Adaptive Blended Learning Environments

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Abstract **- Adaptive learning refers to the use of what is known about learners, *a priori* or through interactions, to alter how a learning experience unfolds, with the aim of improving each learner's success and satisfaction. Blended learning refers to the use of learning activities of differing kinds and venues to synergistically achieve overarching learning objectives. We have developed a technology infrastructure that supports online learning, where activities can be designed to adapt in response to an individual learner's situation. Recognizing that what is learned about learners from these activities could subsequently be used to adapt classroom-based learning, we have begun introducing technology features that support coordination between these venues. These same capabilities enable human interventions in adaptive online learning activities, thereby extending their responsiveness. From these beginnings, we anticipate the prospect of *adaptive blended learning environments*, where what comes to be known about learners from activities performed in any venue can be used adaptively by subsequent activities. This paper presents and discusses some opportunities and issues related to this prospect, both technologically and pedagogically.**

Index Terms – adaptive learning, blended learning, learning environments, learning technologies, VaNTH ERC.

INTRODUCTION

Blended learning is a phrase introduced by the distance learning community in recognizing the value of synchronous learning activities, like face-to-face interactions with instructors and collaborative work with peers, as complements to activities performed asynchronously by individual learners. In formal education settings, learning experiences have almost always consisted of classroom-based learning (synchronous) complemented by work performed outside class (asynchronous); that is, formal education has traditionally been "blended". While this outside-class work is an integral aspect of a learning experience, there is typically a loss of immediacy with respect to feedback, since assignments performed outside class must await human evaluation and subsequently be returned to the learner for reflection. This time-shifting has implications both for the learner's self-assessment and for the instructor's ability to collectively (and contemporaneously) respond to evidence of difficulties and misconceptions shared among learners.

Brosvic et al. [1] examined the effect of immediate feedback, delayed feedback and no feedback on student performance when confronted with previously encountered quiz questions on the final examination. They found a significant improvement in retention when students were initially provided with immediate feedback rather than delayed feedback or no feedback, and even greater retention when provided with multiple attempts on the initial encounter. This agrees substantially with an earlier meta-analytic review by Kulik and Kulik [2], in which immediate feedback was generally found to be superior to delayed feedback. The term "informative tutoring feedback" has been used to describe elaborated feedback that provides strategically useful information guiding the learner towards successful task completion. This includes various cues and hints, and the ability to make multiple attempts to solve problems. Several studies have shown that this kind of feedback is an effective way to improve learner motivation and achievement [3].

Modern learning technologies are making it possible to provide immediate feedback to learners during learning activities performed online or otherwise within technology-supported learning environments. An important aspect of these technologies is their potential to be responsive to the learner's situation as he or she progresses through a learning activity. The phrase *adaptive learning* is being used to refer to this kind of responsiveness. The National Academy of Science's "How People Learn" report [4] refers to this interest as being "learner centered", one of four fundamental quality aspects of effective learning environments it recognizes. Adaptive learning uses what is known about an individual learner, *a priori* or through interactions, to dynamically alter the flow or content of learning activities. Such an approach has a long tradition in research on intelligent tutoring systems [5], and more recently adaptive hypermedia [6]. The NSF Engineering Research Center for Bioengineering Educational Technologies (called VaNTH) [7] has recently pioneered learning technologies specifically for adaptive learning that are presented and discussed later in the paper.

Blended learning is concerned with effectively leveraging the strengths of differing kinds of learning activities and venues in achieving some overarching learning objectives. Adaptive learning is motivated by being more responsive to learners as individuals. These ideas intersect in the notion that both synchronous and asynchronous learning activities can be informed by what is known about individual learners, and how learning activities are effectively combined can and should be responsive to the actual learners at hand. This paper examines some of the opportunities and issues of *adaptive blended learning environments*, a phrase we will use to refer to this intersection of concerns.

