Interaction Strategies and Emerging Instructional Technologies: Psychological Perspectives

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Abstract: Interaction strategies for emerging instructional technologies have typically reflected mathemagenic. designer-centered views of lesson design. Recent developments in cognitive psychology, however, have important implications for redefining interaction to include predominantly learner-centered methods. In particular, generative strategies designed to promote individually relevant cognitive processing have important, generally untapped potential. In this paper, the traditional functions of interaction are reviewed, quantitative and qualitative perspectives on interaction strategies are described, and several methods for promoting cognitive engagement via both mathemagenic and generative interaction strategies are presented.

The growth of interactive instructional technologies has been staggering. The relatively crude hardware and software employed even one decade ago have evolved to provide truly extraordinary capabilities. We have witnessed a metamorphosis of computer-based instruction with the advent of state-of-the-art hardware and software, a transformation that has empowered instructional researchers and designers with unparalleled tools for manipulating instructional strategies.

Yet, we are both the beneficiaries of innovation and the victims of our own ignorance. We have embraced the electronic monolith having neither understood nor tamed its powers: We have a clear sense of what technology can do, but are comparatively naive as to how best to employ it instructionally. We describe the instructional capabilities of the ever-expanding arsenal in largely technological or procedural terms, with little regard for the requirements of effective instructional transactions. The elements we comprehend best are those easiest to characterize through descriptions of features, not those of greatest importance to advance a "science of design" (c/Glaser, 1976).

One important step toward advancing a science of design is to better understand the potential of lesson-learner interaction. Virtually every CBI author has lauded the interactive potential of the computer. Yet apart from relatively primitive questioning techniques, little has been done to exploit the

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instructional potential of varied interaction strategies. The purposes of this paper are to analyze the functions of various interaction methods, to assess critically the psychological requirements of methods, and to describe strategies designed to increase the value of lesson-learner interactions.

Functions of Interaction

Interaction can be thought of as accomplishing one or more instructional functions from simply providing procedural control through causing differentiated levels of cognitive processing.

Confirmation. Confirmation is designed to verify that intended learning has occurred. Confirmation typically focuses on learner attainment of intended lesson objectives. Through confirmation, student progress is monitored, branching is executed, and decisions are enforced regarding subsequent lesson activities. Typically, criterion-referenced questions are embedded during a lesson which require that knowledge or skills be demonstrated.

Pacing. In many cases, interaction is required to control lesson pace. Directions such as "Press the <SPACEBAR> to Proceed," or "Touch the Screen When You're Ready to Answer," require a response to govern when lesson procedures will be executed. Pacing options presumably optimize learning by accounting for varied reading and processing rates.

Inquiry. Student-centered inquiry increases access to lesson support based upon uniquely defined needs. In effect, the responsibility for addressing learning needs shifts from the global, largely mathemagenic strategies imposed by the designer to the metacognitive dictates of individual learners. Inquiries often take the form of help routines, or student-accessible lesson features such as current or ongoing performance updates and lists of lesson sections completed.

Navigation. Navigational interaction is concerned with how lesson sections are executed. Interaction provides the learner with controlled access to defined parts of a lesson. Typically, explicit navigational functions are provided via designer-imposed menu options. In other cases, implicit navigational control is provided as a consequence of learner accuracy, such as in repeating or skipping lesson segments in adaptive branching designs.

Elaboration. Elaboration allows learners to combine known with to-be-learned lesson information. The goal is to encourage students to relate successfully encoded knowledge with current lesson content, thereby both enriching the context for understanding and improving the retrievability of new information through association (Wittrock, 1974). Elaboration is accomplished by strategies such as encouraging the learner to compare and contrast existing knowledge with new lesson content or to combine additional relevant information with current lesson content.

