new topics via intentional seeking (e.g., a web search) or incidentally while working on other tasks (e.g., word-of-mouth from a colleague). After discovering a topic, learners might engage in *Dabbling*—low-effort and undemanding review of learning materials, such as skimming a website, watching a short video, or playing a mini-game. In these activities, the learner gains familiarity with the domain and begins to form interests and confidence. Finally, *Bridging* involved committing to more effortful and engaged learning. In this activity, learners assess their competence and understanding, formulate plans and goals for learning, and consider their available time and resources.

The Explore phase most closely paralleled the *planning* phase of SRL. In particular, "bridging" appeared to align with descriptions of intentional planning, wherein learners analyze and define tasks, gather resources, set goals, and establish metrics. The concepts of "discovery" and "dabbling" offered a reasonable elaboration that incorporated initial exposure to the domain. That is, rather than assuming learners were already aware of relevant topics, the PERLS model explicitly acknowledged this introductory step. Developers mentioned the need to address both intrinsic and extrinsic learning motivations for adult learners (Freed et al., 2014; citing Deci & Ryan, 2000). However, the model could have established much stronger foundations for SRL related to achievement goals (Bernacki, Byrnes, & Cromley, 2012; Duffy & Azevedo, 2015), self-assessment (Fraile et al., 2017; Panadero et al., 2017), or task selection (Kostons et al., 2012; Raaijmakers, Baars, Schaap, Paas, van Merriënboer, & van Gog, 2018).

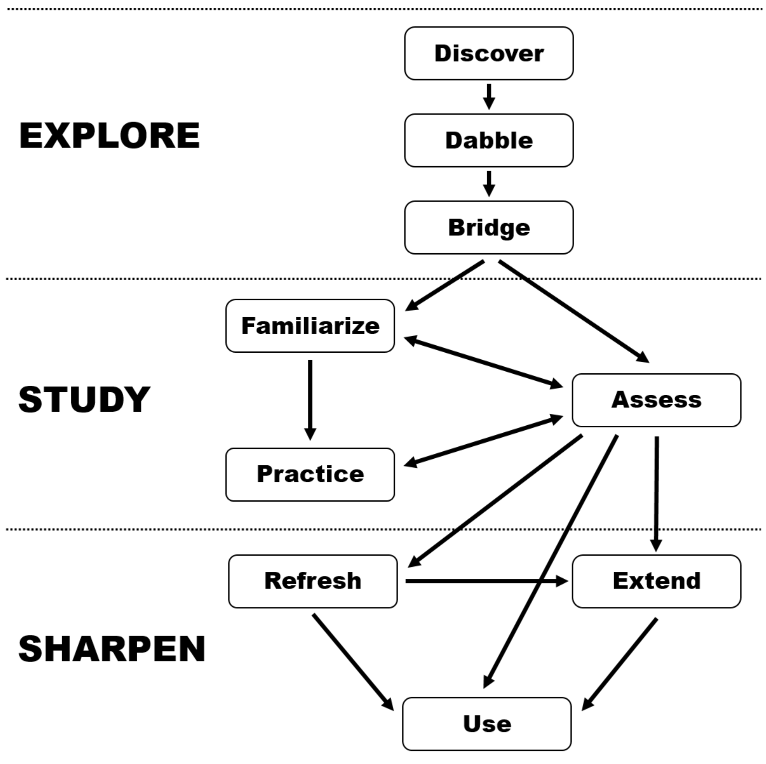

Figure 1. Prior PERLS Self-regulated Learning (SRL) Model.

The *Study* phase (Familiarize, Practice, and Assess) was defined as a period of engaged learning in which learners attempt to complete courses, build competence, develop skills, or otherwise learn the material. In *Familiarization*, learners review introductory materials to become familiar with key concepts, principles, and procedures. In *Practice*, learners develop fluency in retrieving and applying both declarative and procedural knowledge based on perceived knowledge gaps. Throughout these activities, learners are believed to engage in *Assessing*. Learners are assumed to use self-evaluations or external feedback to gauge progress. In turn, these assessments ostensibly enable "course corrections and adoption of new strategies to improve results [and] determine when the learner is ready for more advanced learning" (Freed et al., 2018, p. 4).

The Study phase appeared to focus on *enacting*, but also incorporated elements of *planning*, *monitoring*, and *adapting* phases. The overall conceptualization was somewhat muddled. For example, familiarization seemed highly similar to "dabbling" and "bridging." Familiarization also emphasized "introductory" studying; this aspect of the model neglected SRL activities that are focused on advanced topics, deeper comprehension (e.g., Graesser, McNamara, & VanLehn, 2005; McNamara, 2017), critical thinking (e.g., Ghanizadeh, 2017), or transfer (e.g., Leberman, McDonald, & Doyle, 2016; Zepeda, Richey, Ronevich, & Nokes-Malach, 2015). These forms of learning might be represented under "practice" but insufficient detail was provided. The developers appeared to describe deliberate practice but did not clearly connect to that research base (e.g., Ericsson, Krampe, & Tesch-Römer, 1993; Macnamara, Hambrick, & Oswald, 2014).

The inclusion of assessment in the PERLS model was a strength, but also demonstrated lack of specification and might be fruitfully separated into distinct processes. Feedback is a powerful resource for scaffolding self-regulation (Butler & Winne, 1995; Lee et al., 2010; Nicol & Macfarlane-Dick, 2006; Shute, 2008), but PERLS developers did not seem to draw on that literature to inform feedback design, such as how feedback may differ by source, specificity, complexity, or timing (e.g., Shute, 2008). Similarly, the model did not articulate details about the roles or timing of different types of metacognitive judgments (e.g., prospective vs. retrospective, Baars et al., 2014; Mihalca et al., 2017) nor distinguish between the effects of self-assessments versus peer-assessments (Panadero et al., 2016, 2017; Panadero & Romero, 2014). Finally, it was not clear how learners *use* such information to refine future learning activities, plans, or strategies. The model seemed to simply assume that adaptation would occur.

The final phase of the PERLS SRL model, *Sharpen* (Refresh, Extend, and Use), focused on maintaining, building, and applying knowledge and skills. In *Refreshing*, learners try to reinforce their skills and knowledge. During *Extending*, learners build upon existing knowledge or skills, perhaps developing greater proficiency than required for the tasks at hand. Finally, learners can *Use* their knowledge to investigate or solve real-world problems and situations.

