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FAIL BETTER: TOWARD A TAXONOMY OF E-LEARNING ERROR

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ABSTRACT

The study of student error, important across many fields of educational research, has begun to attract interest in the field of e-learning, particularly in relation to usability. However, it remains unclear when errors should be avoided (as usability failures) or embraced (as learning opportunities). Many domains have benefited from taxonomies of error; a taxonomy of e-learning error would help guide much-needed empirical inquiry from scholars. Drawing on work from several disciplines, this article proposes a preliminary taxonomy of three categories: learning task mistakes, general support mistakes, and technology support mistakes. Suggestions are made for the taxonomy's use and validation.

Try again. Fail again. Fail better.
— Samuel Beckett

INTRODUCTION

Educators have seldom needed reminders of Pope's observation that "To err is human." It is no surprise, then, that the study of errors has long been of interest to educational researchers (for example, Buswell & Judd, 1925, as cited in Lannin, Barker, & Townsend, 2007). Researchers have analyzed student errors and misconceptions in nearly every discipline, including work in mathematics

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(Brown & Burton 1978), speech and language acquisition (Salem, 2007), writing (Kroll & Schafer, 1978), reading (Goikoetxea, 2006), and science (Champagne, Klopfer, & Anderson, 1980).

A nascent interest in errors has also accompanied research into the new field of e-learning. "E-learning" is a diffuse term with multiple definitions, but in this article I will use an inclusive definition that includes any "electronically mediated learning in a digital format that is interactive but not necessarily remote" (Zemsky & Massy, 2004, p. 6). However, while many researchers have mentioned the significance of errors in e-learning, particularly in relation to the usability of e-learning systems, little research has focused specifically on this subject.

Such research is sorely needed, given that there is a significant tension between two major understandings of errors in e-learning. While a significant and still-active strand of research examines errors in order to minimize them, voices from within the influential discovery-learning (Bruner, Goodnow, & Austin, 1956; de Jong & van Joolingen, 1998) and Constructivist (Jonassen, Davidson, Collins, Campbell, & Haag, 1995; Smith, diSessa, & Roschelle, 1993) movements have advocated an increased appreciation of errors in their own right. Practitioners and designers are faced with a quandary: should e-learning systems aim to reduce student error, or should they accept and even encourage it (Anson, 2000)? Unfortunately, there has been little effort to integrate work answering this question.

A definitive answer lies well in the future. However, we can make an important first step by establishing a framework from which to examine the question more carefully: a taxonomy of e-learning error. Such taxonomies have been widely deployed and valued in the study of error in other domains. As a guide to research, this proposed taxonomy would not take sides in debates about the role of error; rather, it would provide a *lingua franca* for practitioners and researchers to discuss and reflect upon understandings and directions for research and practice. This article proposes the beginnings of just such a taxonomy. The next section will discuss the relevant literature both "for" and "against" errors. We shall then review efforts to taxonomize error in both e-learning and wider applications. A provisional taxonomy will then be proposed and defended, and we will suggest some ways to validate and use the taxonomy.

RESEARCH ON ERRORS IN E-LEARNING

Errors as Harmful

A wide variety of authors from within several disciplines have asserted that e-learning errors are disruptive; a sample of this work is summarized in Table 1. Errors may have a particularly corrosive effect on computer self-efficacy (Compeau & Higgins, 1995), as users often blame themselves for technology errors (Norman, 1988); low computer self-efficacy, in turn, has been shown to negatively influence e-learning use (Lee, 2001). E-learning errors are also likely

Table 1. Negative Approaches to Student Error in Guidelines and Heuristics for E-Learning Usability

Author	Stance toward error
Nielsen and Molich (1990) Nielsen (1994)	Include a "prevent error" heuristic. Note that these usability heuristics are not designed specifically for e-learning, but have proved highly influential in adapted form.
Quinn (1996)	Advocates adoption of Nielsen's "prevent errors" heuristic.
Albion (1999)	Uses Nielsen's "prevent errors" heuristic.
Parlangeli, Marchigiani, and Bagnara (1999)	Use Nielsen and Molich's "prevent errors" heuristic.
Squires and Preece (1999)	Adapt Nielsen's "prevent errors" heuristic.
Benson, Elliott, Grant, Holschuh, Kim, Kim, et al. (2002)	Adapt Nielsen's "prevent errors" heuristic.
Karoulis and Pombortsis (2003)	Include a heuristic for "Error prevention, error handling, and provision of help."
Wong, Nguyen, Chang, and Jayaratna (2003)	List "error prevention" as one of 15 usability evaluation factors.
Triacca, Bolchini, Botturi, and Inversini (2004)	Use the MiLE methodology for usability evaluation; it does not note errors specifically, but does give advice to help minimize errors.
Ardito, Costabile, Marsico, Lanzilotti, Levialdi, Roselli, et al. (2006)	Adopt Systematic Usability Inspection: errors should be prevented on the "Presentation" dimension, but encouraged in the "Application Proactivity" dimension.
Adeoye and Wentling (2007)	Use Nielsen's "prevent errors" heuristic.

to exacerbate computer anxiety (Heinssen, Glass, & Knight, 1987), which in turn can multiply errors in a vicious cycle (Brosnan, 1998; Reason, 1990), significantly handicapping motivation, learning, and performance when using educational computing tools. When e-learning students do make mistakes, they may be less likely to receive corrective feedback from instructors, as the e-learning interface offers a diminished "bandwidth" (Van Lehn, 1988) for assessment: subtle verbal and physical cues of frustration or confusion are not visible to computers or distance-learning instructors.