Though useful, these functions have not yet yielded particularly innovative interaction methods. Have we failed to identify functions appropriate to the expanded power of emerging technologies? It seems unlikely that the basic functions have changed appreciably v.ith the advent of sophisticated computer-based instructional systems, but certainly the designer's toolkit has expanded dramatically. Our ignorance is not simply limited vision in functions, but limited understanding of instructional transactions. Interaction methods vary not only according to function, but to response requirements and cognitive complexity as well. Though interaction has been traditionally described in quantitative terms, it is clear that varied instructional transactions must be considered.

THE NATURE OF INSTRUCTIONAL TRANSACTIONS: QUANTITATIVE AND QUALITATIVE VIEWS

In order to understand instructional transactions, the events requiring interplay between lesson content and the learner, it is important to differentiate among various views of interaction. Damarin (in Jonassen, 1988) proposed six levels of interactivity in courseware: watching, finding, doing, using, constructing, and creating. To date, most interactions address only the first three levels, with comparatively little evidence of using, constructing, or creating during interaction. Jonassen (1985) also developed a taxonomy of interactive lesson designs. In effect, each level requires progressively greater grasp of the meaning and conceptual nuances of the instructional content; presumably each then requires qualitatively different interactions.

Most commonly employed strategies support learning primarily via the raw frequency of interaction. Traditionally, drill and practice advocates have espoused the importance of frequent responses to criterion questions, with associated feedback and supplementary instruction and practice as needed. Recently, however, increased interest in methods designed to deepen processing requirements via practice has been noted (see, for example, Salisbury, 1988). In this section, quantitative and qualitative perspectives on such interaction strategies are examined.

Quantitative Views of Interaction

Increased interaction potential has been identified as a fundamental difference between traditional and emerging instructional technologies (Hannafin, 1985). Traditionally, interactions have been operationalized as objective, quantitative entities; instructional interactions were designed to promote "competence." Bork's (1985) recommended interaction every 15-20 seconds during lessons typifies quantitative views of interaction. Such views reflect the fixed interval reinforcement schedules espoused by early behavioral psychologists as well as the recommendations of early programmed instruction theorists (Hannafin & Rieber, 1989a). Likewise, interaction can be viewed quantitatively as the number of questions (or fixed ratio schedule) embedded during an instructional module. Presumably, the increased opportunity to produce task-relevant responses (and presumably to receive feedback) increases in proportion to the number of questions posed.

Other quantitative applications include the emphasis on the so-called "congruence" between the adopted performance standards reflected in objectives and the corresponding implications for the number of assessment (practice as well as posttest) items. Such standards are common elements in the typical instructional systems design (ISD) models in widespread use. [See, for example, Dick & Carey (1985); Sullivan & Higgins (1983).] In such cases, successful responses to a prescribed number of test items that are aligned with the content and standards of the objective are taken as evidence of mastery or competence.

An underlying premise of quantitative views of interaction is that learning is causally regulated by external factors such as response frequency or interval. Quantitative emphases are typically rooted in the same behavioral influences that were applied first to PI and subsequently to early CBI (Hannafin & Rieber, 1989a). Many believe that quantitative methods permit a needed degree of structural and procedural control over lesson design and execution. Students demonstrate objective, tangible evidence of learning in order to assess subsequent instructional needs; consequently, the strategies employed tend to be bounded by the content of the corresponding lesson.

Qualitative Views of Interaction

Qualitative views reflect a stronger cognitive psychology influence, and place a substantially greater emphasis on the learner's role in mediating interactions. Learners are not viewed simply as responders to the externally generated lesson questions or queries, but as controlling the degree to which information is selected, organized, and integrated (Mayer, 1984). In effect, we are concerned with the manner in which instruction fosters cognitive engagement - the intentional and purposeful processing of lesson content.

Cognitive engagement is mediated by a number of factors. It is influenced by the nature of the presentation stimuli, the associated response requirements, and the consequences of the responses (Hannafin & Rieber, 1989b). Responses made with minimal effort offer objective (quantitative) evidence of interaction, but little about the degree to which the relevant concepts have been processed, associations with prior knowledge made, and meaning assigned.

