What Really Works in Hybrid Learning: A Cognitive Perspective

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Abstract. This paper synthesizes two decades of research focused on understanding what "really works" in education, with a focus on hybrid learning environments. A cognitive perspective approach shaped research on diverse learning environments. All of these learning environments had empirical foundations for improving student learning outcomes. The fundamental conclusion reached is that development of hybrid learning environments must be driven by educational research that would be on the scale and rigor analogous to large clinical trials designed to promote evidence-based practices in healthcare.

Keywords: Theories of cognition · Personalized learning · Adaptive learning · Competency-based learning · e-learning · Misconception development · Healthcare curricula · CIT curricula

1 Introduction

Over two decades, we studied frameworks for evidence-based approaches to improve science, technology, engineering, and mathematics (STEM) education in the United States [1]. Much of this work focused on factors shaping exclusions of students from STEM majors, especially minority, women, and first generation university students. We tried to provoke the educational community to start framing educational research that would be on the scale and rigor analogous to large clinical trials designed to promote evidence-based practices in healthcare. Early research analyzed factors shaping success of STEM students in four-year baccalaureate liberal arts colleges in the United States [2, 3]. Scant research explored the suites of psychological factors shaping cognition and learning. Beginning in 1996, we took advantage of the growing international interest in computer-based simulative environments to design and study complex learning objects built as virtual worlds. These were designed for computer-based tutorial systems or nested within environments that were the early precursors of learning management systems for online and hybrid courses. Using the National Research Council guidelines as a foundation [4–6], we initiated a decade long effort (2001–2011) to build evidence-based educational environments that could be sensibly

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nested: (a) within emerging computer-based tutoring systems; (b) within serious games designed for education; and (c) integrated into the rapidly evolving online learning management systems.

2 Knowledge Gaps

2.1 Gaps in Our Understanding of Cognition and Learning

During a decade of work, we identified ten knowledge gaps that remain unresolved. For your review, we present these gaps below:

1. How does an educational environment impact disposition to engage in a learning process?
2. What are the relationships between the level of realism in an educational environment and learning outcomes?
3. How do you define the threshold of experience within an educational environment that leads to measurable learning outcomes?
4. What are the knowledge domains being developed during learning?
5. In which knowledge domains has learning been retained and how stable is that retention?
6. What is the disposition to act on the knowledge gained from learning within an educational environment?
7. How well can the knowledge be transferred to related problems in the same domain area?
8. What learning outcomes (conceptual and performance competencies) are developed during the learning process while working within an educational environment?
9. How are misconceptions developed during and sustained after working within an educational environment?
10. How do teacher-student and student-student social networks or e-communities impact learning.

Development of misconceptions proved the gap most difficult to study. An interesting body of work on personalized learning environments evolved in Europe [7–9]. However, our studies of misconception development resulted in a methodology that allowed study of all ten gaps, but focused on misconception development [9–13]. We argue the neurologically dynamic condition of a "misconception" instantiated, even temporarily, within a person's mind is that person's state of being unaware some knowledge domains and cognitive processing are incomplete or incorrect, and how we believe we are right even when we so often are not [14–17].

The methodology we developed was applied to study all ten gaps [9, 10]. Indeed, and though we focus on hybrid or blended education, these ten gaps are common problems for any educational format or setting. No learning management systems (LMS) or course designs, to date, bridge the ten gaps listed above. From an operational research perspective, part of the difficulty is the startling diversity of hybrid-bended courses that have been designed and implemented—the majority with scant evidence that they really work to improve learning. This diversity of course types imposes enormous barriers to studying how hybrid learning "*might*" improve learning outcomes and bridge the gaps we have been discussing.

2.2 Taxonomies of Hybrid Courses

So far, we have not found a coherent theoretical framework to guide systematic studies of the enormous complexity inherent in hybrid-blended learning. There are few truly systematic delineations of all of the possible types of blended learning courses as well as courses not yet developed but imaginable in the ever evolving milieu of educational technology.

We developed a taxonomy for hybrid-blended learning courses with full communication capacities, which means such course include all or multiple forms of communication, including social networks, with interactions among students, among students and faculty members, and among students and sources outside of a course. Table 1 shows Course types disaggregated by the relative proportion of face-to-face (F2F) and online course elements. To simplify, we used Low Percentage F2F ($\leq$35 %), Medium Percentage F2F (36–70 %), and High Percentage F2F (>70 %). We further disaggregated course types by degree of complementarities of the face-to-face and online course components [11, 18].

For course structure, we included: (1) Complete Release – all materials of all course elements are available from the start and remain accessible throughout the course duration; (2) Time Hierarchical Release – with course materials released on a time schedule and without requirement for demonstration of student mastery; (3) Topic Hierarchy without Mastery – course elements are released to students by topic-subject area cluster but without condition of their mastery of prior topic-subject cluster; (4) Topic Hierarchy with Mastery – course elements are released by course topic-subject area cluster and with the condition of mastery of the prior topic-subject cluster. We then added an additional disaggregating variable suite related to the degree of educational scaffolding provided for each course structure. To simplify somewhat, we used the terms "Guided" to mean high levels of scaffolding and "Unguided" to mean no or little educational scaffolding related to the course structure and how to move through that structure. Table 1 shows this taxonomy as a $\{6 \times 8\}$ matrix of cells, each cell representing a type of hybrid course. In Table 1:

- Cell "A" represents blended courses that have a low percentage of faculty face-to-face components (so mostly online), with the face-to-face and online course elements integrated and complementary, with course materials released at the start of the course and available throughout the course, and with guidance provided to the student by scaffolding on how to proceed through the course.
- Cell labelled "B" represents blended courses that have a medium percentage of faculty face-to-face components (more balanced face-to-face and online elements), with the face-to-face and online course elements not very well designed to be complementary, with course materials released on a timed schedule not necessarily correlated with topic-subject clusters, and with little guidance provided to the student by scaffolding that would facilitate how to proceed through the course.