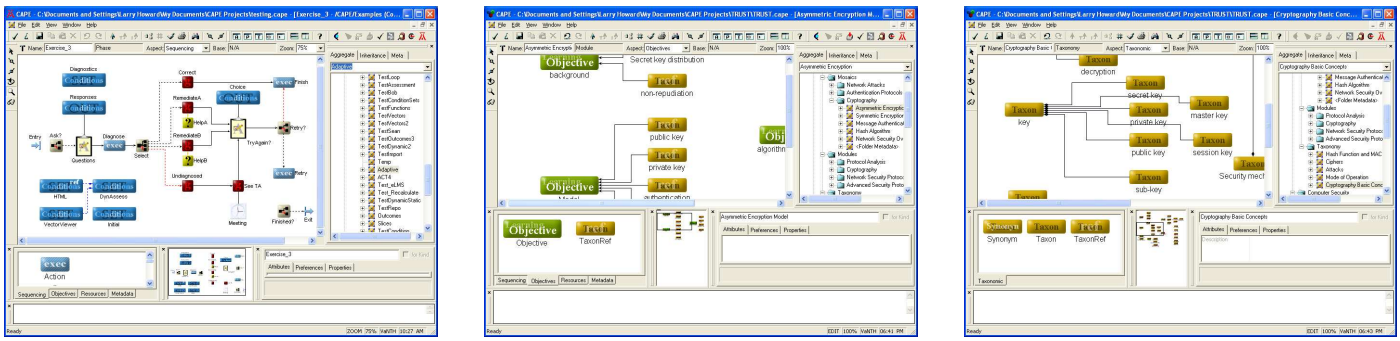

FIGURE 1: THREE VIEWS OF THE CAPE AUTHORING ENVIRONMENT

As learning technologists, the primary lens we will use for this examination is technological, specifically innovations that enable new possible interrelationships between classroom and outside-class learning. In the first part of the paper, we will describe the learning technologies for adaptive learning created by VaNTH and discuss how they can be employed in blended learning environments. But our motivation in developing new technologies is ultimately pedagogical: improving the practice of teaching. In the second part of the paper, we will identify some challenges for educators in making blended learning environments more adaptive.

ADAPTIVE LEARNING TECHNOLOGIES

The VaNTH ERC has developed a technology infrastructure for adaptive learning that consists of two primary components:

- A repository-based authoring technology for adaptive web-based courseware (CAPE)
- An online learning platform (eLMS)

The Courseware Authoring and Packaging Environment

CAPE is used to design online learning experiences involving static, interactive, and dynamic content elements created with conventional web authoring tools and within CAPE itself. [8] The designs specify when, or under what circumstances, content elements are presented to a learner during the course of a learning experience. Interactive elements can elicit information from a learner, and the outcomes are available immediately to adaptations incorporated into designs. A data modeling facility enables capturing facts, including data defined abstractly by expression, for use in realizing adaptation schemes. Simple sequencing constructs can be extended with computational components for more advanced reasoning.

CAPE designs involve other kinds of specifications in addition to sequencing models. These include the statement of learning objectives and their association with content knowledge represented by curricular taxonomies, as well as tagging with community-specific and standards-based metadata. Such specifications play no direct role in design enactment, but are used to communicate the original designer's intentions to other authors and to provide additional descriptions of elements and resources for use by other tools. Figure 1, from left to right, shows adaptive sequencing, learning objectives, and taxonomy models, and model aspects, in the CAPE authoring environment.

As you can see from Figure 1, the design representation used by CAPE is a domain-specific visual language [9], where hierarchically organized icons and connections represent concepts and relationships in the language, respectively, and attributes uniquely characterize occurrences. The choice of a visual language for CAPE reflects our interest in a representation that is both expressive and easily constructed. The interface style for such languages, consisting of drag, drop, interconnect, and specify operations, offers many affordances over textual representations. As a desktop application, CAPE lacks the convenience of web-based authoring tools, but enjoys distinct advantages over forms-based authoring, especially in terms of scalability.

CAPE supports both elaborative (top-down) and integrative (bottom-up) approaches to design. Rapid prototyping of adaptation schemes can be performed prior to content development. Existing content and design elements can be readily incorporated into new designs. The environment supports design-time adaptation by providing abstraction facilities that can be used to capture invariants among families of designs and elements as *instructional design patterns*. [10] While CAPE—as a general-purpose design tool—is pedagogically neutral, these design abstractions can be used to scaffold particular learning strategies that can then be shared with other authors through an integrated web-based design repository.