Cognitive engagement is also influenced by the degree to which prior knowledge exists to support the encoding of new knowledge. Though lessons often require a significant degree of new learning, it is neither necessary nor wise to "dis-engage" lesson content from the wealth of available knowledge from which learners can make reasonable associations and inferences, and within which the knowledge is to be subsumed. Activities that cultivate intentional processing by detaching current content from prior knowledge are simply unlikely to engender the kind of assimilation needed to promote meaningful learning (Mayer, 1984).

One aspect of meaningful learning that is generally unavailable for much rote learning is the degree to which insight is gained: Knowledge encoded with little meaning may be retrievable under specified conditions, but typically provides few implications for related knowledge. Meaningful learning, on the other hand, is more completely integrated within existing schemata, presumably increasing both the utility of the knowledge and the potential for transfer to untaught problems.

Clearly, both quantitative and qualitative interaction methods are important. Yet, it seems equally clear that we have relied heavily on quantitative methods to the virtual exclusion of qualitative approaches. We have, for the most part, transferred our largely quantitative notions to the design of emerging technologies. Such designs are successful for training individuals in what to do, but not for gaining deeper understanding or for acquiring the insight necessary for cognitive development. In addition, we have generally failed to alter dramatically the nature of instructional transactions. They remain essentially objectives-driven and convergent in nature, much as they were before the advent of sophisticated computer technologies. As technological capabilities expand, we must likewise expand our notions of interaction if both technological and human processing capabilities are to be optimized.

LOCUS OF INTERACTION STRATEGIES

Designer-Centered Interaction

Designer-centered strategies are generally mathemagenic in nature, that is they are "...concerned with the effective management of instructional processes relevant to the attainment of instructional objectives" (Rothkopf, 1970, p. 326). Activities such as embedding criterion questions and asking the student to list lesson events are examples of designer-centered interactions. Such strategies reflect what must be learned from a lesson, and offer a variety of methods to satisfy the external requirements for which the lesson was designed. In effect, designer-centered interactions are "strategies for the masses," designed to promote cognitive processing specifically related to externally-defined standards.

Learner-Centered Interaction

Generative interactions, on the other hand, emphasize methods requiring greater learner responsibility for assessing learning needs and seeking appropriate information (Wittrock, 1974). Such methods attempt to optimize the meaningfulness and efficiency of instruction by permitting learners to apply metacognitive skills to identify learning needs rather than to adopt activities across learners. Typically, learner-centered methods provide devices such as menus and indexes to permit user-assigned lesson access needed information.

Though the rationale for, and locus of, mathemagenic and generative methods are quite dissimilar, we have done little to maximize the potential of either method in typical computer-mediated instruction. Designer-centered activities do not inherently invoke shallow processing of information, nor do learner-centered methods necessarily deepen relevant processing. There are occasions where strict mathemagenic methods are essential and others where they are neither required nor desirable. For instance, mathemagenic methods are often limited to simple criterion questions with fairly routine and predictable consequences while other substantially more integrative methods exist, such as posing questions requiring the establishment of relationships among various lesson concepts. Likewise, presumed generative methods often assume the form of relatively simplistic menus that simply mirror the lesson structure already established. It is essential that both task and cognitive requirements for various interaction methods be evaluated systematically before appropriate methods can be prescribed.

INTERACTION AND EMERGING TECHNOLOGIES: COGNITIVE REQUIREMENTS

Bork (1982) described three components of interaction: the student's response, the analysis of the response by the computer, and the conditional reaction of the computer based upon the student response. This exchange mirrors the $S \rightarrow R \rightarrow S^R$ paradigms of behavioral psychology: Stimuli are presented in the form of a question, responses are produced in the presence of the controlling stimuli, and reinforcement is conditionally provided in the form of the computer's reaction. Notably present in this definition is an emphasis on physical actions and computer analysis; notably absent is an indication of student processing or purposeful manipulation. These are more or less inferred by virtue of the student responses. In addition, the emphasis on the computer's reaction as a necessary component of interaction has been questioned since it is basically a technological adaptation based upon more fundamental design logic (Jonassen, 1988).

