Realizing Adaptive Instruction (Ad-In): The Convergence of Learning, Instruction, and Assessment

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Abstract. In this paper, we define adaptive instruction, or Ad-In, as applied to sophisticated skills development systems that target learning and assessment in a highly individualized and interactive manner. We argue that the successful design and use of such systems rely heavily upon the interrelationships among learning styles, instructional theories, and assessment methods, in the context of personalized learning. We outline and structure the links among these topics by drawing upon recent empirical studies of virtual environments and augmented realities. The paper also presents a candidate architecture for applying Ad-In concepts in an intelligent interactive environment for skills development.

Keywords: Adaptive instruction, augmented reality, immersion, intelligent tutoring assistant, multi-user virtual environment, neomillennial learning styles.

1 Introduction

Adaptive Instruction (Ad-In), as argued in this paper, is characterized by dynamic programs of instruction that are readily capable of adapting or of being adapted to individual learning requirements. Ad-In addresses the unique and situation-specific needs of learners by concurrently providing clear information, opportunities for thoughtful practice, informative feedback, and a favorable combination of intrinsic and extrinsic motivators tailored to the individual learner. Central to Ad-In are interactive and immersive technologies that target learning, instruction, and assessment. Such learning innovations build on previous research, which demonstrates that technology enhances learner understanding when it (a) supports learning in real-world contexts, (b) connects learners to experts and communities of learners, (c) makes possible visualization and analysis tools for thinking with data and datasets, (d) scaffolds problem solving that enables more complex reasoning than possible otherwise, and (e) provides opportunities for feedback, reflection, and revision of knowledge construction [1].

Delving into and articulating Ad-In, we examine the interrelationships among learning styles, instructional theories, and assessment methods, in the context of personalized learning. We draw upon recent experience in empirical studies of virtual environments and augmented realities, and we explore how new learning styles, instructional theories, and tools for measuring understanding are emerging from the use

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of these technologies, which may affect training program development and delivery from an adaptive instruction perspective.

2 Media-Based Learning Styles

Learning styles are theoretical constructs designed to help explain the learning process, a complex and nuanced phenomenon. Learning styles are comprised of (a) *cognitive styles*, which consider concept formation and retention and sensory reception; (b) *affective styles*, which consider attention, expectancy, and incentive; and (c) *physiological styles*, which consider the functions and activities of human organisms, including all physical and chemical processes [2].

Early scholars and researchers of learning styles held as axiom that styles were inflexible, context-independent, and solely determined by ability and personality [3]. Modern conceptualizations of styles reject such principles and view the construct as (a) shaped by physical and mental development, personal interests, and sociocultural influences; (b) preferences in the use of abilities, not abilities themselves; (c) existing within all people in varying degrees, resulting in profiles of styles; (d) variable across tasks and situations, having the potential to change over time; (e) measurable, teachable, and socializable; and (f) variable in terms of flexibility and adaptability within people [4-6].

A growing number of researchers and scholars have begun investigating media-based learning styles, which are modern learning styles understood in relation to three complementary human-computer interfaces that are reshaping thinking, learning, and instruction [7]. The *World-to-the-Desktop*, the first and most mature interface, is facilitated through laptop, desktop, and tablet computers connected to the Internet. By bringing the world to the user, this interface provides users access to archives and sophisticated databases and also enables collaborations, mentoring relationships, and virtual communities-of-practice [8, 9]. *Multi-User Virtual Environments* (MUVEs), the second interface, are characterized by participants controlling digital emissaries to engage digital content and interact with fellow users to complete various kinds of tasks in three-dimensional virtual contexts. At a time when nine of the ten best selling computer games of 2007 are MUVEs, a growing number of projects have developed MUVEs specifically for teaching and training [10, 11]. *Ubiquitous computing*, a third human-computer interface, provides dynamic, temporal, and contextually specific tools through computers that are no longer perceptually foregrounded [12, 13]. Interactivity seamlessly and imperceptibly integrates into activity. On a variety of scales, users obtain ever-present connectivity and access to capture, process, send, and receive information through multiple devices anytime and anywhere [14-16]. Participatory simulations and augmented realities (ARs) made possible through wireless handheld computers have provided the basis for learning and teaching using ubiquitous computing [17-19].

One primary difference among the World-to-the-Desktop interface, MUVEs, and ARs is immersion. Immersion can induce a user into a perceived state of being present with others or in a place other than where the user is physically located; it depends in part on the ability to empower actions and activity while facilitating affective factors that influence learning, such as emotional awareness, self-control, and self-efficacy [20, 21]. Given that the World-to-the-Desktop interface is context independent, it cannot bring about a sense of "being there" to the same extent that MUVEs and ubiquitous computing can support a sense of "presence" in a virtual world or an AR. Such differences make possible learning in MUVEs and ARs that supports the situational and distributional nature of cognition with respect to thinking, learning, and doing in ways that are limited or absent in World-to-the-Desktop computer interactions.