The Sharpen phase appeared to revisit the *enacting* phase of SRL, but with a focus on elaboration and application rather than initial acquisition—elements that were missing from the Study phase. This component of the model was perhaps the least specified. It remained unclear what strategies learners might use to improve retention or comprehension, such as returning to "familiarizing" and "practicing" or invoking new activities. "Extending" could encompass a variety of constructive or co-constructive learning activities (e.g., Chi, 2009; Chi et al., 2018; Chi & Wylie, 2014). However, developers did not connect their definitions of "extending" or "use" to existing theories of knowledge construction, transfer, creativity, or similar processes.

Overall, although PERLS SRL phases, activities, and terminology exhibited plausible links to established SRL concepts, it is uncertain whether the model was deeply informed by prior SRL theory and research. The available literature on PERLS does not articulate these foundations (Freed et al., 2014, 2017, 2017b, 2018), and core assumptions in the model were not strongly grounded in prior work or validation studies. The resulting PERLS model was thus vague—it might be most accurately characterized as an idealized "use case" rather than an empirically-derived model of learning. These theoretical issues introduce concerns for PERLS design. If the guiding model demonstrates gaps (e.g., lack of clear monitoring and adapting phases), it is plausible that system itself might exhibit gaps (e.g., neglecting one or more platforms for SRL). In the next sections, we heuristically evaluate how PERLS design—based on available publications and reports on the system—addressed (or not) planning, enacting, monitoring, and adapting.

Heuristic Evaluation of SRL Platforms and Supports in PERLS

Reported PERLS design (e.g., Freed et al., 2018) comprised a variety of features for accessing learning materials, which were supported by tools for planning, quizzes, and recommendations.

The heuristic evaluation begins with PERLS' content-delivery system and its role in the enacting phase of SRL. We then evaluate how and whether PERLS addresses planning, monitoring, and adapting within that context (see Appendix B). This analysis focuses on explicitly described features of PERLS rather than implied or assumed usage.

Enacting Phase in PERLS 1.0. PERLS design emphasized a potentially powerful platform for enacting learning and related tasks. PERLS can provide direct access to diverse content or steer learners toward external resources, and PERLS users can study this material via reading, listening, watching, interacting, or other modality supported by the resources. Using a "card-based interface," learning objects are presented as "content cards" in various formats, such as expository texts or multimedia videos about a principle or process, recordings of interviews or demos, and more. Following the PERLS SRL model, content curators (e.g., instructors) can incorporate materials that range from quick, engaging "dabbling" videos to detailed materials for "practice" or "extending." Sets of related learning objects can be grouped into "topics" (materials related to a similar theme) or "courses" (materials to be completed in a specific order).

Learning materials can be hosted internally on servers dedicated to a given PERLS context (e.g., converting employee training materials into PERLS content). However, PERLS can also interact with external resources in two ways. First, content cards might link to approved external websites or mobile-enabled software. For instance, links might send learners to news sites or podcasts, thus enabling them to connect ideas learned in a PERLS course to current events. Similarly, learners could access other learning technologies such as simulations, intelligent tutoring systems, or games. Via this approach, the library of resources available through PERLS users is potentially unlimited. Although this content is not managed by PERLS curators, the system can potentially track learners' interactions with the relevant content cards.

Second, later PERLS development considered both Total Learning Architecture (TLA, e.g., Folsom-Kovarik & Raybourn, 2016; Gallagher, Folsom-Kovarik, Schatz, Barr, & Turkaly, 2017; Smith, Gallagher, Schatz, & Vogel-Walcutt, 2018) and Experience API (xAPI, ADL, 2012). In brief, these approaches and tools emphasize interoperability and communication between different platforms. Ideally, multiple applications should be able to communicate to share data on users' performance, behavior, and contexts. xAPI uses human and machine-readable data to track these variables, which permits dynamic tracking across any platform or system that also use xAPI (e.g., Learning Management Systems, tutoring systems, wearables, and so on) (e.g., Alonso-Fernández, Cano, Calvo-Morata, Freire, Martínez-Ortiz, & Fernández-Manjón, 2019; Bahkaria, Kitto, Pardo, Gašević, & Dawson, 2016; Sottilare, Long, & Goldberg, 2017). Thus, if PERLS is connected with other learning technologies using xAPI, the systems can share information about users' actions and outcomes, which in turn enables deeper assessment and personalization. Freed et al. (2017) reported a demonstration of integration using PERLS and Perceptual Adaptive Learning Modules (PALMS) to train learners on pattern recognition tasks (e.g., recognizing anatomic structures). PALMS provided the training content whereas PERLS provided additional learning materials, content, and coordination.

Support for the enacting phase is tenuous. PERLS offers no instruction or "action cards" for specific learning strategies, such as strategies for reading, integrating information across sources, learning with multimedia, or online information search. Thus, although PERLS connects learners to vast resources, it is not clear that the system directly assists learners in understanding these materials. One solution might be to develop "strategy cards"—specialized content cards that teach learning strategies. Similarly, there is no clear support for *independence*. Indeed, the developers stated that "effective support technology must be engaging and habit-forming so that self-learners use it regularly during learning trajectories that can last months or years" (Freed et al., 2017). Thus, rather than envisioning a future when learners no longer need PERLS, the intention appeared to make PERLS a permanent learning resource.

PERLS offers weak metacognitive support via "quiz cards" that contain short multiple-choice quizzes (often only one question) to test retention. Thus, learners are partially supported in assessing shallow memory of facts rather than deeper metacognitive evaluations of understanding, knowledge gaps, or needs (e.g., comprehension monitoring, judgments of learning, and judgments of knowing). As with learning strategies, PERLS could leverage existing card features to prompt effective metacognitive monitoring while learning.

One potential strength of PERLS is its contextually-aware recommendation functionality, which aims to provide *motivational* support by connecting learners with content that is relevant, interesting, and important (Freed et al., 2018). Notably, it is not clear whether these features were functionally implemented within PERLS, but the design concept is well-aligned with the principle of motivational support. As outlined by Freed et al. (2018), the system might track learners' goals and interactions with learning objects (e.g., how often and how recently) to estimate their current interests, which in turn could prompt recommendations for similar content. Additionally, PERLS design includes "value propositions" that offer a rationale for accepting a recommendation—PERLS provides "selling points" to convince learners to access the recommended content. These selling points might be based on learners' interests, location (e.g., nearby landmarks), urgency (e.g., impending deadlines), or attitudes (e.g., preferences for challenge or social interaction).

It is worth noting that the ability for PERLS to leverage external resources might offset some of the above critiques. Although PERLS may not teach strategies, learners could be directed to outside resources (e.g., websites or intelligent tutoring systems) that do cover these topics. Subsequently, when learners return to their PERLS course(s), they may be better prepared to learn. In other words, what support that PERLS does not provide itself could be "outsourced" with careful collaboration and planning.