Floyd (1982) defined interactive video as "...any video program in which the sequence and selection of messages is determined by the user's response to the material" (p. 2). Essentially this definition applies across a range of interactive video applications, including, but not limited to, instructional applications. This definition is satisfactory as a starting point, but it must be qualified for instructional applications. The strongest evidence for effective instructional transactions is guided learner mediation of relevant instruction and not simply technologically differentiated presentations. If we produce varied sequences for different learners but fail to stimulate appropriate processing, have we designed interactive instruction? Conversely, if lesson execution is undifferentiated by virtue of student response, should we conclude that the lesson is not interactive instructionally?

For instructional purposes, then, we are less concerned with the physical evidence of interaction than with the cognitive activities that the lesson is designed to engender. For present purposes, effective instructional transactions require a student response bised upon the information, events, or processes depicted via technology and the appropriate cognitive restructuring associated with transaction. The response itself may be purely cognitive, such as the judgements, analyses, and inferences made while reading this article. Unlike Floyd's definition, it is of primary importance that cognitive processing be mediated by the transaction and of secondary importance that lesson execution be differentiated.

Interaction Modes

The vehicles through which cognitive engagement is elicited via emerging instructional technologies have expanded dramatically. Yet, all modes of interaction are not equally effective for all aspects of learning. The physical and cognitive requirements of typing, for example, exist along a continuum based upon response demands that range from single keystroke through complex typing of phrases, sentences, and paragraphs. In some cases, typing provides an appropriate method for interaction; in others, the cognitive and physical requirements of typing have long been known to confound true assessments of learning. In general, the simpler the typing requirements, the less externally valid the response as a measure of interaction; the more demanding the typing requirements, the greater the probability of underestimating true learning.

Touchscreens provide perhaps the least physically demanding and least abstract method of interaction commonly available. They also permit the use of natural visual images in lieu of descriptive text where it is useful to minimize text processing requirements. Whereas touching reduces many of the confounding effects during interactions, it generally limits the nature of the interaction inherently to simple response formats. Low-level touching poses only nominal processing requirements, an advantage where simple effortless procedural control is desired but a disadvantage when the goal is to elicit high levels of integration. Many systems employ devices such as a mouse to permit the student to click on answers, or to "point" to or select from various screen displays. Such devices are slightly more abstract than simply having student touch the same parts of the screen due to the requirement to maneuver across a table-top rather than directly on the image (Hannafin & Peck, 1988). However, many of the same potential limitations exist for pointing devices as for touchscreens. They tend to encourage very simple responses, allowing users to proceed through lessons with minimal mental effort — a phenomenon rarely sought during instructional applications (Salomon & Gardner, 1986).

Attempts to develop "natural language" interfaces, designed to normalize the interaction between user and machine in human terms, have been among the most widely publicized developments in the human factors field. For many applications, the ability to simply state a response appears ideal. Yet voice recognition technology remains frustratingly slow to develop, and has been wrought with unfulfilled promise. Numerous problems persist with regard to user dependence, limitations in active vocabulary, discriminations among homophones, contextual meaning, and colloquial usage to name but a few.

Instead of liberating both designers and students, most voice recognition technologies require interaction that is neither natural in syntax nor typical in form.

Simulators and more recently stimulators (computer-managed working versions of the actual devices to be manipulated) provide a measure of reality unavailable in most lesson designs. Generally, simulators that approximate retrieval contexts during instruction, as well as the performance requirements within the retrieval context, provide the closest match available among the cognitive, affective, and sensory aspects of performance (Hannafin & Rieber, 1989b). Three-dimensional flight training stimulators, for example, are designed to capture as many relevant factors affecting performance as possible. Interactions, therefore, assess not simply knowledge or simplified pieces of a complex task, but performance under circumstances nearly identical to those ultimately required.