As an illustrative example contrasting learning through an immersive versus non-immersive interface, a learner studying disease and disease transmission with the World-to-the-Desktop might communicate with epidemiologists via email or join a listserv devoted to the transmission and control of epidemic diseases, thus beginning an ongoing exchange of ideas and questions. The ebb and flow of information through the World-to-the-Desktop interface, however, is not generally characterized as immersive. The learner is not part of the events he or she is studying. Rather, he or she is a distant observer as compared to an active participant. The River City Project, on the other hand, uses a MUVE called "River City" to support the situated study of disease and disease transmission [22, 23]. Based on authentic geographical, historical, and sociological conditions, River City is a town besieged with health problems that affect the wellbeing of its residents. The mayor of River City has commissioned learners to travel back in time, bringing their 21st-century knowledge and technology to address a 19th-century epidemic. The affordances of the MUVE and its accompanying storyline allow learners to think and act as scientists in an environment of intermediate complexity. It is less complex than the real world, which can be overwhelming, but more complex, authentic, and nuanced than a "cookbook" lab, which is designed to be instructor- and learner-proof. If asked where learners are located while interacting with the River City MUVE, users are likely to state they are in River City and with their teammates instead of where they are located physically.

As a second illustrative example, "Reliving the Revolution" (RtR) uses wireless handheld devices to support an AR game that teaches historic inquiry, effective collaboration, media fluency, decision-making, and critical thinking skills [24]. RtR enables participants to traverse the present-day site of the Battle of Lexington to relive this historic battle from the American Revolution through the eyes of one of four historic figures. Participants use their device to collect information or evidence to determine who fired the first shot in the Battle, a source of continued debate in American history. GPS-enabled devices provide participants location-based virtual information on the social, historical, economic, geographic, and political processes relevant to both the Battle of Lexington and the American Revolution.

River City and RtR utilize key aspects of Ad-In and are readily capable of (a) adapting or of being adapted to individual learning requirements; (b) addressing the unique and situation-specific needs of learners by concurrently providing clear information, opportunities for thoughtful practice, informative feedback, and a favorable combination of intrinsic and extrinsic motivators tailored to the individual learner; and (c) utilizing interactive and immersive technologies that target learning, instruction, and assessment [22, 25].

3 Neomillennial Learning Styles

The relations between participatory and immersive media and learning styles, shown in Figure 1, have become an important new research direction. Research on MUVEs, ARs, and other immersive, personalized, and interactive media led Dede and colleagues to propose a new classification of media-based learning styles [26].

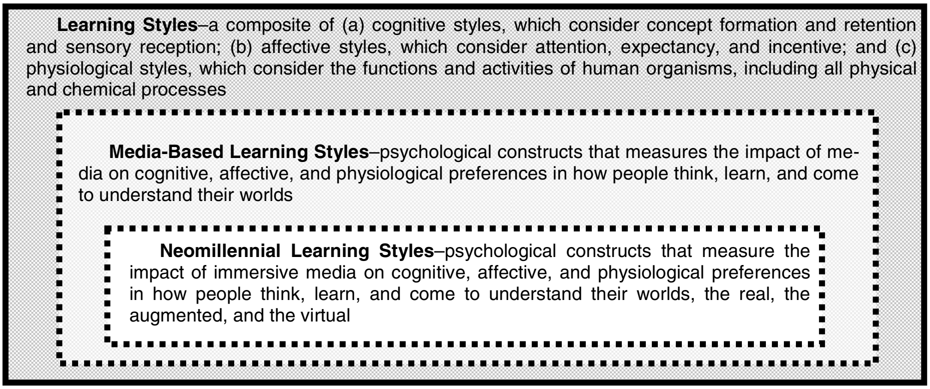

Fig. 1. Nested diagram depicting the interconnections between learning styles, media-based learning styles, and neomillennial learning styles

"Neomillennial" Learning Styles (NLS) include a person's preferred cognitive, affective, and physiological styles in which they think, learn, and come to understand their worlds, in the real, augmented, and virtual domains and are characterized by:

- Fluency in multiple media, valuing each for the types of communication, activities, experiences, and expressions it empowers.
- Learning based on collectively seeking, sieving, and synthesizing experiences rather than individually locating and absorbing information from some single best source; preferring communal learning in diverse, tacit, situated experiences; valuing knowledge distributed across a community and a context, as well as within an individual.
- Active learning based on experience (real and simulated) that includes frequent opportunities for embedded reflection; valuing bicentric, immersive frames of reference that infuse guidance and reflection into learning-by-doing.
- Expression through nonlinear, associational webs of representations rather than linear stories (for example, authoring a simulation and a Web page to express understanding rather than writing a paper); using representations involving richly associated, situated simulations.
- Co-design of learning experiences personalized to individual needs and preferences.