Planning Phase in PERLS 1.0. PERLS offers a platform for two aspects of planning: topic selection and goal-setting. Learners can find topics and courses via recommendations and searches, and then can choose which topics to pursue and how much effort to invest. For example, choosing the topic "Computing" might display options for websites with overviews of computing, short videos about augmented reality or conversation analysis, websites about cybersecurity, and on. In a goal-setting interface, users have the option to "Set Learning Goal" in terms of PERLS' learning model, such as the following prompt types (e.g., Freed et al., 2014):

- "I want to *Explore*. Get a taste. Make a commitment."
- "I want to *Study*. Dig in. Work toward your goal."

- "I want to *Master*. Lay a foundation. Become an expert."
- "I want to *Stay Sharp*. Keep up to date. Build your expertise.

Selected goals refine the recommendations; choosing to "explore" results in shorter and less challenging topic recommendations, whereas "master" will lead to more advanced content.

The system offers two supports for strategic planning. All content cards include indicators for type (e.g., audio, web, or document) and time (i.e., expected duration). Learners can potentially organize their learning activities based on their available time and resources (e.g., listening to a 30-minute podcast while committing versus reviewing a short glossary of terms immediately before a meeting). However, these strategic decisions appear to be left to the learners—the system does not include explicit guidance in how to plan well. Similarly, there is no calendar function for users to schedule activities on particular days or times. The recommendation system ostensibly facilitates planning by offering topics and activities that align with stated goals and SRL learning states (e.g., offering entertaining content when learners are "dabbling"). The system can also encourage learners to set more intensive learning goals (e.g., "master") after they have become familiar with basic ideas. In this way, the recommender system might encourage learners to be more goal-oriented.

Metacognitive support for planning is superficial. Users can access an "Activity" summary that reports days and time spent learning, lists chosen goals, and displays progress toward completion. This information may help learners to track their plans and progress. However, metacognitively, there is no specific support for learners to evaluate the quality, feasibility, or relevance of their plans. Learners might benefit from feedback that helps them judge when their plans are consistently too easy or difficult, disorganized, or off-topic relative to their needs.

Monitoring Phase in PERLS 1.0. Although isolated metacognitive tools are provided for testing recall and recognition (i.e., single-item multiple-choice quizzes) and reviewing plans (i.e., activity reports), the monitoring phase of SRL is largely neglected in PERLS. Learners are assumed to monitor themselves periodically or accurately, but platforms within the system do not directly enable or support such work. For example, the system includes no formal functions for conducting summative or formative assessments. Learners have no obvious means for gauging their understanding and performance across multiple topics, courses, or over time. One remedy could be to expand existing quiz functions to include more items and items that test understanding and integration. The results of these assessments would offer learners critical information to make better choices about learning and studying. Such "tests" could be self-administered at any time: learners could use them *before* studying to identify their prior knowledge and needs, and again *after* study to measure their mastery (or reveal lingering gaps).

PERLS also lacks features to prompt or motivate metacognitive predictions (e.g., "How much time will this take?"), self-monitoring (e.g., "Is anything about this topic confusing?"), or other reflections (e.g., "How will this information be useful in my career?"). Similarly, learners could also be taught strategies or cues for making accurate and calibrated self-evaluations (e.g., Bjork et al. 2013; Van Laer & Elen, 2019). As suggested above, specialized content cards could explain concrete strategies for practicing self-monitoring at multiple time points.

Adapting Phase in PERLS 1.0. A critical component of SRL is "closing the loop," which refers to using metacognitive evaluations or external feedback to adapt existing plans, behaviors, criteria, and other learning processes. Such iteration is *possible* within PERLS, if learners do so spontaneously, but the system lacks clear platforms or supports for adapting. In practice, learners *can* delete or change their goals, abandon irrelevant lessons, select new lessons, and more. However, nothing in the system highlights or reinforces these activities as explicit attempts to self-regulate. One possibility might be to allow learners to choose "adapting" goals. For example, learners might be able to set goals such as, "Challenge me! The previous lessons were too easy" or "I overestimated my free time. Let's find shorter lessons this week." Learners should be able to more explicitly connect their plans and efforts to their self-assessed needs and competencies.

Summary

Driven by a plausible but underspecified learning model, the strongest feature of PERLS is perhaps its role as a gateway to a wealth of instructional materials. Whether hosted on a dedicated server to externally linked, learners can access diverse multimedia content or other software to acquire the knowledge and skills they need to succeed. A self-regulated learner would likely judge PERLS to be a very useful resource. And, to enable and support such self-regulation, PERLS also includes a platform for goal setting along with functions for motivating learners with timely and relevant content recommendations. Based on a heuristic evaluation of SRL-promoting technology design (Appendix B), PERLS currently addresses *planning* and *enacting* phases of self-regulation. Additional support features (e.g., strategy instruction, prompting, feedback, and independence) might increase the potential value and effectiveness of these tools. However, platforms and support for *monitoring* and *adapting* aspects of SRL were largely missing. Individuals who already possess such skills could likely employ them within the system, but PERLS does not explicitly or directly enable or scaffold them. Existing assets within the software (e.g., quiz cards, content cards, and recommendations) could be further developed or redesigned to fill these gaps.

During the period of analysis for this report, a usable version of PERLS 1.0 was not available. Therefore, cognitive walkthroughs were not conducted. However, the heuristic analysis revealed numerous tasks to be assessed in future work. An incomplete list of tasks includes identifying and searching for learning topics, using goal-setting interfaces to choose or modify goals, using activity reports to track goal completion, taking quizzes, receiving and responding to recommendations, and testing whether recommendations are responsive to location and prior system activity. These *technology-level* walkthroughs will allow evaluators and developers to document experiences with using these tools, such as possible sources of confusion, errors, or obstacles. In addition, walkthroughs might also reveal untapped potential. In taking on the role of users, evaluators may discover affordances or opportunities for assistance that could be built into future versions. Finally, *SRL-level* walkthroughs will explore engagement in all phases of SRL using PERLS. Our heuristic evaluation suggested that monitoring and adapting are under-supported, but evaluators could creatively imagine ways they might monitor and adapt within PERLS. This design activity could inspire new platforms and supports for these phases in future iterations of PERLS.