- Cell labelled “C” represents blended courses that have a high percentage of faculty face-to-face components (thus, little online), with the face-to-face and online course elements integrated and complementary, with course materials released by topic-subject cluster and on the condition of student mastery or prior topic-subject clusters, and with guidance provided to the student by scaffolding that would facilitate how to proceed through the course.

We believed that any study of “what really works” in blended learning would have to accommodate all of the course types in our taxonomy. Examining the history of blended and more recent developments, we felt the taxonomy was a reasonable starting point for the development of theory related to how, why, when, and with what outcomes does blended learning really work to improve students’ and trainees’ learning outcomes. In particular, we explored the robustness of the taxonomy in the context of integrating theories of cognition and behavior into instructional design. Our research turned to a focus on course types A and D in Table 1.

Table 1. Blended course taxonomy derived from the Rudak-Sidor taxonomy.

		Course structure							
		Complete release		Time hierarchy		Topic hierarchy		Topic hierarchy with mastery	
Face-to-Face		G	U	G	U	G	U	G	U
Low (≤35 %)	C	A							
	NC								
Medium (36–70 %)	C	D							
	NC				B				
High (>70 %)	C							C	
	NC								

C = Complementary, NC = Not Complementary, G = Guided by Scaffolding, U = Unguided by Scaffolding.

3 Evidenced-Based Educational Simulations

3.1 Theories of Cognition and Design of Instructional Materials

During the period 1998–2014, we studied how cognitive and learning sciences could inform instructional design, especially in development and evaluation of complex learning objects within online course components. Patel, Yoskowitz, Arocha, & Shortliffe [19] pointed out that in healthcare delivery settings cognition will be shaped by the situated encounters in that workplace, which are dynamic and strongly influenced by social contexts as well as by a diverse array of other elements in the setting such as technology, temporal and spatial heterogeneity in the patient’s condition, changing shifts of providers caring for the same patient, and ongoing coordination of many different tasks and decisions as well as health information management [19].

Effective action requires development of pattern recognition capabilities as providers move from novice to expert.

We conducted an analogous analysis for computer sciences education, studying a system built by Northern Arizona University to provide a personalized learning experience for an online CIT curriculum [9]. For both healthcare and CIT curricula frameworks we examined students' cognitive processing and knowledge formation. One can find a variety of models for cognition and learning, summarized nicely by Patel and colleagues [19] for healthcare education. We believe such models are easily extended with validity to CIT education as well as other discipline domains [13, 20]. However, through time a student is exposed to many new educational and life experiences.

As a starting point, we examined several theories of cognition. We realized that a very sophisticated virtual world could be constructed as an educational simulation and such a world might be valuable to test theoretical frameworks that have been proposed for cognition—for example cognitive load theory, cognitive flexibility theory, adaptive character of thought theory, and situated learning theory. Some of these theories cluster into more individualistic structured learning—such as adaptive character of thought and cognitive load theories. Others fit within what many educators call constructivist learning theories—such as cognitive flexibility theory and situated learning theory [19]. We also realized that most educational simulation developers had not developed their simulations from grounded theory or have not conducted research on students' learning outcomes using different instances of their simulations using different theoretical framework or a synthesis of frameworks to inform the design and various engines of the simulations. We concluded there were no rigorous large scale studies (i.e. analogous to clinical trials) of simulation design that would give us an empirical foundation for "what really works" to improve student learning outcomes, let alone knowledge retention, knowledge transfer, development of misconceptions, of any of the other knowledge gaps described earlier in this paper.

As we built different models of education simulations for healthcare education, we could choose a theoretical framework for cognition and that framework would drive instructional design. Within that design, we could build very sophisticated virtual worlds and assess conceptual and performance competencies. Here, we are using conceptual competencies as a thorough understanding of a knowledge and/or skills domain. Often conceptual competencies are further elaborated as: (1) competencies in which a person can describe how and why to use the knowledge or skill in different but appropriate contexts (generativity [19]); and (2) competencies in which a person can describe how to use the knowledge or skill in situations that are unfamiliar (robustness; [19]). However, performance competencies are those competencies in which knowledge is acted on as an expression of a variety of behaviors and decisions or skills that are implemented in the real world or some very close simulation of the real world.

We were able to build simulations that engaged students in opportunities to demonstrate competencies, knowledge, and skills. For simulations without haptic interfaces or augmented reality, we could not embed and measure performance competencies involving psychomotor activities. However, we were able to assess conceptual competencies and through longitudinal studies see how measures of conceptual competencies and disposition to act on knowledge and skills acquired might predict performance competencies.