Ideally, interactions permit responses that optimize cognitive engagement while matching the performance requirements of a lesson. However, we are typically limited to available input formats. Few systems enable voice input, some support touchscreens, and virtually all provide keyboards. We cannot be certain that the optimal input technologies will be available whenever needed, but we can provide a measure of confidence in the interactions based upon the manner in which the methods elicit, heighten, and sustain cognitive engagement.

EXTENDING INSTRUCTIONAL TRANSACTIONS: STRATEGIES THAT PROMOTE COGNITIVE ENGAGEMENT

Table 1 (see following page) contains a summary of the basic interaction functions, the assumptions inherent in the different interactions, sample interaction methods, and additional strategies designed to heighten cognitive engagement. The following is a brief description of selected engagement activities. The activities include both mathemagenic and generative methods for heightening the degree to which the lesson content is engaged and processing is deepened.

Fault-Free Questions

Fault-free questions cause the student to process lesson content in ways that are unique to the individual. Typically, complex responses are constructed, requiring the interrelating of multiple aspects of a lesson, or the integrating of various lesson concepts within uniquely evolved learner schemata. Responses are not evaluated - cognitively, in fact, the correctness of the response is relatively unimportant compared with the elaboration provided to support encoding and the additional pathways that are created to aid in retrieval (*cf* Wittrock, 1974). Fault-free questions can be mathemagenic in nature, requiring the student to compare and contrast various aspects of the

TABLE 1
Summary of Interaction Functions, Assumptions and Strategies

Interaction Function	Psychological Assumptions	Typical Interaction Strategies	Additional Engagement Strategies
Navigation	metacognitive skills orientation to lesson components	menus option buttons	structure hypertext options ask why section(s) selected
Query	supporting prior knowledge metacognitive skills assimilation of answers to schema	query-structured menu natural language questions options for more information references to related info	ask for predicted answer ask why question is important ask to identify related questions and concepts
Verification	retrieval of encoded knowledge to STM learning strengthened via	embedded questions appropriate feedback for responses conditional branching	ask for confidence estimates ask students to generate questions that assess skills employ real-time responses
Elaboration	supporting prior knowledge strengthened encoding spread of activation among related nodes increased ease of retrieval	"think about" strategies induced introduce relationships with familiar content examples provided	ask for other instances where concepts apply ask for explanations of why answers correct or not employ cooperative dialogue to broaden available input
Procedural Control	metagocnitive skills STM not overtaxed	"Press <SPACEBAR> to Go On..." "Touch the screen when you've seen enough to answer"	ask for summaries in own words ask to record notes or unclear points ask to generate questions

lesson content. For example, students might be asked to compare and contrast the structure of a particular element with one recently presented. The interaction should deepen learning of each element in accordance with lesson objectives, while supplying elaboration that supports the conceptual relationships ofboth. Likewise, fault-free questions can be generative, requiring that uniquely assigned meaning be applied to lesson information. Questions that prompt the student to generate examples to explain a concept to another child, sibling, or colleague require that knowledge be not simply acquired but restructured in ways that promote utility.

Queries

By allowing the learner to pose questions rather than simply to answer them, a fundamental shift in the nature of the instructional strategy occurs. The interaction shifts from being essentially mathemagenic, designer-centered in nature to generative, student-centered in nature. Students can elicit information based upon schema-driven needs-to-know, ensuring greater integration than imposed questions. Queries can be made using fixed choices, where learners select from among defined options (e.g., who, what, when, or where) based upon need to know. Such methods standardize those features of the knowledge base to be made available for student queries. In some cases, questions can be generated more uniquely by individual students without the obtrusiveness of the supplied structure. Student queries may take the form of keyword searches, or in certain cases may query more deeply through a series of clarifying comments and prompts.