CAPE provides a set of extension components that assist the author in creating, previewing, and packaging designs. An event-based agent continuously monitors the author's actions looking for opportunities to provide time-saving assistance. An online learning component makes CAPE-authored tutorials directly available within the design environment to support just-in-time learning. The environment can be extended with "wizards" that automate complex or repetitive actions. A design previewing component is complemented with a web-based debugger. Content and computational elements can be interchanged with traditional development tools. Completed designs can be directly uploaded to the delivery platform for subsequent assignment to learners.

The experimental Learning Management System

eLMS is an adaptive learning platform that supports interoperation using web services, both in conjunction with enacting courseware designs and in managing domain-specific objects, such as classes, users, and courseware. [11] The heart of the eLMS platform is a model-based delivery engine that enacts learning designs authored with CAPE.

The platform automatically captures detailed instrumentation of these design enactments, and additional instrumentation—to support grading using custom rubrics, for example—can be incorporated into courseware designs with CAPE. The resulting *delivery records* can be queried by instructors and authors using an integrated data mining facility. (Figure 2) These capabilities enable an intimate understanding of what learners actually do with on-line learning experiences, which is essential to making incremental improvements over time.

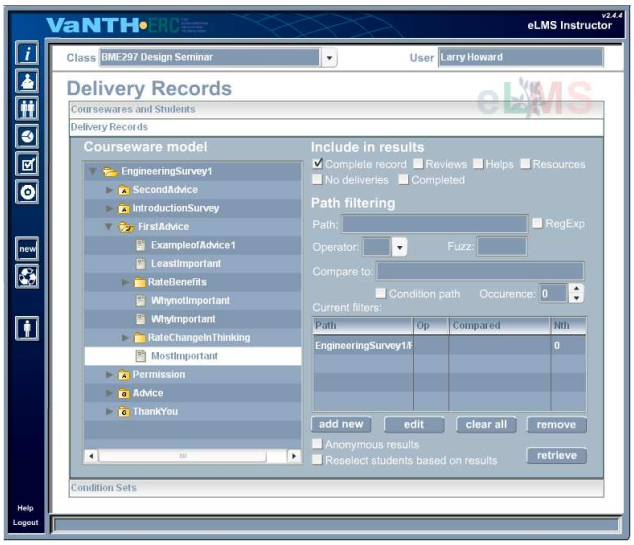

FIGURE 2: DATA MINING OF DELIVERY RECORDS WITH ELMS

Profiles can be used to collect information about learners, classes, and courseware resulting from design enactments. Courseware profiles can be used to collect statistics about the use of a particular learning design, whether this use occurs between semesters at a single institution or across multiple institutions. Learner profiles can collect information elicited from a learner during an earlier courseware for use as part of an adaptation scheme in a subsequent courseware. Class profiles can create digests of information from assignments performed outside class for scaffolding classroom learning.

eLMS allows learners to continue the delivery and review materials and activities across multiple sessions (Figure 3), to take private notes that can be exported from the learning environment, and to access context-sensitive help resources provided by learning designs. eLMS instructors and teaching assistants can manage the rosters of classes and make courseware assignments to a class or to individuals in the class. The status of learners completing assignments can be monitored, learners can be selectively released from synchronization points defined by learning designs (discussed later), and instructors can replay assignments with learners during face-to-face meetings. Courseware revisions uploaded by authors are differentially versioned to avoid disruption of in-progress enactments with learners.