NLS are present in varying degrees in learners of all ages and not just "digital natives" [7]. Ongoing interaction with immersive technologies, such as MUVEs and ARs, develop and enhance NLS. Dieterle and colleagues have utilized both qualitative and quantitative methods to study NLS in MUVEs and ARs [25, 27, 28]. Such studies of the links between MUVEs and ARs and learning theory have produced valuable insights for designing more effective ways to adapt instructional processes to the learning style of the learner. For example, learners who generally enjoy tasks that require creative strategies, such as working with ideas in new ways, and mashing up and sharing information, appear to be more well suited for learning scientific problem solving skills in MUVEs than those who avoid the same activities and don't share the same predilections [27].

4 Instructional Theories

Previous generations of instructional design tended to provide all learners with uniform experiences that required learners to adapt to the pedagogy [29]. Cost savings from the systemization of schools, resulting from the mass production and distribution of materials and techniques, were primary factors motivating the use of the factory model of instruction in many formal learning institutions [30]. This instructional philosophy, however, conflicts with contemporary research into how people learn, revealing that, with enough time, access, guidance, and motivation, almost everyone can learn just about anything to a great extent and yet, almost no one learns exactly the same way, through the same pathways, or to the same degree [31-34].

Where modern instructional theories advocate for personalized instruction, an inability to leverage an economy of scale has limited and restricted the scope and freedom to implement personalized instruction widely. Efforts of researchers and engineers, however, are on the verge of changing the way instruction is personalized and adapted to individual learners profoundly. Applying scientific knowledge of mind, brain, and education to generate economically viable solutions that address the challenges associated with advancing personalized learning significantly to large numbers of individuals is one of the National Academy of Engineers 14 grand challenges [35].

Ad-In involves orchestration among members of the research team and participating instructors and learners, which can be understood through a music metaphor with the research team as composers, instructors as conductors, and learners as musicians. All three groups work in harmony to co-design learning experiences that are personalized to individual needs and preferences, while adhering to the spirit of the curriculum. As composers, the research team develops a curriculum. Instructors, in turn, receive the curriculum and act as conductors, using knowledge of the local culture and learning setting to getting the most out of their learners. The instructor's role is to guide learners' performance through immersive and interactive experiences. Diversity of prior knowledge among learners provides a wealth of experience and knowledge from which teams can draw upon to engage the complexities and challenges the curriculum provides. Just as musicians tend to specialize, not all learners need to master every aspect of the curriculum equally well. Instead, teammates play off each other's strengths while buoying up their collective weaknesses to produce the best team performance possible.

Increased levels of challenge, incremental growth of understanding, and ongoing opportunities for success characterize adaptive instruction. The focus of the learning environment is the learner, rather than the content or the instructor. Learners are not viewed as blank slates upon entry into the learning environment. One-size does not fit the needs, skill levels, interests, or abilities of all learners. Cultural differences and prior knowledge add to variation among learners. Learners work through important and relevant content topics cohesively (as compared to piecemeal) that encourage doing with understanding (as apposed to simply hands-on doing). Learners are regularly given assessment opportunities to demonstrate what they know (and don't know) and can do (and cannot do) within learning activities (as compared to stepping out of the activity to complete an assessment). Learners and their instructors use the formative assessment feedback to understand the learner's progress and to shape and guide instruction. We should carefully distinguish this aspect of learner assessment from the process of testing if the learner can be certified as having 'passed the course'.

5 Assessment Methods and Tools

We recognize the need for methods of assessing the impacts that the technology (i.e. the adaptive instruction and automated tutoring techniques) has upon the learner and the learning experience. This is the traditional domain of researchers' experimental data gathering and analysis of outcomes. As Sheingold and Frederiksen observe, "to change our expectations about what students should know and be able to do will involve also changing both the standards by which student achievements are judged and the methods by which student's accomplishments are assessed" [36].

An insightful new theoretical frame put forth by Solomon and Perkins identified three levels by which technology influences thinking and learning. The immediate results are the *effects with* a technology, which resulting in expanded cognitive capacity and amplified perception. After considerable experience with a technology, users exhibit the *effects from* a technology, the residual impact of a technology when it is no longer present. The most profound effects are the *effects through* a technology, which fundamentally reorganize cognitive activity [37]. Accurately assessing effects with, from, and through technology requires measurement methodologies and objectives that match our evolving expectations for learning outcomes, as well as new ways in which they learn.

