

Perspectives on the Design of Interaction Strategies

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14. ABSTRACT While few question the importance of active responding for effective computer-supported learning, insufficient attention has been directed toward understanding the implications of contemporary research and theory for the design of interactions. With technologies of vastly expanded capabilities, the potential for interaction design has expanded still further. What kinds of interactions should be cultivated? Are these strategies truly unique for specific technologies, or are they generalizable? How are differences inherent in diverse learning tasks accommodated in the design of interaction strategies? Can these guidelines be derived, based upon existing research and theory, that emphasize durable technological attributes rather than transitional media forms? In this paper, several perspectives on interaction and computer technology are presented and critically analyzed.					
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ABSTRACT

While few question the importance of active responding for effective computer-supported learning, insufficient attention has been directed toward understanding the implications of contemporary research and theory for the design of interactions. With technologies of vastly expanded capabilities, the potential for interaction design has expanded still further. What kinds of interactions should be cultivated? Are these strategies truly unique for specific technologies, or are they generalizable? How are differences inherent in diverse learning tasks accommodated in the design of interaction strategies? Can guidelines be derived, based upon existing research and theory, that emphasize durable technological attributes rather than transitional media forms? In this paper, several perspectives on interaction and computer technology are presented and critically analyzed.

Perspectives on the Design of Interaction Strategies

Few contemporary researchers, theorists, or practitioners question the importance of interaction for computer-aided learning. Interaction generally refers to purposeful, overt responses made by an individual during instruction and the consequences of the responses on lesson activities, content, or sequence. Interaction involves conditional two-way exchanges between a learner and a learning system. Each exchange has the potential to alter subsequent transactions based on the intentions of the learner and/or the requirements of the learning system.

Several views of interaction have been espoused in the computer-based learning field. Bork (1982), for example, described three basic components: student response, computer analysis of the response, and the computer response to the input. Heinich, Molenda, and Russell (1989) stated that, for interactions to occur, learning systems must permit some physical activity, such as a typed response, which subsequently alters the sequence of presentation. A similar definition was proposed by Floyd (1982), who emphasized that presentation sequences in interactive video must be altered by user response. Each of these views emphasizes physical responses and differentiated lesson execution.

While there is consensus as to the importance of interaction during learning, research has largely failed to generate reliable, empirically-referenced interaction strategies. Insufficient attention has been directed toward understanding the implications of available research and theory for the design of interactions. With the emergence of technologies of vastly expanded capabilities, the potential for interaction has expanded dramatically. What kinds of interactions should be cultivated? Are these strategies truly unique for specific technologies, or are they generalizable? Can guidelines be derived, based upon existing research and theory, that emphasize more durable technological attributes? How are differences in learning tasks addressed in the design of interaction strategies? In this paper, several perspectives on interaction are presented and critically analyzed.

PERSPECTIVES ON INTERACTION

Three perspectives will be considered: operational, functional, and integrated.

Operational Perspectives

Operationally, interaction includes four elements: a physical response, feedback based on the response, a mental task, and symbols or codes used to convey information.

Physical Response. The physical response has been the cornerstone of traditional CBI (Computer-Based Instruction) programs. Lessons were designed to branch differentially based upon the overt responses (e.g., typing, touching a screen) made by learners during instruction. More than other single features, response-differentiated branching distinguished computer-supported instruction from its noninteractive predecessors. Early applications, consequently, emphasized frequent physical responses to embedded criterion questions, and differential branching based upon the accuracy of the responses.

Interaction strategies differ in the complexity of the physical responses. Fitts (1964) maintained that the time required to create associations between new and old information, and to develop appropriate responses by correcting movement errors, is contingent on the complexity of the skill: the more complex the skill, the more time required to strengthen associations. Holding (1989) noted that many complex responses, such as playing the violin, are continuous and involve substantial fine motor control. Other simple motor responses, such as shot-putting, are more discrete physical tasks, but involve significant gross motor control. Although both responses are physical, they are quite distinct in nature.

Complexity can also refer to the number of simultaneous responses that must be elicited. In some cases, it may be desirable to elicit a series of simple responses which can be subsequently chained to form a complex physical response. Mané, Adams, and Donchin (1989), for example, maintain that in learning tasks involving a massive body of knowledge of graduated difficulty, a part-whole strategy may best facilitate learning. In their experiment, subjects using a part-task strategy performed significantly better than those using

adaptive strategies. Apparently, the breakdown of the more complex task enabled participants to respond to smaller pieces of the complex task, making them easier to assimilate. Wickens (1989), on the other hand, reported that adaptive training methods are often most appropriate for tasks involving complex physical responses. Such training simplifies the task itself without altering the nature of the desired physical response while progressively adapting the complexity of the task requirements. Wickens suggested that many complex learning tasks (tasks requiring more than one response) are not only facilitated by adaptive training, but may actually be hindered by part-task training.

Response frequency is also a topic of considerable interest. Some have advocated frequent interactions both to control the amount of information to be addressed and to maintain active learner engagement. Bork (1982), for example, recommended that responses should be elicited every 15 to 20 seconds. Others have estimated frequency requirements in terms of conceptual density of the lesson, the individual's prior knowledge, and the cognitive load associated with the task (Hannafin, 1989). Generally, lessons that are conceptually dense or high in cognitive processing requirements require more frequent interactions than those less densely or of lower associated cognitive load. Likewise, more frequent interactions are often indicated for individuals with limited prior knowledge.