Conclusion for Section 1: SRL Heuristic Framework & PERLS 1.0 Evaluation

Self-regulated learning (SRL) has identified as an important facet of successful learning in diverse settings across K-12 education (e.g., Dent & Koenka, 2016), higher education (e.g., Mega, Ronconi, & De Beni, 2014; Pintrich, 2004), online learning (e.g., Broadbent & Poon, 2015), and workplace learning (e.g., Siadaty et al., 2016). However, engaging in effective SRL often a challenge for many learners due to the complex cognitive, metacognitive, and motivational demands (e.g., Azevedo et al., 2008; Bjork et al., 2013; Kornell & Bjork, 2007; Smit et al., 2017). Driven by such findings, numerous scholars have considered the use of computer-based learning environments to promote SRL (e.g., Azevedo, 2005; Winters, Greene, & Costich, 2008). To facilitate the development and assessment of SRL-promoting technologies, this report articulated a *heuristic evaluative framework* informed by (a) established SRL theory and research and (b) best practices in usability assessment and inspection.

Our overview of SRL research identified four "phases" that characterize self-regulation: *planning* (e.g., analyzing tasks and setting goals), *enacting* (e.g., reading, writing, and problem-solving), *monitoring* (e.g., self-evaluations of progress and performance), and *adapting* (e.g., using self-assessments or feedback to modify behavior). Likewise, we also identified several factors that affect SRL for many learners, including *strategies*, *metacognitive skill*, *motivation* and *independence*. Based on this overview, two overarching design principles were developed: the platform principle and the support principle. The *platform principle* states that SRL-promoting technologies should include functions and tools that enable planning, enacting, monitoring, and adapting phases of SRL. Learners should be able to use the system to "complete the loop" of SRL—getting ready to learn, doing the work, evaluating the results, and trying to improve. The *support principle* states that SRL-promoting technologies should include scaffolds for strategies, metacognition, motivation, and independence. Technologies should offer assistance with engaging in SRL (e.g., instruction, prompting, and feedback) that gradually fades over time such that learners are eventually *self*-regulated.

The platform and support principles serve as guidelines for developing and testing SRL-promoting technologies. To assess how well systems adhere to these design principles, usability testing literature (e.g., Dumas & Fox, 2009; Kortum, 2016) describes *inspection* methods that can be employed early, frequently, and iteratively by development teams before end-users ever encounter the system. Specifically, we briefly described (a) *heuristic evaluation* methods (e.g., Hvannberg et al., 2007; Nielsen & Budiu, 2013; Zaharias & Koutsabasis, 2013) that systematically examine system designs (e.g., specifications, mockups, and prototypes) based on a pre-defined set of parameters, and (b) *cognitive walkthrough* methods (e.g., Mahatody et al., 2010; Polson et al., 1992) in which developers take on the role of users to complete key tasks and explore potential obstacles, needs, and affordances. Both methods have been implemented in educational technology development to identify usability threats and improve future iterations.

The current report demonstrated the use and utility of the heuristic evaluative framework via PERLS, a mobile, personalized system for delivering content and recommendations to learners in the workplace or informal settings (e.g., Freed et al., 2018). Our evaluation first critiqued the SRL model underlying PERLS design, which revealed (a) plausible connections to established SRL theory, yet (b) overall lack of specification and (c) possible neglect of monitoring and adapting. Key concerns were upheld in a review of the PERLS system design. Although the system provided platforms and several supports for planning and enacting activities, monitoring and adapting were not clearly enabled nor supported by the software. Existing platforms and supports could also be improved in several salient ways to likely improve their impact. Notably, prior versions of PERLS have been deployed in several contexts to assess feasibility and user experience, and these studies observed positive perceptions of flexibility, portability, tracking, and motivation (Freed et al., 2014, 2017b; Suvorov, 2017). We do not argue that PERLS is “useless” or “unusable.” However, our systematic inspection suggests that future iterations could build enormously on earlier successes to better attain PERLS goals. Without conducting the current evaluation, these design gaps in promoting SRL would have been overlooked.

We encourage researchers and developers to adopt (and adapt) the current framework to design and evaluate their SRL-promoting technologies. For instance, developers might use the framework to articulate their design intentions and goals from the earliest stages of “brainstorming” and ensure that key platforms and supports are not unintentionally ignored. Similarly, researchers can use the framework to map out key features and affordances of various tools for experimental comparison (e.g., testing the relative contributions of planning-focused tools and enacting-focused tools on learning outcomes). Educators may also find the framework useful for systematically comparing various technologies, which may facilitate choosing technologies that best match learners’ needs. Finally, given that diverse models of SRL exist (e.g., Panadero, 2017), our framework does *not* purport to be the only acceptable version. We invite modifications that specify key SRL platforms and supports in greater detail, and welcome extensions of usability testing methods to further explore system design.

Section 2: SRL Heuristic Evaluation Update Using PERLS 2.0

Concurrently with the literature review and analysis of prior PERLS materials (i.e., Section 1), development began on an updated version of PERLS—henceforth referred to as PERLS 2.0. An “alpha” prototype of the redesigned system was provided for heuristic review. Importantly, as an early prototype, PERLS 2.0 is necessarily incomplete and numerous defining features have yet to be implemented. In addition, the charge for the development team was to recreate PERLS rather than to reimagine the underlying heutagogy or learning model. Thus, many of the Volume 1 evaluations and recommendations remain pertinent. Nonetheless, the ability to interact with a “live” version of PERLS affords additional insight into system features and needs. In some cases, SRL tools became more salient. This update considers how currently available features map onto or extend PERLS and SRL.

To conduct this evaluation, members of the research team downloaded and installed PERLS 2.0 on a mobile device (including both Android and iPhone platforms). Researchers then collaboratively documented available features (e.g., search tools, bookmarking tools, tip cards, etc.) and considered their role(s) in the heuristic evaluative framework. Given the incompleteness of the alpha version, and the limited example content available, it was not feasible to conduct walkthroughs on these features. In addition, limited documentation on the current (or intended) features of PERLS 2.0 (i.e., a “user manual”) hindered analysis. Researchers could only review the visible software, and thus features might be overlooked. Nonetheless, we continued to build on the suggestions and recommendations from Volume 1 regarding the gaps and potential uses of these tools.

SRL Learning Model Review for PERLS 2.0 Alpha
The SRL Learning Model is not explicitly visible to the PERLS user. However, the prior model (i.e., Explore, Study, and Sharpen) remains the underlying framework for PERLS 2.0. In authoring interfaces, instructors and curators can "tag" learning objectives regarding their intended learning "phases" (e.g., dabble, familiarize, and extend) using a drop-down menu. As noted in Volume 1, a critical need is to update this learning model and improve alignment with established SRL conceptualizations (e.g., planning, enacting, monitoring, and adapting). This update might simply revise the labels in the drop-down menu. Instructors could label certain activities and objects as "planning" or "monitoring" elements rather than "discovering" or "assessing." In addition to aligning PERLS design with established SRL theory, this change would also allow PERLS instructors and content curators to be more explicitly mindful of how or whether their course designs instantiate SRL for their users.