Educational MUVEs such as River City and intelligent tutoring systems (ITSs) have the ability to record and store every keystroke users generate inside the MUVE or with the tutor [22, 38]. Through such technologies, researchers can collect, store, retrieve, process, and analyze information on the activities of individual users, teams, or groups of teams as they participate in the simulation. The level of detail in these records is comprehensive, indicating exactly where students went, with whom they communicated, what virtual artifacts they activated, and how long each of these activities took. This richly varied store of data can couple with other artifacts of learning to develop novel, performance-based assessments of complex performances that leverage NLS, disciplinary reasoning, and procedural skills.

6 Adaptive Instruction in Context

We now briefly examine how Ad-In can be applied within the context of an intelligent interactive environment for individualized skills development. Figure 2

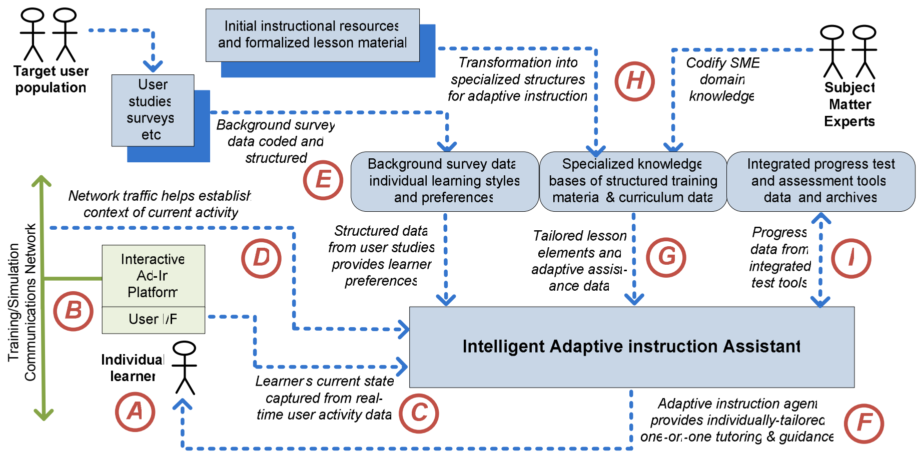

Fig. 2. Integration of an intelligent Ad-In assistant into an interactive, adaptive instructional environment

illustrates how an automated Ad-In tutoring assistant may be used in conjunction with a target application system. This example is structured around a typical military training system, although the concepts discussed are broadly applicable in other application domains.

A human learner interacts with the target application via the training platform (A), which may be a standalone unit or, quite frequently, linked to a broader networked simulation/training infrastructure (B). The user interface of the platform is instrumented so that data and observations on the learner's activity are sensed and provided to the Ad-In assistant in real-time (C). Such sensors may include augmented cognition tools, such as eye trackers or EEG devices, as well as more traditional user interaction monitors. The assistant also monitors the communications network, possibly both voice and data traffic, which helps to situate the context of the learner's current activities and goals (D). Information from background user studies and individual survey data (E) is available, which the assistant can draw upon to help identify the learner's likely behavioral preferences and learning style.

These inputs enable the Ad-In system to react to changes observed in the training activity, and to provide individualized tutoring support, dynamically and inconspicuously, as the lesson proceeds (F). To do this, it draws upon knowledge bases and teaching plans that have been specially structured for use in the Ad-In environment (G), and which have been constructed from instructional material, curriculum data, and reference manuals, as well as broader background knowledge sources, including subject matter experts (H). The assistant also retains and uses the learner's prior lesson history, as well as data from integrated progress tests and assessments, to document the learner's areas of improvement, and to identify elements where additional work is needed, thus enabling the system to adapt the instructional process to the evolving requirements of the individual (I).

7 Conclusions

We believe that the Ad-In approach, in which the independent but interrelated elements of learning styles, instructional theories, and assessment methods comprise a unified whole, is a particularly useful way to characterize adaptive instruction systems in the realm of augmented cognition. Although scientists that study how people learn have for some time believed that media impacts thinking, learning, and understanding, it is only relatively recently that we have found reliable ways of articulating media-based learning styles from empirical evidence. Thus far, quantitative and qualitative studies of this type have concentrated upon measuring the cognitive and affective preferences of the learner with regard to MUVEs and ARs. The addition of new data from refined studies of cognitive, affective, and physiological styles will offer valuable new insights into future strategies for adaptive instruction and augmented cognition. Further research into quantitative measures, which measure the 'what' and 'how', complimented by qualitative measures, which measure the 'why', can help to predict which learners should be directed toward immersive game-like training and which should be provided alternative learning experiences.

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