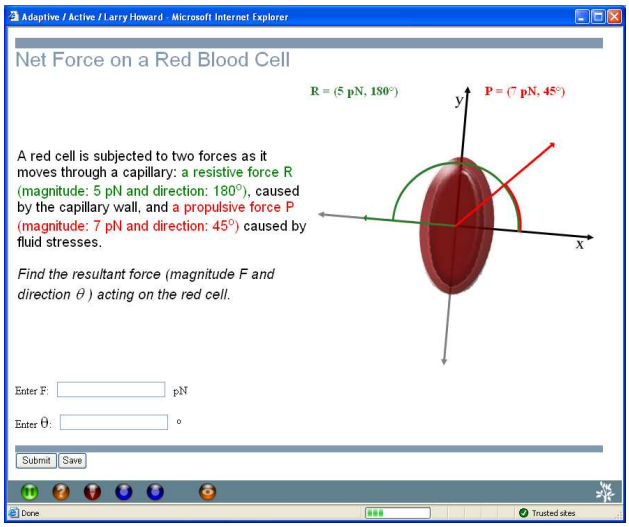

FIGURE 3: COURSEWARE DELIVERY WITH ELMS

While eLMS can be employed directly to manage the use of CAPE-authored designs by classes of learners, it can also be transparently embedded into other learning platforms. A building block integration of eLMS with the popular Blackboard Learning System has been developed as an example of a custom integration. With this plug-in, instructors can assign eLMS courseware to their learners just as any other kind of Blackboard assignment. eLMS also supports packaging its courseware using the SCORM standard [12], thereby enabling delivery from a standards-compliant learning platform. This approach to integration is similar to the SCORM platform delivering material from an external content repository. Using SCORM packaging, eLMS courseware can be transparently delivered from a variety of commercial learning platforms, such as WebCT, as well as non-commercial platforms, such as Moodle and Sakai.

APPLICATIONS IN BLENDED LEARNING ENVIRONMENTS

CAPE and eLMS have incorporated features that contribute to their use in blended learning environments. Two that we will discuss here are *interventions* and *in-class polling*.

Interventions

Perhaps not surprisingly, CAPE and eLMS have been used predominantly within the VaNTH ERC to create interactive and adaptive learning activities that parallel problem sets traditionally given as homework in bioengineering courses. The improvements these designs offer are immediate remediation of diagnosed difficulties experienced by learners and adaptations to the flow of the problem-solving process, such as breaking larger problems down into constituent sub-problems when learners experience difficulties. [13]

Of concern in designing these kinds of online assignments is the diagnostic "reach" of the adaptations they incorporate. Human instructors are versatile diagnosticians and they understand not only how to remediate difficulties, but also how to be helpful in appropriate ways and in degrees to stimulate the learner's own reflection about difficulties. Encoding this versatility into an adaptive online learning design is non-trivial, and in most circumstances the result will be a weak approximation of the original. But instructors often can give similar assistance multiple times to different learners in a single class or across semesters. So there are efficiencies to be realized in encoding some of this experience.

Our response to limitations in technology-based diagnosis and remediation is providing a capability in the technologies to support a kind of "triage" for learners. Learners having difficulties that can be diagnosed by the online assignment directly receive the prepared remediation and proceed. Learners whose difficulties cannot be diagnosed are referred to a human—typically an instructor or teaching assistant—for help. Progress in the assignment for these learners is suspended until they receive the help and the instructor or teaching assistant releases them to continue. This referral of learners who need help that the online assignment cannot provide enables effective utilization of instructor and teaching assistant time, where time would otherwise be spent grading homework assignments where most responses are correct.

Support for human interventions in adaptive online assignments addresses some of the shortcomings of learning technologies that support diagnosis and remediation of learner difficulties. Our future direction with respect to these capabilities is for the human performing the intervention to decide not just *when* the learner can proceed, but also *how* they can proceed. For example, sometimes it is appropriate for the learner to repeat certain portions of the assignment. Other times the remediation makes such repetition unnecessary. Still other times the learner might be redirected to remedial materials already present in the assignment, suggesting merely a deficiency in the diagnostics.

A more limited use of CAPE and eLMS within VaNTH, but one that is noteworthy in the context of this paper, concerns using online assignments as elements within a larger learning design. VaNTH emphasizes constructivist-inspired pedagogical strategies such as anchored instruction [14]. Learning designs based on anchored instruction are organized as a set of phases "anchored" by a motivating challenge. (Figure 4) The earlier phases of the cycle concern problem setting; that is, they concern reflection by the learner on the salient features of the problem, the applicability of prior knowledge, and the needs for new learning to address knowledge "gaps". The later phases of the cycle provide learning resources to address these knowledge gaps and resources for the learner to self-assess the current state of their knowledge *viz.* solving the challenge. In VaNTH, a majority of the phases of such inquiry cycles were conducted as classroom-based learning activities. Sometimes, however, online elements were given roles to play in enacting a phase, of some aspect thereof, within the cycle.