SRL Model Recommendation:

- Update learning model to reflect an accepted SRL learning model.

General Features Review for PERLS 2.0 Alpha
Several features appear to have broad applicability across multiple contexts and phases of SRL. For example, PERLS 2.0 includes "Tip Cards" that briefly present a single content item or message related to a topic, such as a "fun fact" or "background information" to enrich users' understanding (see Figure 1). These tip cards are not a specific platform for any SRL phase, but have significant potential as supports. As recommended in Volume 1, a Strategy Tip card could recommend timely strategies for searching or scheduling (planning), reading and note-taking (enacting), self-assessment and reflection (monitoring), or regulating one's learning environment (adapting). Similarly, a Motivational Tip card might provide information about relevant applications and utility of the information, or might describe a link to other content to inspire curiosity.

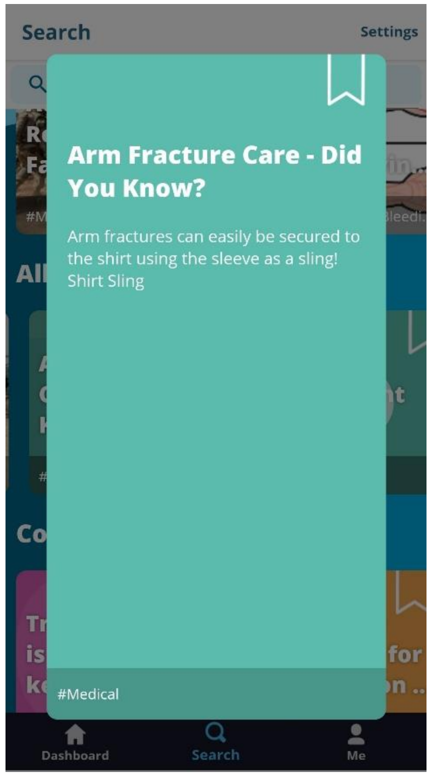

Figure 1. Example Tip Card with brief informational content.

PERLS 2.0 also includes Flash Cards (see Figure 2). These cards offer a single content item (e.g., a key term or concept) on one “side,” and clicking the card “flips” it over to reveal additional information or explanation. As with Tip Cards, Flash Cards may have broad applicability for engaging in SRL. As platforms for enacting and monitoring, Flash Cards might introduce main ideas, enable learners to review these ideas, and allow learners to test their recall. However, one suggestion may be to allow users to *create their own* flash cards in the system. Rather than being limited to a finite set of cards provided by instructors, card creation would engage learners more generatively and metacognitively (Chi & Wylie, 2014). This platform for constructive learning could be support by tips and strategies for developing higher quality flash cards that support deeper comprehension beyond memorization, and strategies for using flash cards in self-questioning and self-testing activities.

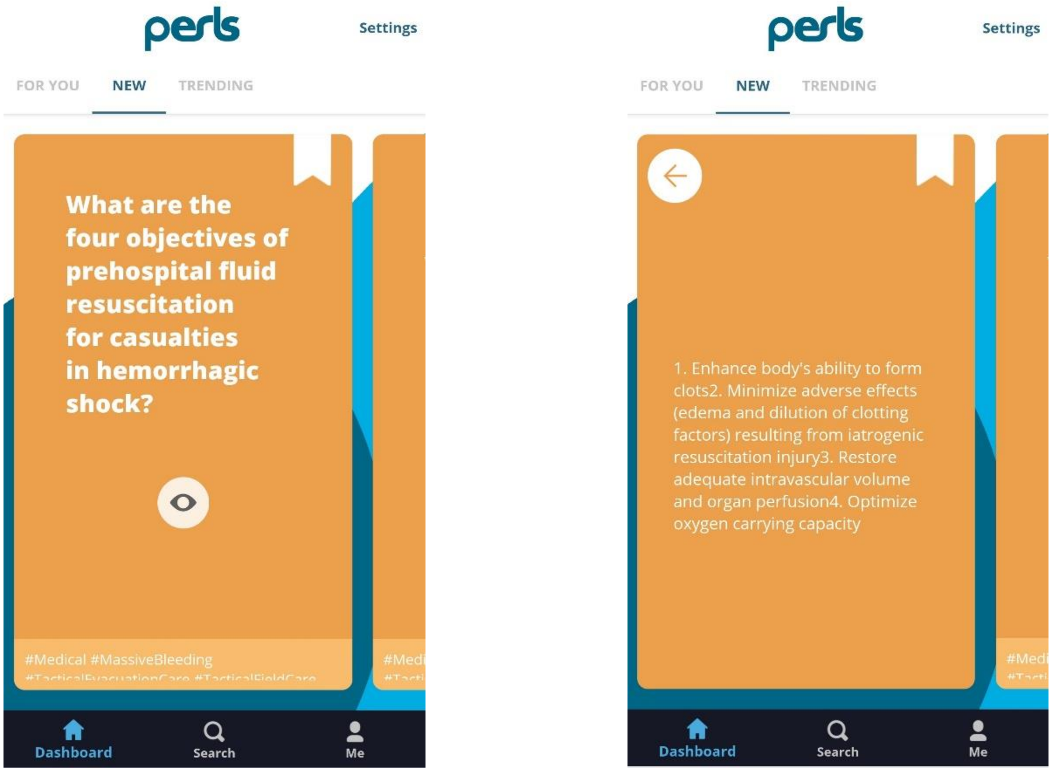

Figure 2. Flash Card featuring topic (left) and information (right).

General Features Recommendations:

- Features of PERLS 2.0 can be applied across many phases of SRL. This capacity should be explored more within the system.
- Allow user to create their own flashcards
- Flash cards that support deeper comprehension beyond memorization, and strategies for using flash cards in self-questioning and self-testing activities

Planning Features Review for PERLS 2.0 Alpha

The goal-setting and motivational recommendation features in PERLS 1.0 have not yet been implemented in the PERLS 2.0 version we reviewed. That is, users do not appear to be able to establish explicit learning goals (e.g., "I want to learn about…" or "I want to test myself…") nor does the software offer personalized suggestions. There does not appear to be a means for learners to schedule content, nor do current learning objects include information about duration or preferred course sequencing. These features—some of the strengths of PERLS 1.0—should be a high-priority target for PERLS 2.0.