Real-Time Responding

Real-time refers to the ability to interact with phenomena as they occur. Real-time responding allows the element of time, as either a critical factor in assessing performance or as a motivational device, to be factored into interaction methods. In some instances, real-time interaction is integral to successful performance, such as simulated engine stalling during flight training. In others, however, they simply permit students to control events generatively as they unfold during lesson execution. For instance, students might be told to stop the lesson as soon as sufficient information has been obtained to support a differential diagnosis during an instructional sequence depicting patient case history and medical symptoms. The added element of real-time helps to create a "living" instructional environment, where students respond to actual events as they unfold, and not merely to descriptions of the events.

Notetaking

Some lessons encourage students to elaborate via electronic notetaking. Peck and Wambaugh (1988), for example, developed a simple mouse-based system for both selecting notes from the script of an interactive video segment and for annotating both lessons and notes. Again, such methods can be primarily mathemagenic or generativ - in nature. The student may selectively record verbatim transcripts to support learning of particular objectives, or may elaborate lesson information with individual analyses, anecdotes, and other learner-generated comments. The system broadens potential interaction to permit inspection (and recording) of key points normally presented only aurally, to locate key points in the notes or script, and to accumulate and manipulate notes via word processing software. Such methods open a wealth of interaction alternatives, much of which have a considerable empirical foundation in non-electronic form.

Predicting I Hypothesizing

Salomon and Gardner (1986) have cautioned that mental effort is mediated by perceptions of self efficacy and the perceived demand characteristics of the medium. In effect, it is often necessary to structure activities to increase the demands of the task in order to ensure high levels of cognitive engagement. Causing students to make and justify predictions during a lesson has important consequences. Students build an anticipatory set of expectations regarding subsequent events. In effect, students generate propositions, which in turn organize a schema. New information can then be evaluated relative to predictions and not only presented. Such methods are useful for a variety of learning tasks, including a good deal of scientific and mathematical content as well as prose and social studies.

Hypertext

Hypertext refers to text access methods that permit user-assigned pathways through instructional content. Hypertext interactions may range from directly addressing given words or concepts within a lesson to navigation through the supplied structure of the knowledge. Jonassen (1986) described three levels of hypertext: Node-link, structured, and hierarchical. Node-link essentially provides random access among all nodes within the available content, such as through the use of indexes, elaborate menus, or direct queries by the student. Structured hypertext permits access across sets of logically organized nodes, such as through top-level access to defined lesson segments or activities. Hierarchical hypertext further prescribes access according to hierarchical relationships presumed within the lesson. Control decisions could be based upon making the content structure apparent to the student or imposing starting points within nodes based upon the presumed hierarchical structure of the task or lesson.

Cooperative Dialogue

Recently, considerable work has been published concerning the utility of cooperative learning techniques in computer-mediated learning environments. [See, for example, Carrier & Sales (1987); Johnson & Johnson (1986); and Mevarech, Stern, & Levita (1987).] Cooperative interaction, featuring groups of two-to-four students, can provide an unusually rich method for promoting cognitive engagement. Typically, one-on-one CBI is limited only to the perspectives provided by the computer and those introduced by the student. The potential for elaboration, competing perspectives, and plausible alternatives, therefore, is necessarily reduced. Cooperative learning, however, provides a variety of techniques designed to stimulate dialogue, provide needed explanations and supporting rationale, and to otherwise elaborate basic content. In addition, such methods help to overcome many of the logistical problems resulting from insufficient numbers of computers.

CLOSING COMMENTS

The quest for a meaningful perspective from which to understand and guide interaction in the face of rapidly evolving technology is no small matter. We cannot be certain of the form technology will assume in the future, but it seems certain that it will continue to change. It is no longer adequate to simply describe interactions in terms of either the input technology employed or the physical characteristics of the responses made - these will certainly change over time. We need a richer understanding of the psychological requirements associated with instructional tasks and responses, and a sense for how to extend design science beyond the methods that have evolved through the years. If we do not acquire a richer understanding, then we will fail to understand how best to utilize the capabilities of future technologies; if we do not understand the capabilities of the technologies, then we will have doomed the potential of such developments by our ignorance.

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