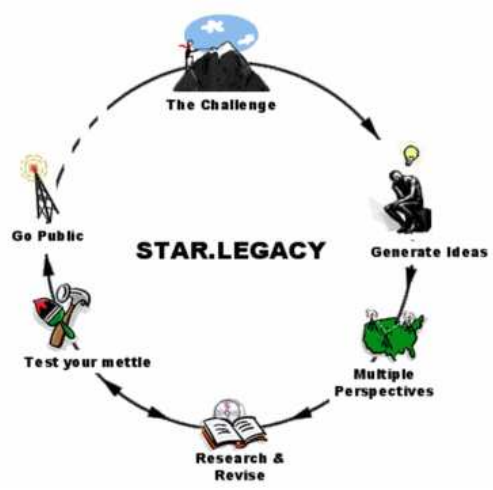

FIGURE 4: CHALLENGE-BASED INQUIRY CYCLE

An example of this type of "blending" is the use of an online assignment to support the "Generate Ideas" phase of the inquiry cycle. This phase is used to elicit from the learner their initial thoughts about what will be important to solving the challenge, to reflect on the applicability of their prior knowledge and to recognize which aspects of the problem cannot be addressed using what they presently know. The use of an online assignment to capture the initial thoughts of learners enables the instructor to follow-up in class with full knowledge of their responses. It also gives the instructor some lead-time to prepare, or adapt, materials for the subsequent "Multiple Perspectives" phase used to help learners shape their problem-solving strategy in pursuing their solution.

A straightforward extension of this approach is the interleaving of online and classroom-based elements within an inquiry cycle. This is where the technology feature of interventions is again relevant. The eLMS learning platform makes it possible for interventions to be collective for all the learners in a class as well as individualized. In this way, the online elements can be coordinated with the classroom-based elements, with learners proceeding to subsequent online phases or activities under the direction of the instructor. Of course, this same capability could be achieved by breaking the online elements up into individual assignments. The obvious disadvantage of this approach is a separation of elements that conceptually belong together, and a concomitant need to manage more elements. Also, while the support for profiles by eLMS allows the transfer of information about learners between assignments, keeping the elements in a single design provides a simpler approach to using such knowledge.

In-Class Polling

VaNTH has made extensive use of classroom feedback devices, such as personal response systems (PRS). What is learned about learners using such devices can be useful to the instructor in planning future improvements to a lecture or other kind of classroom learning activity. This information can also be used to immediately adapt the classroom activity,

if the instructor has pre-planned alternatives that can be chosen based on learner responses or can extemporize them. However, the classroom remains primarily a utilitarian space. The needs of a few learners with difficulties with concepts or skills might be outweighed by the majority.

Our response to this situation is providing a means of using what is learned about learners during class to trigger adaptations to online assignments performed subsequently outside class. eLMS was extended to support in-class polling functionality for "wired" classrooms. Learners use their laptops and a web-browser to respond to questions posed by the instructor. Their responses are retained by eLMS, where they can be are used by adaptations during one or more follow-up online assignments. Learners that are recognized to be having difficulties with in-class activities, where the instructor decides not to address these difficulties in class, can be automatically provided specific remedial resources online after class.

The questions for this in-class polling can be authored ahead of time with CAPE, or polls can use generic responses with the instructor posing questions verbally or projected from presentation materials. When authored with CAPE, the subsequent follow-up activities can be authored together with the poll questions. This approach is similar to many online learning activities that begin with a profiling phase and then adapt the remainder of the activity to the learner's responses. CAPE and eLMS make it possible for the same design to be used in both ways.

Our future direction in this area is to support adding responses to eLMS from external polling systems, like PRS. Our motivation for this extension is that not all classrooms are "wired" and it is not always possible for students to have a laptop computer with them during class. PRS systems are more innocuous in terms of how their presence affects a class, yet the information about learners they provide is equally useful. Interfaces that allow learner responses to questions posed by such systems to be imported into eLMS learner profiles would allow the intended benefits to be achieved without the need for laptops and classroom networking.

ADAPTIVE BLENDED LEARNING ENVIRONMENTS

From these experiences we anticipate that the future holds much tighter integration between the classroom and outside class learning environments. There is clearly a technological dimension to this integration: getting information from where it originates to some point of use in time to be useable and in a form that makes it useful. When online activities are used to prepare learners for a synchronous event, like a classroom session or a lab, integration means that what is learned from learners is available to an instructor for use in preparing for the event. When such a synchronous event yields information about learners, integration means that this information is available to subsequent learning activities, whether performed inside or outside class. Figure 5 depicts these kinds of information flows.