3.2 Evidenced-Based Educational Simulations with Engines for Capturing Cognitive Traces of Student's Learning

As use of hybrid-blended and totally online courses increased, we studied how to nest into such courses educational simulations that had an empirical foundation for improving student learning. We chose to design simulations that were grounded in the situated learning theory of cognition. This constructivist theory posits that learning develops within the activity, context, and culture in which it is situated. From an instructional design perspective, a simulation based on situated learning would involve learners in what some call a *cognitive apprenticeship* that provides a variety of engagements that support learning of a knowledge and skills by enabling learners to develop and use their cognitive tools within authentic activities of the knowledge-skills domain. [See University of Oregon, Accessed January 20, 2015; Reference: http://otec.uoregon.edu/learning_theory.htm#SituatedLearning] We used situated learning theory to develop course maps, such as the diagrammatic representations shown in Figs. 1 and 2.

Course maps provide a sensible way to organize competency or learning outcome domains (C in Figs. 1 and 2), and for each competency to delineate specific educational objectives (O in Figs. 1 and 2). Educational objectives can be developed into teaching-learning-assessment modules (M in Figs. 1 and 2), with each module comprised of suites of potential interactions or student engagements (I in Figs. 1 and 2). Each interaction is a set of one or more learning activities, and each learning activity has a suite of assessments as well as diagnostic feedback and scaffolding for each assessment (respectively LA, A, and D in Figs. 1 and 2). In Fig. 1, we can imagine a learning activity its respective assessment suite and the respective diagnostic feedback and scaffolding suite—for example, in Fig. 1 follow competency C_i to Objective O_{i2} and then to module M_{i2}. Module M_{i2} has four interactions I_{21}—I_{24}. Interaction I_{21} has four learning activities—LA_{211}-LA_{214} each of which has its respective assessment and diagnostic suite.

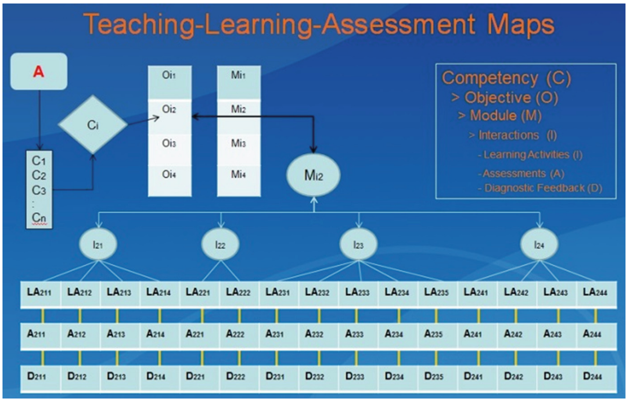

Fig. 1. Diagrammatic representation of a course map for some course A (e.g., Course Type A from Table 1).

The design of the modules, interactions, learning activities, assessments, and diagnostic-scaffolding suites becomes idiosyncratic to the theoretical framework being used. Furthermore, as learners construct knowledge they often require exposure to related learning activities in order to sensibly build an understanding of complexity in a knowledge-skills domain. In Fig. 2, we diagrammatically represent some clusters of related learning activities that are organized under different interactions. Note also in Fig. 2 that a research engine has been inserted to collect data on assessments completed by a student when engaging only in LA_{211} but also when assessed within a related set of knowledge-skills domains embedded within in a larger cluster containing LA_{211}, LA_{213}, LA_{214}, LA_{221}, LA_{222}, and LA_{231}.

Figure 3 shows a clinical setting from one of our simulations—a virtual outpatient clinic on the first floor of a virtual hospital. Figure 4 shows patients being seen in the outpatient clinic as well as some patients who have been admitted to the hospital. A student could be assigned a set of learning activities related to progress of an acute condition in a patient and so have to analyze that patient's electronic medical record from the outpatient clinic as well as within a hospital unit. Furthermore, for some assignments a student could visit and assess the patient in the clinic or a hospital unit, then enter their finding into the electronic medical record. From a situated learning theoretical framework, we developed virtual clinic and hospital settings and nested within those settings enormous numbers of possible interactions with patients, collection of patient data (including interactions with both the patient and the patient's significant others), giving medications and conducting procedures, entering data into the patient's electronic medical record, analysis of patient data, observations of clinical staff interacting with the patient, consultation with other healthcare providers, and access to a medical library. This approach to instructional design created the activities, contexts, and culture of planning and delivering healthcare by engaging learners in a cognitive apprenticeship within authentic activities.

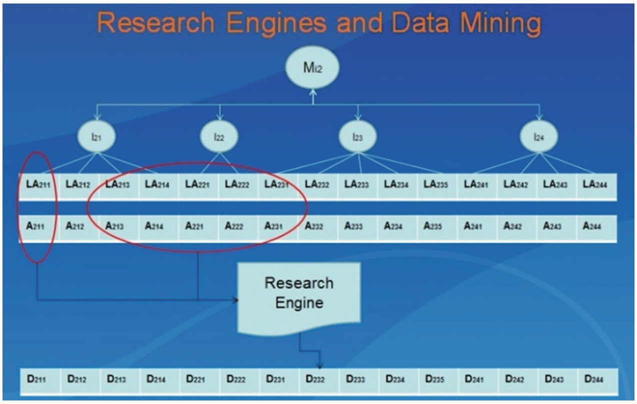

Fig. 2. Diagrammatic representation of a curse map in which clusters of Learning Activities and their respective Assessments are monitored by a software engine that collects data on a student's movements through the course.

Name: Jade Wong
Age: 7 months
Info: Well-child check and immunizations.

Fig. 3. Navigation screen for outpatient clinic that allows selection of patient and then working with that patient in various clinical setting (e.g., Exam Room, Laboratory, Check Out). Within each clinical setting, a student can engage in observing care planning and delivery of the patient, collect patient data, and enter data into a medical record.