Several PERLS 2.0 features contribute to planning in new ways (see Figure 3). PERLS 2.0 includes a "Search" function that appears on a central "home" page for learners (Figure 3, left). This search function allows learners to investigate available content via key words, which are then ostensibly matched to content tags or text in the content. Using this planning platform, learners can locate needed information or explore potentially interesting topics. As with PERLS 1.0, this platform might benefit from more explicit support. The system currently includes a "For You" tab that will eventually provide personalized content suggestions via the recommender system (not currently implemented). This interface is currently rather passive, but future implementation of the recommender system "sell points" may provide a rationale for learners to actively engage with the content. Another suggestion is for the system to offer suggestions for more effective information-seeking strategies (e.g., Walraven et al., 2013). Similarly, metacognitive prompts might support users in reflecting on whether their searches are successfully addressing knowledge gaps and/or the quality of their search queries.

PERLS 2.0 also enables learners to "Bookmark" content to view or review later (Figure 3, middle). At a basic level, this bookmarking offers another platform for planning. To enrich this feature, users might be offered support for more reflective and mindful bookmarking, such as the ability to choose different *types* of bookmarks. Bookmarks might be separated into tags for "important," "interesting," or "required" content. Metacognitive prompts might remind learners to view key bookmarks later if learners fail to follow up. In addition, diverse bookmark types provide information for system adaptivity and personalization. The system can "learn" about the types of learning objects that multiple users flag as critical or engaging, which in turn might inform recommendations for other users.

Finally, PERLS 2.0 allows users to specify their interests (i.e., "add" and "remove" interests from a list) as a basic planning platform related to motivation (Figure 3, right). Currently, these interests seem limited to existing tags and content headers in the system. One recommendation is to allow users to define their own interests more broadly. In addition, this feature could be somewhat expanded to allow learners to specify a time to learn about the topic or otherwise set goals for the topic.

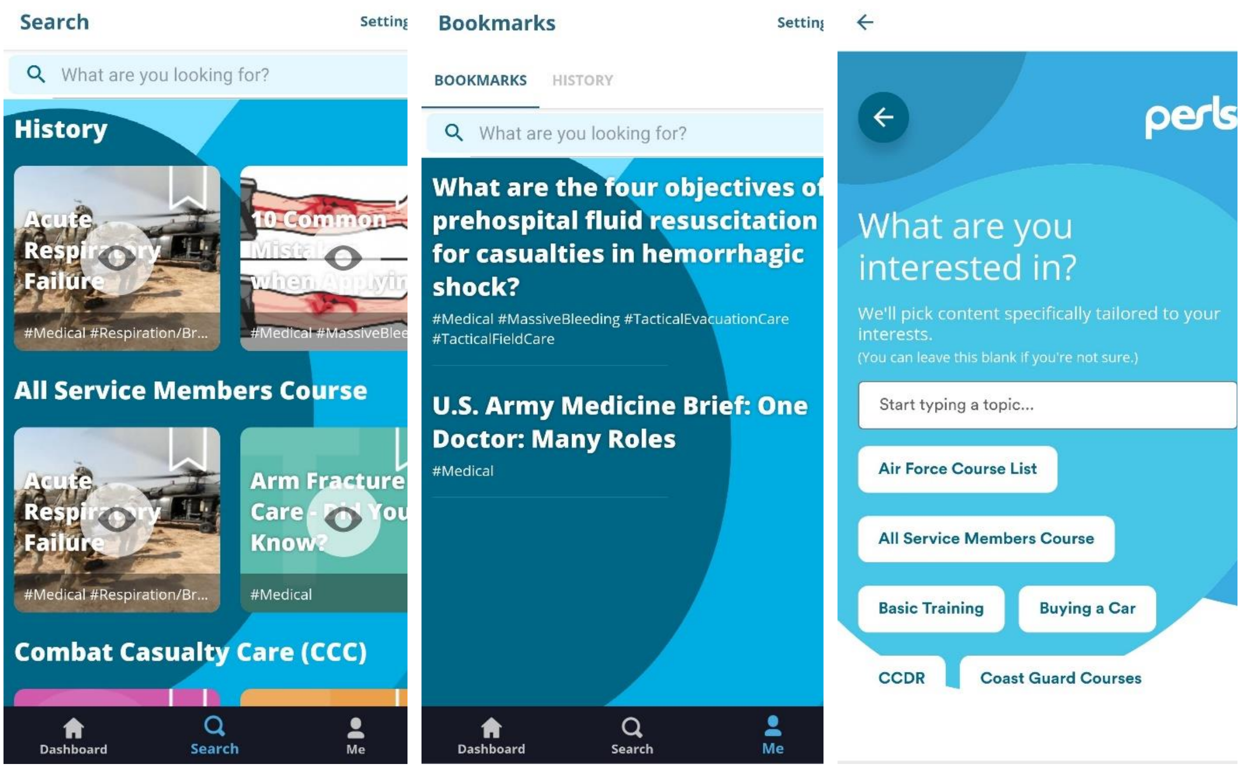

Figure 3. Various planning-related tools for searching (left), bookmarking content (middle), and specifying interests (right).

Planning Recommendations:

- The system could offer suggestions for more effective information- seeking strategies.
- Expand Bookmark feature to include different types of bookmarks
- Add metacognitive prompts
  - Target learner's knowledge gaps for searches
  - Prompts that remind learnings to review important bookmarks
- Allow learners to define their own interest more broadly instead of just selecting from a list of topics.
- Allow users to set time to learn about the topic (timeframes) or set goals.

Enacting Features Review for PERLS 2.0 Alpha

As in the prior version, PERLS 2.0 can deliver a wealth of information content from a various sources and modalities. One new feature includes "Learning Articles" that allows instructors to author their own new learning content (see Figure 4). Thus, rather than solely pulling information from existing resources, instructors and creators can develop content based on their own course needs or expertise. As noted above, creators can "tag" these new objects based on relevant topics and/or intended phases of SRL. Instructors may need guidance in how to author content that is clear, concise, and organized.