Several major strands of e-learning research have suggested a negative role for error, including work on automated tutoring systems (Intelligent Tutoring Systems or Cognitive Tutors), research centered around Cognitive Load Theory (CLT), and investigation of e-learning usability. Literature related to automated tutoring has long viewed information gleaned from student errors as an important resource for modeling student learning (Van Lehn, 1988). However, the ultimate goal of this modeling has generally been the elimination of errors, or as Anderson, Boyle, and Reiser put it, ". . . a more efficient solution, one that involves less trial-and-error search" (1985, p. 457). Further, immediate feedback on errors so as to reduce time spent making additional errors has been the norm (Mathan & Koedinger, 2005), in keeping with a behaviorist perspective (Skinner, 1968).

Sweller's Cognitive Load Theory (Sweller, 1994) suggests that working memory may be overloaded by errors, interfering with learning. He questions the acceptance of errors inherent in popular discovery learning approaches, and proposes errorless "worked examples" be employed instead (Tuovinen & Sweller, 1999). This theory has been highly influential in the realm of e-learning, particularly in the design of multimedia learning and has given rise to similar approaches including Mayer's Cognitive Theory of Multimedia Learning (2005).

Researchers in the growing area of e-learning usability have emphasized the cost of student error as well. Much of their work has centered around the creation of heuristics, checklists, and guidelines based on similar but more general tools (such as Matera, Costabile, Garzotto, & Paolini, 2002; Nielsen, 1993) and the application of pedagogical theory; many of these sets of heuristics affirm the import of error prevention in e-learning. While work from this perspective has been fruitful, some e-learning usability researchers have joined researchers in the broader study of education in suggesting an entirely different approach to error.

Errors as Beneficial

The view that errors can be useful and even important in education has a long history, with roots going back at least to Dewey (Borasi, 1996; Dewey, 1938). Discovery learning (Bruner, Goodnow, & Austin, 1956) viewed error as a natural part of a learner's exploration, while Piaget (1970) argued that accommodation, a process in which the learner's error plays a central role, was a vital mechanism of learning. More recently, Constructivism has continued to suggest a positive stance

toward student error, arguing that misconception and error have been unduly condemned by the large body of traditional misconception research (Borasi, 1996; Smith et al., 1993).

Unsurprisingly, this view of errors from the wider research community has also been highly influential in the relatively young field of e-learning. Indeed, many authors have argued that e-learning holds unique promise for advancing a Constructivist curriculum (Jonassen et al., 1995), particularly through access to technologies like virtual worlds (Dede, 1995) and computer simulations (Windschitl & Andre, 1998), technologies that can encourage student error by removing real-world constraints and consequences (Ziv, Ben-David, & Ziv, 2005).

Similarly, Cognitive Flexibility Theory (Spiro, Coulson, Feltovich, & Anderson, 1988), an influential perspective in the design of hypertext learning (Spiro, Collins, Thota, & Feltovich, 2003), suggests that learning is facilitated by navigating ill-defined knowledge structures; this less-directed approach seems bound to allow for more student error, at least in the short term. In the realm of Cognitive Tutors, Mathan and Koedinger (2005) point out that essential metacognitive skills may be strengthened by allowing students to discover and deal with errors, and cite studies suggesting that delayed feedback—which allows students to make more and greater errors—improves learning and transfer (Schooler & Anderson, 1990). Though not examining e-learning as such, many researchers using "error training" to teach the operation of computer applications have argued that such training can foster creativity and enhance memory (Frese, Brodbeck, Heinbokel, Mooser, Schleiffenbaum, & Thiemann, 1991; Kay, 2007), suggesting that such errors may be useful in learning to use e-learning software as well. Taken together, this research presents a compelling case for the benefit of errors in e-learning, and presents a dramatic counterweight to the work supporting the opposite position.

SUPPORT FOR A TAXONOMY

Synthesizing the wide variety of research relating to e-learning error is difficult. Errors are studied in different contexts, for different purposes, and even with different definitions. Further, authors seldom go out of their way to situate their work in the context of error-related research as a whole. This confronts designers and teachers with literature on errors that is vast but, for their purposes, relatively disorganized. Researchers who wish to study errors in e-learning in a comprehensive way are also hindered by this lack of organization. A taxonomy of e-learning errors would help alleviate both problems.

One of the chief projects of error research has been the establishment of taxonomies; indeed, these efforts have been so prolific that Senders and Moray (1991) suggest a taxonomy of taxonomies! Error typologies have been frequently applied to workplace settings like medicine (Dovey, Meyers, Phillips, Green,

Fryer, Galliher, et al., 2002), aviation (Leadbetter, Hussey, Lindsay, Neal, & Humphreys, 2001) office computing (Zapf, Brodbeck, Frese, Peters, & Prümper, 1992), and e-commerce (Freeman, Norris, & Hyland, 2006).

In addition to these efforts at domain-specific categorization, two more general taxonomies have been especially influential. The first of these is Norman's taxonomy (1988). He defines two types of error: the first, associated with inattention and lack of monitoring, he calls slips; these are errors like forgetting to turn off the oven or calling someone you know by someone else's name. Mistakes, on the other hand, are higher-level cognitive failures associated with consciously selecting poor goals and plans. Reason's (1990) taxonomy has also been exceptionally influential, and has additionally gone on to influence subsequent taxonomies (Sutcliffe & Rugg, 1998; Zapf, Brodbeck, Frese, Peters, & Prümper, 1992). Like Norman, Reason identifies the two main categories of slips and mistakes. However, he further divides mistakes into two types: knowledge-based and rule-based. This distinction recognizes that some mistakes are closely related to slips. Since relatively high-level routines (choosing to check for error, deciding how thoroughly to read instructions) are involved in checking for slips, many slips are ultimately the result of mistakes in these semi-automated processes. Reason calls these "rule-based mistakes." Although this distinction is not always completely clear, it should not be neglected by a taxonomy of learning error. Given the widespread use of these taxonomies and their grounding in psychological research, it will be useful for us to consider them in making our taxonomy of e-learning errors.