Fig. 4. Screen shots of a virtual hospital simulation that show patients in the outpatient clinic as well within a hospital unit.

3.3 Cognitive Traces

During research studies, we evaluated several ways to follow the cognitive traces of decision making by students within simulations accessed within online teaching-learning-assessment environment. In simple terms, every simulation or complex learning object, indeed every element of an online course, can be operationalized as a virtual place, usually a simulation component or a web page. From that virtual place, a student can access other virtual places as they engage in activities accessed from navigational pathways from any page. We built monitoring systems that followed a student's pathway through every virtual place visited and also measured the time spent in each place. Thus, we could construct what some call space-time worms that were cognitive traces of sequences of decisions made by a student within a virtual world or complex learning object or the course components of an online course. Figure 5 provides a schematic representation of a student's journey within an online simulations.

Using Fig. 5 as a reference, suppose a student starts with a module in an online course, say M_{ij}, and then enters the environment of interactions I_{jk}. From the I_{jk} page, they can navigate to a variety of learning activities, in this figure L_{jkl}, L_{jkm}, and L_{jkn}. The levels 1^0, 2^0, 3^0, and so on, represent levels of navigation within the virtual world simulation, learning object, or course component. So, in Fig. 5, the student enters the module, then the learning activity cluster L_{jkl} (2^0) engages in learning activities at 3^0 and 4^0 navigation levels, completes an assessment at the 5^0 level, and gets on-demand diagnostic feedback or additional scaffolding after the assessment.

Our data collection research engine collects the identifying data tags for each page and records the time spent on each page—this is the space time worm or cognitive trace of the student's work within the teaching-learning-assessment environment. In addition, the data collection engine gathers all assessment outcomes along the pathway and maps these to the space-time worm generated. A key piece of research related to assessment engines led to a software system we called eXAM^3, which is shown diagrammatically in Fig. 6 [21].

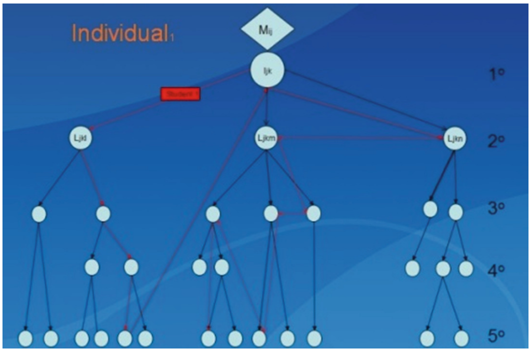

Fig. 5. A student, here designated Individual$_1$ enters a virtual world, learning object, or component of an online course. The read arrows mark that students pathway through various virtual places.

The administrative dashboard for eXAM^3 allows an instructor to enter assessment items, diagnostic feedback related to the item, and educational scaffolding related to the item. Each assessment item can then be placed within a cognitive taxonomy of the instructor's choice. In Fig. 6, we show three levels of a taxonomy as well as four categories of assessment item within each level. The assessment taxonomy an instructor selects would ordinarily evolve from or be dictated by the theory of cognition in which the teaching-learning-assessment environment had been grounded.

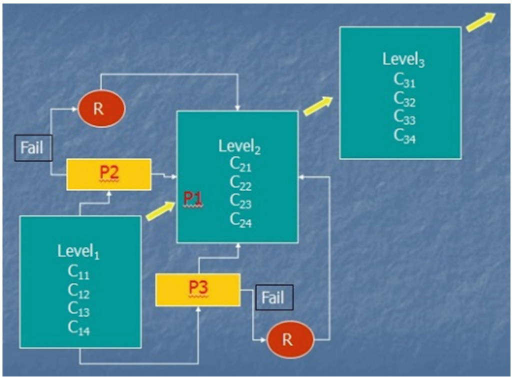

Fig. 6. A diagrammatic representation of the assessment engine eXAM^3. This engine allow establishment of different cells of assessment, using a {Level x Category} architecture. (e.g., different content or different kinds of problems).

If the student scores higher than the threshold for pass, they enter Pathway P1—the next level of assessment items. However, they have access to diagnostic feedback that describes areas of weakness and strength with specific recommendations for additional review and mastery work. If a student scores lower than the pass threshold but equal to or higher than the marginal threshold, they enter pathway P2 and can retake the assessment and either pass into the next level or are sent on a remedial pathway delineated by the diagnostic feedback provided. If the student scores below the fail threshold they enter pathway P3, which first allows them to try to jump to the next level. If they fail again, P3 sets them on a remediation path that is delineated by diagnostic feedback. The key is that the diagnostic feedback does not give the correct answers to assessment items but directs the student to content and skills domains that need to be reviewed and mastered.

As a familiar example, though one not quite appropriate for situated learning theory, suppose that a learning environment had been built around Bloom's revised taxonomy [22]. The categories within each cognitive process could be the four knowledge domains—Factual, Conceptual, Procedural, and Metagcognitive. An instructor would create assessment items for each {level-category} cell in the taxonomy, and then set three thresholds—pass, marginal, or fail.

The space-time worm and the eXAM^3 assessment engine provide researchers and instructors with new types of tools that can be used to create evidence-based practices in education. On one level, faculty members have detailed information on the amount of time a student spent within various course components and the cognitive trace of their learning activities in space-time worm. Faculty members also have much more detailed information a student's breadth and depth of knowledge and skills development, as well as progress a student makes on remediation pathways. On the course or curriculum level, students' space-time worms and results of eXAM^3 type assessments engine can provide rich opportunities for program self-study and research on refining instructional design to optimize student learning outcomes.