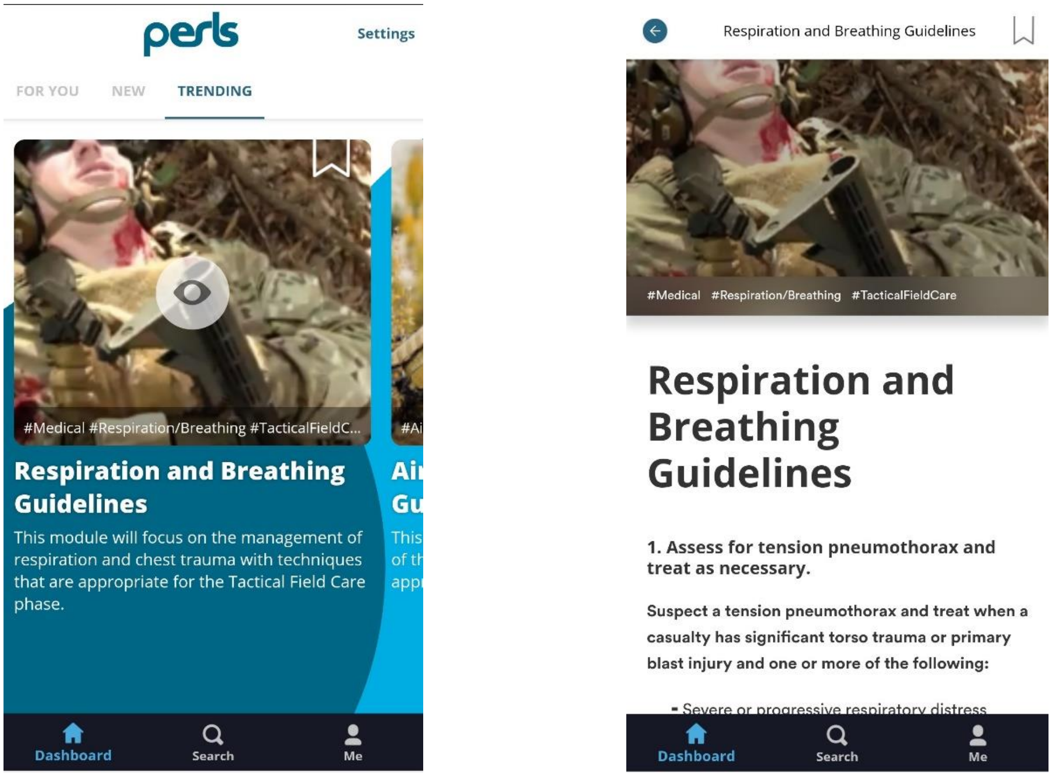

Figure 4. Learning Article featuring topic in PERLS (left) that opens to a detailed explanatory article (right).

PERLS 2.0 also includes “Learn Links” that accesses content of the application (see Figure 5). One way to provide support for learners is to offer strategies for locating or using external content, and perhaps explanations for how and why learners may benefit from such content. Learners may have the misperception that all of the needed information is encapsulated in PERLS.

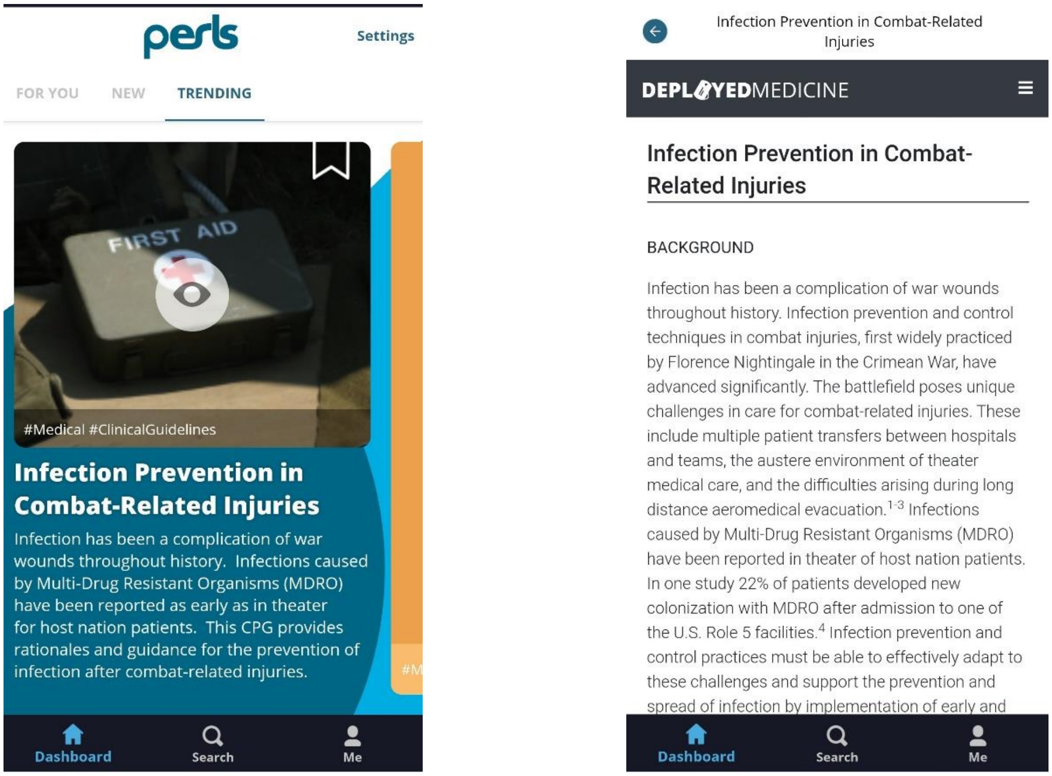

Figure 5. Learn Link featuring topic in PERLS (left) that connects learners to additional external information via Deployed Medicine (right).

Enacting Recommendations:

- Add strategies for locating or using external content

Monitoring Features Review for PERLS 2.0 Alpha

PERLS 2.0 continues to include "Quiz Cards" that comprise a single multiple choice question. From an inspection of authoring tools, quiz creators can specify the correct answer along with feedback messages triggered by answer selections (see Figure 6). For instance, each incorrect answer could receive a unique response that explains the correct answer and key errors of the selected response. However, such design is dependent on the instructor or creator. Thus, instructors may need support or guidance in creating higher-quality questions and feedback.