However, these efforts are designed to examine performance errors; learning involves fundamentally different processes that require specialized explanations in e-learning (Mayes, 1996) and elsewhere. It is important, therefore, for us to consider taxonomies tailored to education. There is no shortage of such efforts, particularly those investigating particular domains: to identify just a few, Chinn and Brewer (1998) categorize responses to anomalous data in science, designed for use by science teachers; several taxonomies have been created for second-language learning errors (Salem, 2007; Suri & McCoy, 1993) and errors in mathematics learning (Lannin et al., 2007); there have also been several efforts to categorize errors in special education populations (Loukusa, Leinonen, Jussila, Mattila, Ryder, Ebeling, et al., 2007). However, these taxonomies are limited to investigating errors in a single academic domain or population, limiting their usefulness for e-learning research. Among attempts to build educational taxonomies that span domains, Bloom's taxonomy (Bloom, 1956) has been exceptionally influential (Anderson & Sosniak, 1994); though not an error taxonomy as such, it has been used to classify student errors (Lister & Leaney, 2003). A large literature relating to intelligent tutoring systems often distinguishes between types of error (Anderson et al., 1985; Mathan & Koedinger, 2005); however, investigation of error is typically limited to students' mistakes within the context of the program; usability errors associated with the program itself,

while not ignored (Anderson & Gluck, 2001), are seldom integrated into a complete taxonomy.

The growing body of work investigating the usability of e-learning has important implications for a taxonomy of error, for two reasons. First, the field has highlighted the differences between learning and support of learning. Karoulis and Pombortsis (2003) distinguish between "usability" and "learnability," while Lambropoulos (2007) points out that the student has a "dual identity," as both a learner and a user, further suggesting the separation of learning and supporting tasks. Muir, Shield, and Kukulska-Hulme (2003) refine this distinction further; their Pedagogical Usability Pyramid contains four stacking usabilities (context-specific, academic, general web, and technical or functional), while Ardito et al. (2006) also suggest a fourfold distinction, proposing four usability "dimensions." Second, this work suggests that differences in types of usability imply differences in types of error as well, and that these differences are pedagogically significant. Ardito et al. (2006), for instance, point out that student error should be approached in different ways, depending upon dimension. Melis, Weber, and Andrès also note that the distinction in error types has pedagogical consequences: ". . . while it is appropriate to immediately provide the full solution and technical help concerning a problem with handling the system, this may not be the best option in tutorial help" (2003, p. 9). Squires and Preece agree (1999, p. 476), maintaining that ". . . learners need to be protected from usability errors. However, in constructivist terms learners need to make and remedy cognitive errors as they learn." This distinction between *learning errors* and *supporting errors* does much to bridge the apparent gap between schools of thought on e-learning errors; accordingly, it will play an important part in our taxonomy.

A PRELIMINARY TAXONOMY OF E-LEARNING ERRORS

Figure 1 illustrates a three-part taxonomy of e-learning errors. Learning mistakes are directly associated with areas of instruction, while support mistakes are in underlying prerequisite skills. Technology mistakes are associated with skills specific to e-learning, like accessing a Learning Management System; general support mistakes are in skills required across many academic domains, like reading. Slips are lower-level, unconscious errors that can occur in any type of task. They are considered a "pseudo-category," since most slips are ultimately attributable to failures of conscious "slip control" routines, which are in turn classed as general support tasks (making their failures general support mistakes).

The first part of any taxonomy must be a more careful description of what we mean by "error." Defining error is by no means a trivial task (Williams, 1981), particularly as the term has acquired an ideological charge in educational theory. Error research from a variety of fields, however, does generally converge around a view of errors as disconnects or mismatches between actions and expectations, a definition we will adopt as well (Borasi, 1996; Dekker, 2006;

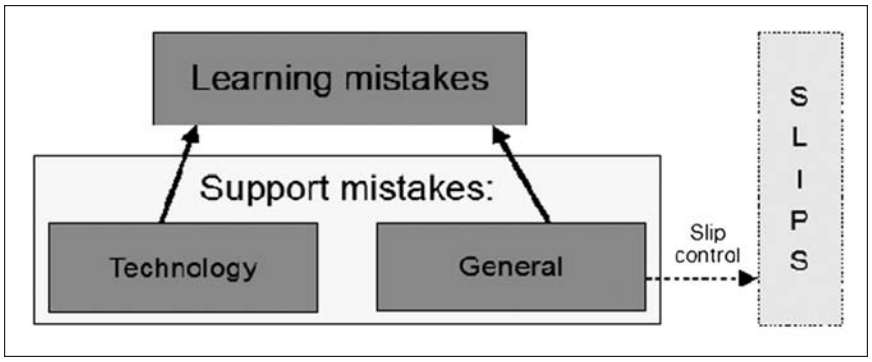


Figure 1. A three-part taxonomy of e-learning errors.

Norman, 1988; Ohlsson, 1996; Peters & Peters, 2006; Rassmusen, 1982; Reason, 1990; Zapf et al., 1992). In the case of e-learning error, we are generally interested in the mismatches between the student's actions and the instructor's expectations. This definition makes no claim about *intrinsic* correctness or error, but acknowledges that teachers and designers are in the business of privileging some methods and outcomes (like "Save your work frequently" or "Iceland's capital is Reykjavik") over others.

We are also interested particularly in errors by the student, rather than errors by the instructor (for instance, improper assessments or inappropriate assignments), or in the technology itself (for instance, a virus or network crash). While these topics merit further study, space dictates that this first effort be focused on errors made strictly by students.

Having defined error, we can finally propose our taxonomy. It has three categories: learning mistakes, general support mistakes, and technology support mistakes. While each may be profitably subdivided further, we have only suggested such divisions in this first exploration, concentrating instead on the relations of the categories. As the first effort to synthesize a large and diverse body of work, this taxonomy must paint in broad strokes.