4 Adaptive Learning Within Hybrid Courses

We now examine hybrid courses we have developed within a framework of grounded theory, evidence-based design of learning objects, and pedagogical strategies as well as educational scaffolding that have some evidence of “really working” to improve educational outcomes. Section 4.1 examines healthcare courses, while Sect. 4.2 explores course development in computer sciences. These courses were developed at the University of Ontario Institute of Technology. Section 4.3 examines a study of a computer science curriculum at Northern Arizona University.

4.1 Health Information Management Courses

In 2006, one of the authors (J. Tashiro) was assigned to develop a health informatics course at the University of Ontario Institute of Technology. The university had moved quickly into hybrid learning formats. We decided to build and implement the informatics courses within a research design that would inform the university’s transition to hybrid learning. The course used situated learning theory as the grounded theory for instructional design. In this framework, we posited learning develops within the activity, context, and culture in which it is situated. We therefore involved students in the situated experience of working as healthcare professionals to use health informatics. The course created a cognitive apprenticeship for students by providing engagements that supported learning knowledge and skills within authentic activities of healthcare professionals working with health informatics systems.

To make the course consistent with other online courses at UOIT, all content was released within BlackBoard at the start of the course. Course content and facilitated face-to-face discussions were complementary (please take a look at Cell D in Table 1). The BlackBoard LMS allowed us to set up a folder structure:

- One set of folders contained lectures available as videos with audio by the instructor as he discussed and showed PowerPoint productions that contained animations, complex images, and the instructor’s notes being written into each slide to emphasize key content. The slides also had hyperlinks for the students that opened options for additional related content. In the lecture folder, we also provided MP4 audio recordings of the lectures, a PDF of the PowerPoint lectures, and the PowerPoint presentation without instructor audio and notes.
- A second set of folders provided an online library with all required reading easily available to students.
- Course content folders contained the syllabus.
- A course schedule folder provided details of course activities and a course activity planning map.
- Assignment folders and subfolders provided assignments for each week.
- A special folder contained a portal to an educational simulation of a virtual hospital (see Figs. 3 and 4). The virtual hospital was designed as the community in which authentic learning activities could take place. We embedded a lot of scaffolding into the simulations, including a virtual guided tour and instruction manual for

navigating the virtual hospital. Online discussions boards were open to create the feel of a hospital intranet. The simulation was accessed through the BlackBoard course instance, but was actually nested within a secure virtual server that allowed fast access to any student with an internet connection. UOIT was the first laptop university in the province of Ontario—all students had university computers and internet access.

- A final folder offered a portal to eXAM^3, the sophisticated online learning assessment system described earlier in this paper [21].

eXAM^3 allowed students to complete self-assessment tests of their knowledge and skills at any time. The assessment engine had options for a variety of assessment types, including complex problem solving using nested videos and data sets students had to analyze. Students could take an assessment as many times as they liked. Each time, they were presented with a set of items that were randomly chosen from the item data base for a particular subtopic within a topic area of the course. The question pools were large enough to preclude students getting many of the same questions at each self-assessment—basically a student engaged in a new assessment set at each sitting, getting a "test" that was equivalent in content and skills covered for each course topic area. The assessment engine did not give students the correct answer to a question, but provided detailed information about specific readings or lecture PowerPoint slides in which they could find the answers to questions. This model of assessment precluded students trying to memorize the "*correct*" answers to an assessment item. The instructor could use a dashboard to examine each student's use of the assessment system and the results of self-assessments.

Graded assessments included proctored face-to-face examinations and short papers. There were four proctored examinations during a semester and items were randomly selected from the appropriate assessment item database of the assessment system to create each graded test. Assessment items were then transferred to hardcopy and provided to the students during the examination period. We also studied how to collect the space-time worm data that would become a model for our adaptive courses. The short papers were graded by an instructor and teaching assistant team.

However, we still struggled with the fundamental set of confounded questions: —"What really worked, how, when, for whom, and with what outcomes?" The central problem was that we still lacked rigorous tools for tracing decisions by students and mapping some kind of cognitive trace to misconception development. As mentioned earlier, we believe that being able to delineate misconception development is crucial to bridging the other knowledge gaps that plague our abilities to create truly evidence-based approaches for developing and implementing hybrid-blended learning (indeed, any kind of teaching, learning, and assessment).

Building on our experience in undergraduate health informatics management, and also starting work on an adaptive learning software system, we created models for professional development courses to serve healthcare workers. One of the authors (R. Tashiro) conducted a series of case studies within the healthcare information technology industry over a 20-year span. This work explored challenges and pitfalls of professional development for healthcare providers implementing an electronic health record (EHR) system. The EHR application is often touted as the industry's panacea for many of the problems that plague the healthcare industry in many countries—improved timeliness and accuracy in collecting and displaying patient clinical information, reduction of unnecessary tests/procedures, and overall cost reduction are just a few of the many woes faced during the American clinical transformation to ubiquitous use of EHR systems. A comprehensive professional development program is critical to a successful implementation and improved patient care. Analyses of over 50 different EHR implementations with over a dozen healthcare organizations across the United States led us to develop a set of competency domains as the focus of professional development training for EHR implementation. Using the types of learning map models shown in Figs. 1 and 2, as well as selecting situated learning as a theoretical framework for cognition and learning, the following competencies became the backbone of knowledge and skills to be taught within a hybrid course for professional development prior to EHR implementation.