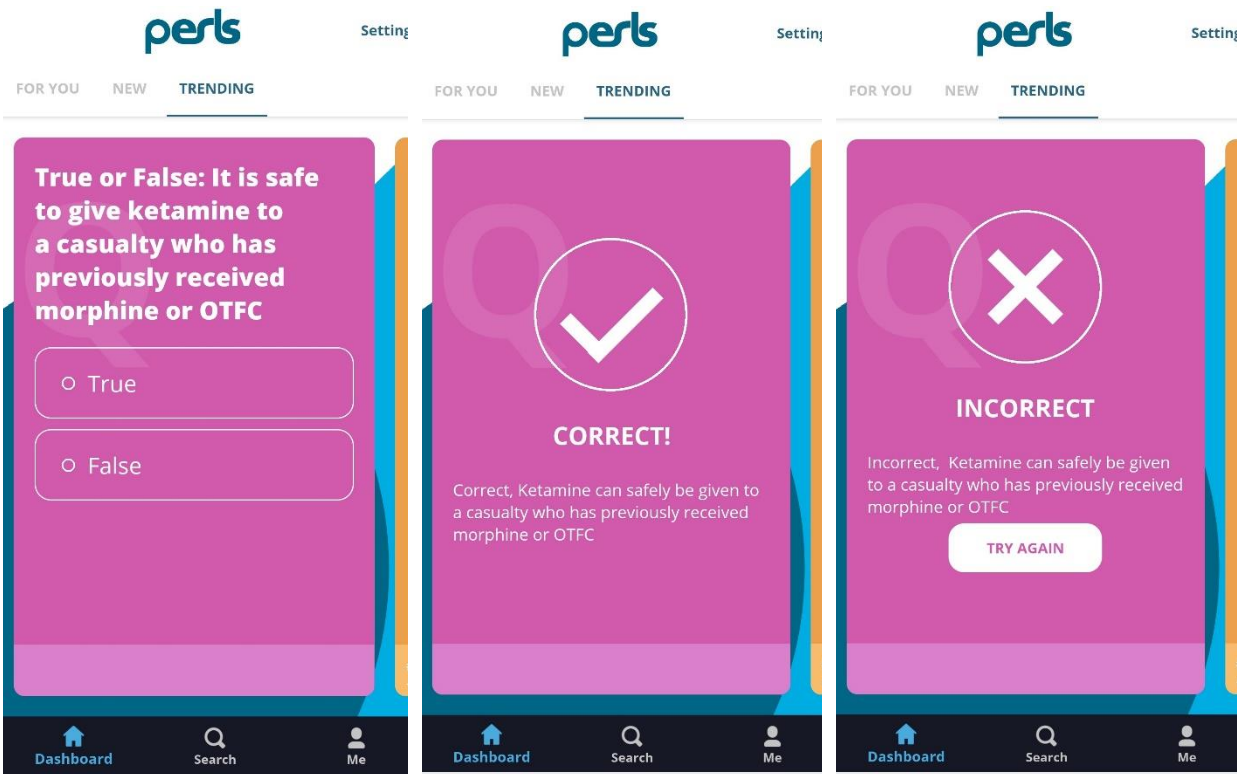

Figure 6. Quiz Card featuring the multiple choice question (left), feedback on a correct answer (middle), and feedback on an incorrect answer (right).

For learners, Quiz Cards may serve as metacognitive supports during enacting, such as testing immediate recall or comprehension after studying a new topic. Similarly, multiple Quiz Cards could be assembled into a longer "exam" or "assessment" as a platform for monitoring overall understanding and performance. Importantly, individual quizzes and longer tests would benefit from guidance in what to do next. That is, if learners are able to answer questions correctly, they might be steered toward the next lesson or stage of the training. However, if learners are unable to answer the questions, they should receive assistance or strategies for improving their knowledge (e.g., Learn Links to external resources for further study or practice).

Monitoring Recommendations:

- Provide instructors guidance in creating higher-quality questions and feedback.
- Ability to combine multiple quiz cards into longer knowledge assessments.

Adapting Features Review for PERLS 2.0 Alpha

PERLS 2.0, based on the available alpha prototype, continues to offer no explicit platforms or support for adapting. Although skilled *learners can adapt and self-regulate on their own*, PERLS 2.0 will need to address this aspect of SRL more directly.

Adapting Recommendation:

- Further consideration needs to be given as to if additional features should be added to support adapting and if the additional feature are feasible.
- Reminders could be added for learners to review their areas of interest to indicate areas that "mastery has been achieved" and select new areas.

Summary of Review for PERLS 2.0 Alpha

In sum, several features in the alpha version of PERLS 2.0 support basic elements of planning (e.g., searching, bookmarking, and choosing interests), enacting (learning the content), monitoring (e.g., quizzes). Several features (e.g., tips and flash cards) have high potential to be leveraged as diverse supports, but such uses have not yet been implemented. There remains no explicit platform or support for the adapting phase of SRL.

We also observed that PERLS 2.0 will include many tools for instructors or content creators to develop learning materials (e.g., tip cards, content cards, and quiz cards). These "authorware" features were not apparent in PERLS 1.0 documentation and represent enormous potential for customized and useful training via PERLS 2.0. However, authoring tools imply another class of user—the instructors and creators—who must also be considered in PERLS design. Our current analyses focused on a heuristic evaluation from the perspective of "learners." From the perspective of SRL-supportive technology design, future iterations of the framework may need to consider "platforms" or SRL-based course creation as well as "supports" for instructors to adhere to principles of SRL (e.g., professional development).

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Appendix A. Heuristic Matrix

Simple Heuristic Evaluation Matrix for SRL Platforms and Supports

	SRL Phase			
Heuristic	**Planning**	**Enacting**	**Monitoring**	**Adapting**
Platform Implementation	**Yes | No**	**Yes | No**	**Yes | No**	**Yes | No**
Strategy Support Implementation	**Yes | No**	**Yes | No**	**Yes | No**	**Yes | No**
Metacognition Support Implementation	**Yes | No**	**Yes | No**	**Yes | No**	**Yes | No**
Motivation Support Implementation	**Yes | No**	**Yes | No**	**Yes | No**	**Yes | No**
Independence Support Implementation	**Yes | No**	**Yes | No**	**Yes | No**	**Yes | No**

Appendix B. Example Heuristic Evaluation Matrix

Example Heuristic Evaluation Matrix for PERLS

Heuristic	SRL Phase			
	Planning	Enacting	Monitoring	Adapting
Platform	**Yes**	**Yes**	**No**	**No**
Implementation	• enables topic-selection and goal-selection using PERLS terminology	• diverse content and formats • both internal, external content • TLA and xAPI integration		
Strategy Support	**Yes**	**No**	**No**	**No**
Implementation	• labels indicate duration and format of every learning object			
Metacognition Support	**Yes**	**Yes**	**No**	**No**
Implementation	• activity report lists goals and current progress • shows days and total study time for the week	• very short (one-item) quizzes • test recall of recently studied information		
Motivation Support	**Yes**	**Yes**	**No**	**No**
Implementation	• recommender system suggests topics and goals • based on interest, location, urgency	• recommender system suggests learning topics • based on interest, location, urgency		
Independence Support	**No**	**No**	**No**	**No**
Implementation				