Table 2 suggests one way a wide array of views on error might be organized by this taxonomy. Again, this preliminary organization is necessarily more suggestive than authoritative; placing all research informed by Cognitive Load Theory, for instance, into one category is simplistic at best. Nevertheless, it does demonstrate this taxonomy's potential for clarifying and systematizing a large and relatively disorganized body of literature.

Learning Task Mistakes

Examples

1. On an online quiz, Angel writes that Cuba is in the Pacific Ocean.

Table 2. A Preliminary Categorization of Several Major Error Perspectives[a]

	Negative	Positive
Learning mistakes	Cognitive Load Theory (Tuovinen & Sweller, 1999; *Mayer, 2005*)	Constructivism (Smith et al., 1993; *Jonassen et al., 1995*)
	Much misconception research; see Confrey (1990)	E-learning usability (*Squires & Preece, 1999*)
	Errorless learning (Wilson et al., 1994)	Error training (Frese et al., 1991)
		Discovery-learning (Bruner et al., 1956; *de Jong & van Joolingen, 1998*)
		Cognitive Flexibility Theory (*Spiro et al., 2003*)
	Self-efficacy (Compeau & Higgins, 1995)	Self-efficacy (longer-term benefits; LorenZet, Salas, & Tannenbaum, 2005)
	Intelligent Tutoring Systems (*Anderson et al., 1985*)	Cognitive Tutors (*Mathan & Koedinger, 2005*)
General support mistakes	Metacognition and executive attention (Flavell, 1979; Jones, 1995; Mathan & Koedinger, 2005)	Goldman (perhaps; 1991)
	Universal accessibility (Shneiderman, 2007; Kelly et al., 2004)	
	Applied psychology/HCI (Reason, 1990; Dekker, 2006; Norman, 1988): General support mistakes are damaging, but spring from generally beneficial mechanisms.	
Technology support mistakes	E-learning usability (*see Table 1*)	

[a]Citations are representative samples of much larger bodies of work. Italics denote studies applying directly to e-learning.

2. Beatrice uses a math tutoring program; she adds fractions straight across without first finding a common denominator

Definition

Learning task mistakes are conscious errors in tasks that directly relate to the main learning objectives.

Discussion

Use of the term "mistake," rather than the more general "error," references the taxonomies of Reason and Norman, both of whom use the terms to refer to higher-cognitive-level errors, as opposed the lower-level, unconscious errors they both define as "slips." *Accidentally* marking "A" instead of "B" on a test could not fit into this category; *choosing* "A" over "B" could. This category also draws upon work in the usability of e-learning that distinguishes between learning and support errors, including Karoulis and Pombortsis (2003), Lambropoulos (2007), Muir et al. (2003), Ardito et al. (2006), Melis et al. (2003), and Squires and Preece agree (1999).

Usefulness of Errors

The literature is divided over the usefulness of errors in learning tasks (see Table 2). However, in recent decades we discern a general trend toward views emphasizing the usefulness of error, linked with the ascendancy of Constructivist perspectives.

Further Division

One useful approach might be to class errors according the cognitive levels of Bloom's (1956) taxonomy, in the manner of Lister and Leaney (2003). In such a system, we would sort errors according to the taxanomic learning domains of the original tasks. This approach would be particularly accessible to practitioners, many of whom are already familiar with Bloom's work (Anderson & Sosniak, 1994).

General Support Mistakes

Examples

1. Amelie knew her discussion board post was due at noon, but she procrastinated; there was no time to finish the whole thing.
2. Bertrand's first language is not English, and his classmates in a synchronous distance learning environment sometimes misunderstand him.

Definition

General support mistakes are conscious errors in tasks that provide *cross-domain support* to learning tasks.

Description

These are errors associated with skills that are prerequisites for learning across domains, rather than being associated with any particular academic subject. Although they may be taught, they are often simply presumed available. There are a wide range of general support mistakes, including high-level cognition like time-management, and low-level skills like maintaining attention. Domain-general support skills may also run the gamut from culturally-determined, as in the case of proper grammar, to nearly universal skills like language use. In all cases, though, errors in these skills create a bottleneck inhibiting learning in a wide variety of domains. Many general support mistakes are associated with errors in metacognition (Flavell, 1979) and executive function (Fernandez-Duque, Baird, & Posner, 2000). Errors in the deployment of metacognition errors may be especially important, given that metacognitive skills play an essential role in students' ability to benefit from learning errors (Yerushalmi & Polingher, 2006). Many authors have supported the explicit teaching of general support skills, including metacognition (Keith & Frese, 2005); by making the support skill the focus of learning this would, for better or worse, mean that mistakes in the skill being explicitly taught would also now be categorized as learning mistakes.

One particularly important general support skill is the prevention of slips: accidental, unconscious errors. Though these errors—say, carelessly spelling "friend" as "freind"—may seem completely accidental, teachers have long realized that practice in appropriate support skills—in this case, proofreading—can significantly diminish the impact of slips. What seems at first like an accidental slip is, at its root, often an error caused by a higher-level decision. Reason (1990) recognizes this phenomenon in part in his category of "rule-based mistakes," the misapplication of high-level heuristics or "rules." An example of a general support mistake that Reason might call a Rule-Based mistake is a student who may always ignore small print; she has found a useful time-saving strategy—until that print contains important instructions. This recognition—that slips can ultimately be explained in terms of higher-level errors ("mistakes")—explains why slips are included in this category, rather than being taxonomized separately.

Usefulness of Errors

The literature relating to general support mistakes is large, and almost unanimously negative. Errors relating to general support skills are bemoaned. Very few authors suggest that making this sort of error is actually useful, choosing instead to emphasize the importance of robust general support skills and suggest ways of strengthening them. This may be most notable in the related studies of metacognition and executive attention, as well as in the growing interest in e-learning accessibility (which aims to support students who are less able to employ general support skills like maintaining attention, reading, or even vision).