1. Readiness for Organizational Change.
2. Governance Structure.
3. Current State Workflow Analysis.
4. Resource Allocation.
5. Effective Educational Technology for Clinical Transformation.
6. Evaluating Implementation Outcomes in the Context of Patient Outcomes.

Each competency domain was deconstructed into learning modules, and each learning module into learning activities with their respective learning outcomes assessments and diagnostic feedback to learners. For example, the Current State Workflow analysis competency has the following modules:

- Building a model of patient journeys through a clinical setting.
- Identification of workarounds and inefficient processes that lead to human error in clinical care or result from software deficiencies.
- Documentation and clinical-IT team integration for documenting and modelling current state processes that leads to better understanding of these processes and how they impact individuals/departments.
- Identification of knowledge gaps that result in departments and/or individuals not following evidence-based practices of care planning and delivery.
- Analysis of usability issues in effective use of electronic health records, especially why individual clinicians make mistakes at critical junctions.
- How to develop an effective evidence-based clinical transformation that results in patient-centric and evidence-based healthcare planning and delivery.

The course design had interesting consequences. We had to build a new type of educational environment, and one much more complex than the original adaptive learning model we envisioned. The result was an adaptive learning environment developed by Tashiro, Tashiro, and Alvarado-Yule [23], named “Adaptive Intervention Management—AIM” (patent pending). AIM overcame the general failure of e-learning educational systems to collect rich and high quality data on educational methods and materials. The system provides options for diverse educational modules; such diversity is very important when addressing the idiosyncrasies different hospitals face when educating staff for implementing new electronic health records.

Additionally, AIM allows various cognitive models for a learning environment or for a particular underlying framework of behavioral change embedded within a module's instructional design. Basic functionality contained mapping of content to learning activities and educational resources in order to create one or a suite of modules based on the cognitive or behavioral models of education chosen by a particular hospital. AIM became a significant improvement over conventional educational systems that adopt only one model of cognition or behavioral change. For example, different hospitals may prefer different models of cognition for the design of their professional development educational systems.

We also had to build better engines for monitoring learners' progress within learning activities as well building better assessment and feedback engines. In brief, AIM had an administrative dashboard that allowed a faculty member to select different choices of cognitive and/or behavioral frameworks. Once a framework was selected, the system created the database structure into which we could load appropriate learning activities, evidence-based assessments of learning, and mapping of assessment outcomes to a database of diagnostic feedback. Such a system would provide clinical staff with data on their progress toward understanding the complexities of implementing electronic health records in their particular clinical setting. AIM made it possible to analyze the trajectories of critical variables that shape clinical staff decisions to change behaviors related to implementing electronic record systems, the stability of such decisions and subsequence behavioral change, the transferability of such decisions to related situations, and the potential for misconceptions being developed related to such decisions. AIM became the prototype for a more complex system we call **MISSED**—**M**isconception **I**nstantiation as **S**tudents **S**tudy in **E**ducational **D**omains, which is discussed in the next section [10].

4.2 Computer Sciences Courses at University of Ontario Institute of Technology

As we worked in healthcare areas, we began to expand our thinking to other knowledge domains, particularly computer sciences. This work was led by two of the coauthors—Vargas Martin and Hung. Both are members of the Faculty of Business and Information Technology at University of Ontario Institute of Technology. Both were teaching hybrid courses. For example, Dr. Hung taught E-Business Technology ($\sim$ 60 students) and Web Services for E-Business Security (55–65) students. Dr. Vargas Martin has taught Introduction to Programming ($\sim$170 students), Cryptography and Network Security ($\sim$60 students), Cryptography and Secure Communications ($\sim$20 students), and Programming the Mobile Web ($\sim$50 students). Key findings emerged during development and implementation of these courses; some of these were discussed in Sect. 4.1 for the Health Information Management course. However, the following issues may be of interest to faculty searching for what works to improve student learning in computer sciences courses.

- Sometimes a faculty member cannot find a good textbook that covers the topics in the course. Consequently, faculty members must create their own libraries of resources for students and sensibly nest these into the learning management system.

Most of the materials will be online—such as research articles in IEEE/ACM Digital library, technology standards published in World Wide Web and OASIS, white papers from industry, and videos at Youtube.
- Quizzes and exams in some of the classes used *Respondus* (a lockdown browser) and were proctored in the classroom.
- Assignments were nested into the learning management system.
- *MyProgrammingLab*, an online resource from Pearson Education which includes numerous exercises in synchrony with some textbooks' sequence of topics.
- For some course instances, lectures were taught online, in real time, and recorded for later access. The course also included face-to-face tutorials taught by the Teaching Assistant.
- Class size shaped the use of certain learning management system functionalities, such as discussion groups, e-community development, and effective use of social media.

For these computer science courses, we also asked: "What really worked, how, when, for whom, and with what outcomes?" The development of the AIM and MISSED systems provide working models for completely adaptive learning systems. Yet, even with functional systems and a research foundation supporting the efficacy of these systems, colleges and universities have invested enormous amounts of funding into learning management systems. Such investments lock instructors into using what the university has purchased. Introducing systems like AIM and MISSED would require a university partner willing to shift their hybrid-blended learning format and focus to include integration of adaptive learning environments that could be nested within the educational technologies and LMS already implemented.