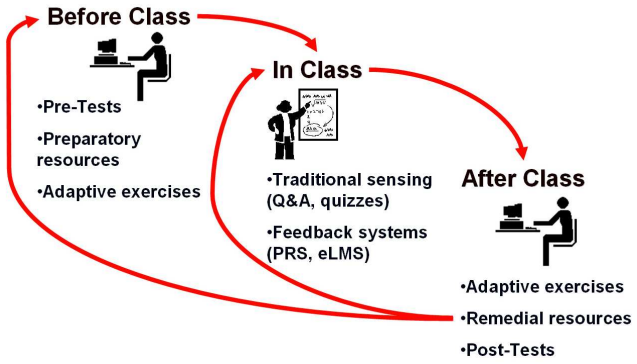

FIGURE 5: INFORMATION FLOWS IN BLENDED LEARNING ENVIRONMENTS

That technology *can* increase the quantity and timeliness of information from learning activities performed in different venues is important only if educators are motivated to use this information to improve the quality and responsiveness of the learning experiences they design. For some VaNTH educators, the availability of information about learners not gathered specifically for evaluating their performance was motivating. This kind of information provided a more process-focused lens for reflecting on their learning designs. Experimental methods for assessing the effectiveness of modules designed by educators for VaNTH (an obligation for participation in the Center) provided many educators a first experience with subjecting instructional designs to rigorous evaluation. What educators learned about assessment of instruction through these activities was important for increasing awareness of the role such assessment plays in improvement processes.

Likewise, creating adaptive online learning experiences was motivating for some VaNTH educators. The process itself is reflective, asking educators to anticipate how learners can misunderstand and misapply learning that the educators themselves are responsible for providing and supporting. Further, the process enables educators to recognize themselves clearly as tutors and mentors as much as instructors and to appreciate how much they contribute to learners in these roles.

These are encouraging signs that educators will be receptive to new capabilities and design possibilities arising from tighter integration between classroom and outside class learning afforded by new technologies. Our optimism is tempered by the realization that, due to the collaborative nature of VaNTH, where educators worked directly with learning scientists, experts in assessment and evaluation, and learning technologists, these educators may be not be indicative of the educational community at large. It remains to be seen how receptive other educators, with little or no such scaffolding, will be to these new possibilities.

There remain many challenges to understanding how increased availability and timeliness of information about learners can contribute to improving their learning outcomes. First, there appears to be a tendency by educators to look at information gleaned from classroom feedback systems and online learning experiences as relevant only to its originating venue, rather than considering it in the context of the learning

experience as a whole. For example, when looking at delivery records of students from an online assignment, we observe a tendency of educators to respond to failures of the assignment to properly diagnose and remediate learner difficulties as suggesting a need to improve these features of the assignment, rather than looking for the root cause of the difficulty, which may originate with preparatory classroom-based activities. We see the need to address such tendencies with a discipline of reflection that emphasizes the identification of root causes over treatment of symptoms.

Other challenges come from the quantity of information available from online learning platforms and the ability to interpret this information. When we designed the eLMS learning platform, we intentionally decided to extensively instrument the delivery of online learning assignments. This decision was both an indication of our uncertainty about which kinds of observations would be more important and our aim that eLMS be useful as a tool for research, where greater numbers and kinds of observations ensure a richer source of data to support inquiry. What we have learned from educators using the platform is that the designs of the learning experiences themselves have a much greater impact on the meaningfulness of observations than the volume of observations that are gathered automatically. Design uncertainties can be more effectively resolved by focused experimentation than by attempting to propose theories for large collections of observations. As in-class polling or other classroom feedback systems become integrated with outside class learning systems, the volume of available information about learners will further increase, making it all the more important that learning experiences are *designed* to reveal meaningful observations about learners.

Perhaps the biggest challenge facing the prospect of adaptive blended learning environment is the commitment of educators to be *reflective practitioners* [15]—to see their teaching as an evolving enterprise. In this enterprise, teacher learning is just as important as student learning. The motivation for adaptive learning designs is to provide learners with the assistance they need when they need it. Modern technologies are making it possible to better understand learners through observations of the learning process, not merely by assessing learning outcomes after the fact. The prospect of adaptive blended learning environments promises richer sources of information about how learners can misunderstand and misapply knowledge as they progress through learning activities performed in multiple venues. The challenge is to turn this information into understanding and to use this understanding to guide more learners to achieving successful outcomes.

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