Further Division

General support mistakes could be further divided along a spectrum of cognitive level, with basic tasks like visual perception at one end of a scale, and higher-level skills like the managing of motivation on the other.

Technology Support Mistakes

Examples

1. Artemis uploads his assignment to a LMS in a format his instructor cannot read.
2. Bianca clicks on four incorrect links before she finds what she was looking for: the link to contact her instructor.

Definition

Technology support mistakes are conscious errors in tasks that support learning activities *in the domain of e-learning.*

Description

As with the other two categories, this class deals with mistakes, not slips. It is our view that most slips, including slips in e-learning tasks (forgetting to save work, for instance), are ultimately the result of conscious mistakes in other, more general support tasks (like remaining attentive when finishing work). Like the learning mistakes category, this class is also supported by the large body of e-learning usability work that separates interaction with "content" versus "container" (Ardito et al., 2006). Like more general support mistakes, technology support mistakes are often made in areas students are simply assumed to have competence in. However, technology support tasks may also be—and often are—explicitly taught. Student technology errors would of course then be classed as learning errors, as well.

Usefulness of Errors

In this category, the relevant literature—mostly from the study of e-learning usability—is unambiguous in its negative view toward errors.

Further Division

Technology support mistakes could be subdivided according to whether the mistakes were characteristic of experts or novices (who have been shown to err in distinct ways; Zapf et al., 1992). Mistakes could also be organized along a continuum from relatively general (using a mouse, understanding file hierarchies) to application-specific (editing WordPress blogs).

Criticisms

This taxonomy represents a first effort to categorize a large and varied literature relating to e-learning errors. As such, it provides ample opportunity for criticism. Here we address three potential strands of potential criticism: that the taxonomy has too many categories, that it has too few categories, and that it attempts to be too objective.

Too Many Categories

Many e-learning usability authors address a twofold division: between tasks related to learning content and those related to using e-learning technology. Why, the lumper asks, should we then add a third category for "general support mistakes?" Mainly because a large literature supports the importance of error-free performance in many general support tasks; little if any research finds a beneficial role for errors in such tasks (unless, of course, they are being explicitly taught; in this case the errors would in fact be learning errors). A classification scheme split between (good) learning errors and (bad) technology support errors, then, is overlooking an important type of error, and cannot be considered complete. Additionally, several others authors (particularly Muir et al., 2003), have proposed understandings of e-learning usabilities that move beyond simple content/interface dichotomies; these support a move toward more nuanced categorization of error.

Too Few Categories

On the other side, the splitter may argue that a simple triplet is inadequate to categorize the many types and contexts of errors. This argument has merit, and we encourage future work to expand upon this initial effort, perhaps using the subdivisions we propose for each category. A particular concern may be our elision of the "slips" category, which is heavily used in error research across several fields. It should be clarified, though, that we have not completely thrown out slips; we acknowledge that such errors exist (speaking from, it must be said, significant firsthand experience). Accordingly, we assign slips a sort of "pseudo-category, " addressing them in the context of the "slip control" general support skill. This is because we see slips as generally, at their root, the result of higher-level cognitive errors—a view which finds some support from error literature (Reason, 1990). This perspective has practical advantages for education, which will be discussed below.

Too Objective

We examine error from the perspective of a teacher or system designer. A Constructivist might object that we ignore the equally rich perspective of the student. On the contrary: we agree that all observers have equal "right" to their

own measures of error, and this taxonomy assumes no "real," or universally correct method or answer. It is widely acknowledged in the Constructivist literature, however, that teachers have a practical interest in supporting some student understandings over others; Smith et al. (1993, p. 133), for instance, point out that, "there are certainly contexts where students' existing knowledge is ineffective, or more carefully articulated mathematical and scientific knowledge would be unnecessary." This said, we encourage taxonomy work exploring both narrower and broader perspectives of e-learning error as well, as such approaches will only improve our overall understanding of error.

APPLICATION AND VALIDATION

A taxonomy such as the one proposed here becomes valuable only when it is validated applied to real-world problems. We suggest deploying and examining this taxonomy in several contexts, investigating its value for use with students, teachers, and researchers.

Students

Research has supported the value of giving students explicit guidelines in how to handle errors (Lorenzet et al., 2005). A taxonomy like the one proposed in this article could form a useful framework around which to structure such instruction. Examining error types could help students plan strategies for error reduction where appropriate, and encourage appreciation of valuable learning errors. The taxonomy understands error as a mismatch rather than failure; such a notion could provide a useful palliative for the student anxiety that often accompanies more traditional, judgmental stances. These uses are well-suited to empirical evaluation. A group of students could be given a short course explaining how errors fit into this taxonomy, with special emphasis on ways to avoid "bad" errors (general and technology support mistakes), and ways to capitalize on "good" (learning mistakes) errors. These students and controls could be compared; researchers could use both qualitative and quantitative methods to examine the effects of taxonomy awareness on students' learning, engagement, and attitudes toward the technologies used.

Teachers

Many teachers use intuitive taxonomies to categorize student error—a method often more reflective of personal idiosyncrasies than actual mistake significance (Anson, 2000). It may be that the lack of any comprehensive taxonomy of e-learning errors has given teachers little alternative. The emergence of such a system of categorization, however, offers teachers a meaningful, accessible tool to guide both research- and experience-based reflective practice (Schön, 1983). This could be examined by introducing the taxonomy to teachers before they teach

a unit or lesson using technology, like one in which students create blogs. Would teachers find the distinctions of the taxonomy useful? Qualitative interviews and content analysis of comments given students could establish whether the taxonomy helps teachers better understand and assess student errors, whether they are missing trackbacks or imbalanced equations.