4.3 Computer Sciences Curriculum at Northern Arizona University

In Fall 2014, we opened a discussion with Northern Arizona University (Flagstaff, Arizona, USA). Northern Arizona University (NAU) had developed a Personalized Learning online program with university support supplemented by a $1 million grant from EDUCAUSE and the Bill & Melissa Gates Foundation. One of the authors (J. Tashiro) had the opportunity to examine the NAU Personalized Learning (PL) online program and suggested a collaborative project. In brief, we were able to conduct a number of Gedanken experiments that were essentially sensitivity analyses for layering an adaptive learning environment into a system like NAU's PL. We believed this approach might have tremendous potential for finding cost-effective solutions to implement more rigorous evidence-based approaches in building and evaluating hybrid-blended and totally online courses and curricula.

Tashiro and colleagues [9] described the NAU PL online interface and course models. Designed in partnership with Pearson and officially launched on June 3, 2013, the NAU PL has three Bachelor degree programs: Computer Information Technology, Small Business Administration, and Liberal Arts. We were interested in these programs because they have an interesting model of online work and faculty mentoring. All content is entirely online and self-paced. However, students also receive direct mentoring from faculty and experts in the field of study, which introduces a hybrid learning component. Furthermore, NAU PL makes all content available to the student at the time of enrollment, so he or she can work as fast, or as slowly, as he or she would like. The student enrolls for 6-month subscriptions, and they are able to complete as many lessons as they would like during the subscription. Interestingly, this subscription is a flat USD$2500 fee, which includes all fees and textbooks. PL is a traditional degree program that has been deconstructed and reconstructed around specific competencies. The NAU PL philosophy and offerings can be reviewed at http://pl.nau.edu/.

The NAU PL model followed best practices of curriculum mapping. A panel of faculty, experts working in the field, subject matter experts, and specialists in teaching and learning delineated measurable competencies that together would be a reasonable core for a Computer Information Technology major. Ten Competency Domains were identified: (1) Information Technology Foundations; (2) Data Management and Administration; (3) IT Business Operations and Leadership; (4) Information Security and Policy; (5) Enterprise Architecture, Network and Telecommunications Technology; (6) Software Engineering and Development; (7) Systems Administration; (8) Business Analysis and Design; (9) Web-based Systems and Technologies; (10) Information Technology.

Using learning maps similar to those shown in Figs. 1 and 2. Each Competency Domain was expanded into one or more measurable Objectives. In turn, each Objective was analyzed to develop Lessons that would achieve the Objective. Each Lesson environment offers a Lesson Guide, a Pretest, Topics, a Posttest, and Mastery. Each Topic area has direct access to a suite of Learning Activities related to the Topic, and each Activity offers a variety of Learning Objects available to the student. The website listed above provides more details about Competency Domains.

The current number of students per faculty mentor is set at 150. Mentors meet with students once a week and on an as-needed basis, using the student's preferred communication environment (e.g. Skype). Subject-matter mentors meet in tutorials with a student based on the respective student's need related to specific content. Faculty mentors provide life-, academic-, and career-coaching. Lead faculty and faculty mentors are full-time faculty. Subject matter mentors are part-time faculty members.

Tashiro and colleagues [9] formed two research teams, one from NAU and the second from UOIT. We asked the basic question—"How can simulative environments and new types of assessment engines be integrated with adaptive learning engines to create much more personalized teaching-learning-assessment environments with truly adaptive capacities." We used the **MISSED** research engine to conduct a series of Gedanken experiments on the NAU-PL environments [24, 25]. In this work, we modelled the learning management system for the NAU PL CIT courses as a set of compartments that must articulate within a courses as well as across courses in order to create a coherent and substantive curriculum. Furthermore, we studied the nature of signals received and sent and received by any compartment of the teaching-learning-assessment environment.

Of course, each compartment could be accessed by a student, and so we needed to add data collection processes to each compartment in order to know what a student "did" within a compartment. These initial studies led us to conclude that the dynamic nature of any given compartment, especially temporally and spatially heterogeneous interaction with different students, would be critically important to building truly adaptive educational environments that could adapt to an individual student as he or she worked within a compartment. Finally, we recognized and studied how each compartment opened to a number of Learning Activities associated with a specific Topic of a specific Lesson within a particular Competency Domain. And, such Learning Activities more often than not evoked one or more Learning Objects with which a student could engage (see Figs. 1 and 2).

We studied how to layer monitoring middleware among and within compartments. Such middleware could record an individual student's navigational and engagement decisions as well as time spent in various activities. Using monitoring data coupled to learning assessment outcomes within the simulations, we could map students' learning and competency outcomes against expectations delineated by panels of content and skills experts [26–31]. To provide a better context for such middleware, please examine the diagrammatic representation of the **MISSED** research platform provided in Fig. 7. Images show preliminary studies that we conducted with Canadian health sciences students. Two patents (now pending; references [24, 25]) resulted from this work. Figure 7 diagrammatically shows the interconnected software engines that monitor educational activities as follows:

1. A student works within the online components of a hybrid course, and engages within a competency domain's objectives, respective modules, interaction clusters of learning activities and associated Learning Objects—all their work is within a Web-based interface, designed as a personalized Inclusive-Adaptive System that assesses a student's accessibility needs and preferences for a personalized educational environment.
2. The Inclusive-Adaptive Interface collects data on the student's needs and preferences, creating a Student Profile database that becomes part of an Electronic Learning Record.
3. The Student Profile data stream to a MatchMaker system that selects an Instructional Deign Template (IDT) based on a theory of cognition and behavioral change selected by a faculty member and consistent with the course content, but informed by the student's needs and preferences.
4. The MatchMaker engine then reads the metadata from the template.
5. The Assembler Engine reads the IDT and metadata brought to it by MatchMaker, searches Learning Object Repositories to find and collate learning activities, resources, educational scaffolding, learning assessments, and feedback personalized for the learner, and then organizes the assemblage to create a Web-based personalized teaching-learning-assessment-diagnostic Educational Environment.
6. Students engage within the Educational Environment (and for some types of hybrid classes also engage in face-to-face settings, such as faculty mentoring, live skills labs, low-fidelity or high-fidelity simulations related to computer information technology).

7. Within the Web-based Educational Environments, each student is constantly monitored by middleware called PathFinder that follows choices made within the Educational Environments and also times a student's engagement in learning activities, resources, assessments, and using diagnostic feedback [23–29].
8. Within the face-to-face environments in some course types (e.g., live skills lab), a student is monitored during learning-demonstration activities, using a video-capture and analysis system called MAXIT EDUCATION [25] that efficiently collects assessment data on students' performance competencies.
9. Prior to, simultaneously with, or after learning-demonstration activities, students enter an assessment engine called eXAM^3 [21] which assesses their learning outcomes within a cognitive taxonomy selected by the faculty member (e.g., Bloom's Revised Taxonomy or a rubric for a CIT Competency Domain or a cognitive taxonomy consistent with a particular cognitive theory).
10. PathFinder, MAXIT EDUCATION, and eXAM^3 stream a student's data to a data analysis and knowledge system called DATUMM.
11. DATUMM, in turn, analyzes the data, creates new information about the student, and sends this information back to the Student Profile. These new information sets are integrated into the Student Profile, with revised data and information facilitating adaptive changes to the flow beginning with the MatchMaker and ending in new configurations of the Educational Environment. Importantly, data from the Student Profile also stream into a subcomponent—the Electronic Learning Record, through time creating a longitudinal record of a student's progress.

Research with the **MISSED** research platform led us to conclude that we could collect data on students' conceptual and performance competencies and thereby create a very detailed Electronic Learning Record (ELR). The ELR also can be constructed to receive data and information from multiple courses, and so create a much more detailed and informative multidimensional student transcript.

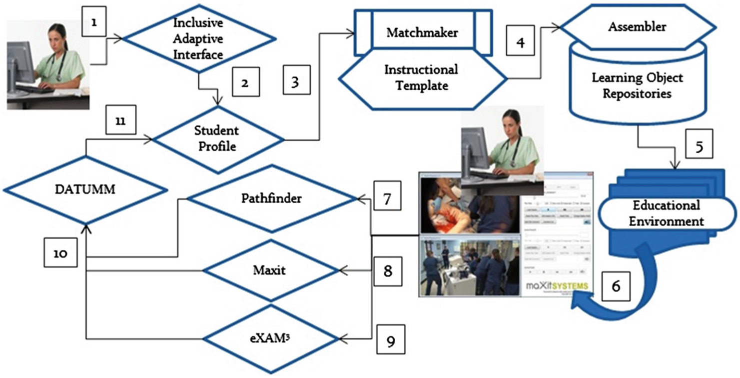

Fig. 7. Diagrammatic representation of the MISSED environment piloted in research on health sciences education.

5 Summary and Conclusion

In summary, systems like MISSED AIM, and eXAM^3 offer a way to study students' development of misconceptions and then to remediate such misconceptions. Our work provided substantial evidence for the efficacy of not reinventing the wheel, but layering into extant learning management systems some adaptive capacities that have a strong research base for bridging the ten knowledge gaps we have identified. Such bridging will lead to authentic assessment of students learning outcomes. However, a key point is that learning management systems and instructional design should be based on grounded theory, but currently there is no consensus theory of cognition and learning. The lack of consensus suggests the need for large-scale cross-thery comparisons of cognition-learning models. Learning management systems, adaptive learning environments and associated instructional materials offered by academic publishers still have many weaknesses. Tashiro [32] critiqued some of the ethical problem both publishers and faculty create when they do not use evidenced-based materials and methods in creating the teaching-learning-assessment-feedback environments used in courses and curricula. Why, for example, have educators not demanded the analogues of clinical trial research for instructional methods and materials? Indeed, a very interesting absence in research is cross-theory testing of models of cognition and learning. We could start there.

What would we need? We would need flexible but powerful systems like MISSED, AIM and eXAM^3 that had the capacities allowing researchers to choose a theory of cognition and learning. For a particular theory, the teaching-learning-assessment-feedback environment must be assembled so that such an environment was consistent with the theory selected. Learning activities with their embedded learning objects, respective learning assessments, and associated diagnostic feedback and educational scaffolding would all be dictated by the grounded theory selected. As with any other learning management system, we would load learning activities, learning objects, assessments, and diagnostics feedback and scaffolding into database repositories. Systems like MISSED and other truly adaptive learning environments simply have more flexibility in types of repositories that would be called into the dynamic formation of a teaching-learning-assessment environment consonant with a particular theoretical framework. In the decade of "big data" analytics, we are poised to step towards educational research and praxis that is evidence-based and as predictive as the best clinical care in the world.

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