Researchers

This taxonomy presents several exciting possibilities for e-learning researchers. First, of course, is the challenge of validating and improving this initial effort. The most important first step would be a study that gathers student errors to see how well they fit the taxonomy. Students might be assigned a technology-intensive learning task—for instance, using Google Wave to create a document analyzing the debate over gun control. Borrowing methods of usability studies, researchers would closely observe student activity, using some combination of note-taking, "think-aloud" protocols, videotaping, and screen recording, and similar methods. The results of this observation, along with the results of the students' work, would be mined to extract a set of student errors. These errors could then in turn be examined to see if they fit naturally into the categories established by the proposed taxonomy. If they do not, the taxonomy could be revised; if they do, the results would confer a valuable empirical backing to the taxonomy.

In addition to validation, investigations into the etiologies of different types of error may prove especially valuable; it seems likely that errors in different categories and subcategories should have different causes, but little empirical work has attempted to demonstrate this. Here the application of work from a psychological perspective, perhaps including psychophysiological measures such as eyetracking (see Anderson & Gluck, 2001, for an example), could be invaluable. It will also be important to examine errors in more specific areas of e-learning. For instance, research should examine and refine the types of Technology Support Mistakes in synchronous vs. asynchronous environments, or in virtual worlds or social networking environments. It may even be that some Learning Mistakes can only occur, or are more likely to occur, in certain e-learning settings. Over time, such research will yield a more textured, nuanced, and useful understanding of error in e-learning.

CONCLUSION

As teachers, designers, and researchers, our understanding of and approach toward student error is a foundation—some might say *the* foundation—of pedagogies we employ and facilitate. It is no surprise, then, that educational research and theory has returned to the investigation of errors again and again over the last several decades. To organize these efforts, many authors have employed

taxonomies of error in particular academic domains. Given the explosive growth of e-learning over the last few decades and the recent interest in the usability of e-learning, we believe that this field would be greatly served by the application of a taxonomy of errors, as well.

The goal of the present effort, then, is less to create a rigid, definitive structure (if that were possible), and more to draw attention to the need for an agreed-upon structure for discussing errors. We see our proposed taxonomy as a promising approach, particularly in its inclusion of the relatively unacknowledged general-support category, and in its interdisciplinary foundation. However, we suggest that other approaches may be profitably pursued, and support future efforts to refine or even replace this preliminary effort. At the end of the day, a more thorough understanding of the nature, etiology, and value of different error types will aid a pedagogy that helps students "fail better."

REFERENCES

Adeoye, B., & Wentling, M. R. (2007). The relationship between national culture and the usability of an e-learning system. *International Journal on E-Learning, 6*(1), 119-147.

Albion, P. R. (1999). Heuristic evaluation of educational multimedia: From theory to practice. In *Proceedings of the 16th Annual Conference of the Australasian Society for Computers in Learning in Tertiary Education* (pp. 9-15). Brisbane, Australia.

Anderson, J. R., Boyle, C. F., & Reiser, B. J. (1985). Intelligent Tutoring Systems. *Science, 228*(4698), 456-462. doi:10.1126/science.228.4698.456

Anderson, J. R., & Gluck, K. (2001). What role do cognitive architectures play in intelligent tutoring systems. In *Cognition and instruction: Twenty-five years of progress* (pp. 227-262). London: Psychology Press.

Anderson, L. W., & Sosniak, L. A. (Eds.). (1994). *Bloom's taxonomy: A forty-year retrospective*. Chicago, IL: NSSE.

Anson, C. M. (2000). Response and the social construction of error. *Assessing Writing, 7*(1), 5-21.

Ardito, C., Costabile, M., De Marsico, M., Lanzilotti, R., Levialdi, S., Roselli, T., et al. (2006). An approach to usability evaluation of e-learning applications. *Universal Access in the Information Society, 4*(3), 270-283. doi:10.1007/s10209-005-0008-6

Benson, L., Elliott, D., Grant, M., Holschuh, D., Kim, B., Kim, H., et al. (2002). Usability and instructional design heuristics for e-learning evaluation. In P. Barker & S. Revbelsky (Eds.), *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2002* (pp. 1615-1621). Chesapeake, VA: AACE.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Handbook 1: Cognitive domain.* New York: David McKay.

Borasi, R. (1996). *Reconceiving mathematics instruction: A focus on errors.* Norwood, NJ: Ablex.

Broadbeck, F., Zapf, D., Prümper, J., & Frese, M. (1993). Error handling in office work with computers: A field study. *Journal of Occupational and Organizational Psychology, 66*(4), 303-317.

Brosnan, M. J. (1998). The impact of computer anxiety and self-efficacy upon performance. *Journal of Computer Assisted Learning, 14*(3), 223-234.

Brown, J. S., & Burton, R. R. (1978). Diagnostic models for procedural bugs in basic mathematical skills. *Cognitive Science: A Multidisciplinary Journal, 2*(2), 155-192.

Bruner, J. S., Goodnow, J. J., & Austin, G. A. (1956). *A study of thinking*. New York: Science Editions.

Buswell, G. T., & Judd, C. H. (1925). *Summary of educational investigations relating to arithmetic*. Chicago, IL: The University of Chicago.

Champagne, A. B., Klopfer, L. E., & Anderson, J. H. (1980). Factors influencing the learning of classical mechanics. *American Journal of Physics, 48*(12), 1074-1079.

Chinn, C. A., & Brewer, W. F. (1998). An empirical test of a taxonomy of responses to anomalous data in science. *Journal of Research in Science Teaching, 35*(6), 623-654.

Compeau, D. R., & Higgins, C. A. (1995). Computer self-efficacy: Development of a measure and initial test, *MIS Quarterly, 19*(2), 189-211.

Confrey, J. (1990). A review of the research on student conceptions in mathematics, science, and programming. *Review of Research in Education, 16,* 3-56.

Dede, C. (1995). The evolution of constructivist learning environments: Immersion in distributed, virtual worlds. *Educational Technology, 35*(5), 46-52.

de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*(2), 179-201.

Dekker, S. (2006). *The field guide to understanding human error*. Burlington, VT: Ashgate Publishing.

Dewey, J. (1938). *Experience and education*. New York: Macmillan.

Dovey, S. M., Meyers, D. S., Phillips Jr., R. L., Green, L. A., Fryer, G. E., Galliher, J. M., et al. (2002). A preliminary taxonomy of medical errors in family practice, *British Medical Journal, 11*(3), 233.

Fernandez-Duque, D., Baird, J. A., & Posner, M. I. (2000). Executive attention and metacognitive regulation. *Consciousness and Cognition, 9*(2), 288-307.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist, 34*(10), 906-911.

Freeman, M., Norris, A., & Hyland, P. (2006). Usability of online grocery systems: A focus on errors. *Proceedings of the 20th Conference of the Computer-Human Interaction Special Interest Group (CHISIG) of Australia on Computer-Human Interaction: Design: Activities, Artefacts and Environments* (pp. 269-275). Sydney, Australia.

Frese, M., Brodbeck, F., Heinbokel, T., Mooser, C., Schleiffenbaum, E., & Thiemann, P. (1991). Errors in training computer skills: On the positive function of errors. *Human-Computer Interaction, 6*(1), 77-93.

Goikoetxea, E. (2006). Reading errors in first- and second-grade readers of a shallow orthography: Evidence from Spanish. *British Journal of Educational Psychology, 76*(2), 333-350.

Goldman, S. R. (1991). On the derivation of instructional applications from cognitive theories: Commentary on Chandler and Sweller. *Cognition and Instruction, 8*(4), 333-342.

Heinssen Jr., R. K., Glass, C. R., & Knight, L. (1987). Assessing computer anxiety: Development and validation of the computer anxiety rating scale. *Computer-Human Behavior, 3*(1), 49-59.

Jonassen, D., Davidson, M., Collins, M., Campbell, J., & Haag, B. B. (1995). Constructivism and computer-mediated communication in distance education. *The American Journal of Distance Education, 9*(2), 7-26.

Jones, M. G. (1995). Using metacognitive theories to design user interfaces for computer-based learning. *Educational Technology, 35*(4), 12-22.

Karoulis, A., & Pombortsis, A. (2003). Heuristic evaluation of web-based ODL programs. In C. Ghaoui (Ed.), *Usability evaluation of online learning programs* (p. 88). Hershey, PA: IGI Global.

Kay, R. H. (2007). The role of errors in learning computer software. *Computers & Education, 49*(2), 441-459.

Keith, N., & Frese, M. (2005). Self-regulation in error management training: Emotion control and metacognition as mediators of performance effects. *The Journal of Applied Psychology, 90*(4), 677-691.

Kelly, B., Phipps, L., & Swift, E. (2004). Developing a holistic approach for e-learning accessibility. *Canadian Journal of Learning and Technology, 30*(3). n.p.

Kroll, B. M., & Schafer, J. C. (1978). Error-analysis and the teaching of composition. *College Composition and Communication, 29*(3), 242-248.

Lambropoulos, N. (2007). User-centered design of online learning communities. In *User-centered design of online learning communities* (pp. 1-21). Hershey, PA: Information Science Publishing.

Lannin, J. K., Barker, D. D., & Townsend, B. E. (2007). How students view the general nature of their errors. *Educational Studies in Mathematics, 66*(1), 43-59.

Leadbetter, D., Hussey, A., Lindsay, P., Neal, A., & Humphreys, M. (2001). Towards model based prediction of human error rates in interactive systems. *Second Australasian User Interface Conference, 2001. AUIC 2001. Proceedings* (pp. 42-49). Gold Coast, Australia.

Lee, C. K. (2001). Computer self-efficacy, academic self-concept, and other predictors of satisfaction and future participation of adult distance learners. *American Journal of Distance Education, 15*(2), 41-51.

Lister, R., & Leaney, J. (2003). Introductory programming, criterion-referencing, and bloom, *SIGCSE Bulletin, 35*(1), 143-147.

Lorenzet, S. J., Salas, E., & Tannenbaum, S. I. (2005). Benefiting from mistakes: The impact of guided errors on learning, performance, and self-efficacy. *Human Resource Development Quarterly, 16*(3), 301-322.

Loukusa, S., Leinonen, E., Jussila, K., Mattila, M., Ryder, N., Ebeling, H., et al. (2007). Answering contextually demanding questions: Pragmatic errors produced by children with Asperger syndrome or high-functioning autism. *Journal of Communication Disorders, 40*(5), 357-381.

Matera, M., Costabile, M. F., Garzotto, F., & Paolini, P. (2002). SUE inspection: An effective method for systematic usability evaluation of hypermedia. *Systems, Man and Cybernetics, Part A, IEEE Transactions on, 32*(1), 93-103.

Mathan, S. A., & Koedinger, K. R. (2005). Fostering the intelligent novice: Learning from errors with metacognitive tutoring. *Educational Psychologist, 40*(4), 257-265.

Mayer, R. (2005). Cognitive theory of multimedia learning. In R. Mayer (Ed.), *The Cambridge handbook of multimedia learning*. New York: Cambridge University Press.

Mayes, T. (1996). Why learning is not just another kind of work. *Proceedings on Usability and Educational Software Design.* London: BCS HCI.

Melis, E., Weber, M., & Andrès, E. (2003). Lessons for (pedagogic) usability of eLearning systems. In A. Rossett (Ed.), *Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2003* (pp. 281-284). Chesapeake, VA: AACE.

Muir, A., Shield, L., & Kukulska-Hulme, A. (2003). The pyramid of usability: A framework for quality course websites. In *Proceedings of the EDEN 12th Annual Conference of the European Distance Education Network, The Quality Dialogue: Integrating Quality Cultures in Flexible, Distance and eLearning* (pp. 188-194). Rhodes, Greece.

Nielsen, J. (1993). *Usability engineering* (1st ed.). San Francisco, CA: Morgan Kaufmann.

Nielsen, J. (1994). Heuristic evaluation. In *Usability inspection methods* (pp. 25-62). New York: John Wiley & Sons.

Nielsen, J., & Molich, R. (1990). Heuristic evaluation of user interfaces. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Empowering People* (pp. 249-256). Seattle, Washington, United States: ACM.

Norman, D. A. (1988). *The psychology of everyday things* (Reprint), 272. New York: Basic Books.

Ohlsson, S. (1996). Learning from performance errors. *Psychological Review, 103*(2), 241-262.

Parlangeli, O., Marchigiani, E., & Bagnara, S. (1999). Multimedia systems in distance education: Effects of usability on learning. *Interacting with Computers, 12*(1), 37-49.

Peters, G. A., & Peters, B. J. (2006). *Human error: Causes and control* (1), 232. CRC.

Piaget, J. (1970). *Genetic epistemology*. New York: Columbia University Press.

Quinn, C. N. (1996). Pragmatic evaluation: Lessons from usability. *Proceedings of ASCILITE, 96,* 437-444.

Rasmussen, J. (1982). Human errors: A taxonomy for describing human malfunction in industrial installations. *Journal of Occupational Accidents, 4,* 311-335.

Reason, J. (1990). *Human error* (1), 316. Cambridge, UK: Cambridge University Press.

Salem, I. (2007). The lexico-grammatical continuum viewed through student error. *ELT Journal, 61*(3), 211-219. doi: 10.1093/elt/ccm028.

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action.* New York: Basic Books.

Schooler, L. J., & Anderson, J. R. (1990). The disruptive potential of immediate feedback. *Proceedings of the Twelfth Annual Conference of the Cognitive Science Society* (pp. 702-708). Cambridge, Massachusetts.

Senders, J., & Moray, N. (1991). *Human error: Cause, prediction, and reduction.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Shneiderman, B. (2007). Forward. In N. Lambropoulos & Z. Panayotis (Eds.), *User-centered design of online learning communities* (pp. vii-viii). Hershey, PA: Information Science Publishing.

Skinner, B. F. (1968). *The technology of teaching*. New York: Appleton-Century-Crofts.

Smith III, J. P., diSessa, A. A., & Roschelle, J. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal of the Learning Sciences, 3*(2), 115-163.

Spiro, R. J., Collins, B. P., Thota, J. J., & Feltovich, P. J. (2003). Cognitive flexibility theory: Hypermedia for complex learning, adaptive knowledge application, and experience acceleration. *Educational Technology, 43*(5), 5-10.

Spiro, R., Coulson, R., Feltovich, P., & Anderson, D. (1988). *Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains*. Champaign, IL: University of Illinois Center for the Study of Reading.

Squires, D., & Preece, J. (1999). Predicting quality in educational software: Evaluating for learning, usability and the synergy between them. *Interacting with Computers, 11*(5), 467-483.

Suri, L. Z., & McCoy, K. F. (1993). *A methodology for developing an error taxonomy for a computer assisted language learning tool for second language learners*. Newark, DE: Department of Computer and Information Sciences, Univeristy of Delaware.

Sutcliffe, A., & Rugg, G. (1998). A taxonomy of error types for failure analysis and risk assessment. *International Journal of Human-Computer Interaction, 10*(4), 381-405.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction, 4*(4), 295-312.

Triacca, L., Bolchini, D., Botturi, L., & Inversini, A. (2004). *Mile: Systematic usability evaluation for e-learning web applications*. Educalibre Project technical report. Retrieved from http://edukalibre.org/documentation/mile.pdf

Tuovinen, J., & Sweller, J. (1999). A comparison of cognitive load associated with discovery learning and worked examples. *Journal of Educational Psychology, 91*(2), 334-341.

Van Lehn, K. (1988). Student modeling. In M. Polson & J. Richardson (Eds.), *Foundations of intelligent tutoring systems*. Mahwah, NJ: Lawrence Erlbaum Associates.

Williams, J. M. (1981). The phenomenology of error. *College Composition and Communication, 32*(2), 152-168.

Wilson, B. A., Baddeley, A., Evans, J., & Shiel, A. (1994). Errorless learning in the rehabilitation of memory impaired people. *Neuropsychological Rehabilitation, 4*(3), 307-326.

Windschitl, M., & Andre, T. (1998). Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs. *Journal of Research in Science Teaching, 35*(2), 145-160.

Wong, S. K. B., Nguyen, T. T., Chang, E., & Jayaratna, N. (2003). Usability metrics for e-learning. *Proceedings of On the Move to Meaningful Internet Systems 2003: OTM 2003 Workshops: OTM Confederated International Workshops: HCI-SWWA, IPW, JTRES, WORM, WMS, and WRSM 2003.* Catania, Sicily, Italy.

Yerushalmi, E., & Polingher, C. (2006). Guiding students to learn from mistakes. *Physics Education, 41*(6), 532-538.

Zapf, D., Brodbeck, F., Frese, M., Peters, H., & Prümper, J. (1992). Errors in working with office computers: A first validation of a taxonomy for observed errors in a field setting. *International Journal of Human-Computer Interaction, 4*(4), 311-339.

Zemsky, R., & Massy, W. F. (2004). Thwarted innovation: What happened to e-learning and why. *Final Report: The Weatherstation Project of the Learning Alliance at the University of Pennsylvania*.

Ziv, A., Ben-David, S., & Ziv, M. (2005). Simulation based medical education: An opportunity to learn from errors. *Medical Teacher, 27*(3), 193-199.

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