There is ample evidence that physical responses, as essential to working definitions of interaction, are both misunderstood and often unnecessary. Although interaction is a cornerstone of early views of learning via computers, there still exists a remarkable gap in our understanding of the role of complexity. It is clear that the nature of the response—its relationship to criterion tasks and complexity—affect greatly how, or if, learning will occur. At the same time, considerable evidence exists suggesting that physical responses *per se* are not the most essential element of successful learning, and may be unnecessary or counterproductive at times.

Feedback. Interaction strategies also vary as to the type, amount, frequency, and placement of feedback. Though feedback generally subsumes the function of reinforcement, it also provides information

which can be used to deepen, modify, or qualify understanding. As a reinforcer, the feedback increases the probability of a desired (correct) response to the lesson content depicted.

Traditionally, feedback and physical responses have been interdependent: each directly influences the other. Conventional notions of interaction, therefore, require that a physical response be generated in order to differentiate subsequent feedback. More recently, however, the concept has been broadened. Adaptive feedback, for example, may be influenced by cumulative response history, unique individual historical data, or even the failure to respond (Tennyson, Christensen, & Park, 1984). Contemporary views of feedback involve not simply strengthening specific associations, but providing strategic knowledge and affective support as well (Hannafin, Hannafin, & Dalton, in press).

The timing of feedback has also been studied. Computer technology has been hailed for its capacity to deliver immediate feedback to students. Schimmel (1988), for example, maintained that the greatest meaning can be extracted when the feedback follows immediately after the learner's response. Others (e.g., Charp, 1981; Dalton & Hannafin, 1984) have likewise emphasized the importance of immediate computer feedback to student responses. Presumably, immediate temporal contiguity between the response generated during the interaction and the associated feedback improves the probability of forming the desired associations.

Though initial views emphasized immediacy of feedback, subsequent research emphasized the importance of associated cognitive processing and the individual's response confidence (Kulhavy, 1977). Postponing feedback during interactions permits individuals to purge unimportant or poorly processed information from working memory facilitating the so-called delayed retention effect (Surber & Anderson, 1975). Brief delays may also minimize the influence of false-positive feedback resulting from chance guesses. Hannafin (1989), for example, noted that brief delays often facilitated learning by allowing subjects to self-correct or affirm responses through the induction of new knowledge.

There are predictable operational limits to the benefits of feedback. Schaffer and Hannafin (1986) maintained that performance increments associated with interaction and associated feedback during interactive video instruction reach a ceiling after which little value is added. Learners reach a saturation point, where additional knowledge cannot be derived via increases in response-differentiated feedback. Typically, this point is encountered when the complexity of the learning task itself limits feedback's value, as in cases where individuals simply cannot process the additional information successfully due to a weak or deficient grasp of basic supporting concepts.

In summary, independent of the perspective taken, the value of feedback varies based upon learner, task, and prior experience. The probability of eliciting a desired response in the presence of a particular stimulus depends upon whether the individual's feedback history was punishing, reinforcing, or nonreinforcing (Klein, 1987): Feedback, like reinforcers, must be valued by the learner to be effective. Since information perceived as unimportant is unlikely to be processed very deeply (Hannafin & Hooper, 1993; Keller & Burkman, 1993), the perceived relevance of feedback is integral to effective interactions. The importance of feedback has not been seriously disputed; the nature of feedback, however, can vary widely.

Mental Task. Neither physical responses nor feedback, traditionally defined, is always needed or desired. Research in observational learning indicates that physical responses are not necessary for learning to occur (c.f. Bandura, 1986). Much of what is learned by children, for instance, is modeled vicariously with considerable mental processing but no associated physical responses. Presumably, learners perform certain cognitive operations that increase the memorability of knowledge. Some students might, for example, recall certain childhood events vividly in a sort of "flashbulb memory" (c.f. Brown & Kulik, 1977; Neisser, 1982) whereas others might recall nothing under identical circumstances. Over time, physical responses may strengthen knowledge initially acquired vicariously, but it is often not essential to either initial acquisition or

retention. Alternatively, knowledge may be strengthened considerably by purely cognitive responses that help to shape rich knowledge structures.

In certain cases, physical responses may actually inhibit learning. Baggett (1988) suggested that learning is not necessarily facilitated, and may occasionally be hindered, when physical responses are required. In her experiment, a series of treatments were administered providing differing levels of traditional (on-terminal) and hands-on (off-terminal practice) interactions related to the building of given objects. Some participants received only the basic information without either traditional or hands-on interaction, while others received combinations of on-terminal and/or hands-on practice. Baggett concluded that participants who received off-terminal practice were less efficient in constructing the objects than were those receiving only the on-terminal interaction. Additionally, no significant performance differences were observed between the non-interactive, passive response group and the interactive treatments. Apparently, increases in the physical response requirements actually hindered performance.

Interaction cannot be satisfactorily characterized strictly in terms of mediating stimuli and overt responses. Meaningful learning involves encoding, storing, and retrieving knowledge. Interactions, therefore, must support the varied ways in which individuals make their knowledge meaningful. In effect, for interactions to be effective, they must emphasize needed mental, rather than physical, processes. While physical responses may help to elicit relevant mental responses, they in no way ensure them. Cognitive response requirements, therefore, are of substantially greater significance than physical response requirements.

How, then, can mental resources be managed to promote needed cognitive processing? There are many views about the nature and dynamics of information processing. Most views assume limited capacity, making it essential that interactions aid the learner in selecting and processing relevant information in appropriate ways. A basic tenet is that a series of perceptually-driven transformations is made on environmental stimuli (Best, 1989), that is, stimuli are selectively processed, elaborated, and encoded within complex schemata

(Gagné, 1985). Meaningful learning, consequently, may be defined as the degree to which learners integrate new with existing knowledge and restructure their schemata accordingly.

Cognitive requirements also range along a continuum of complexity based upon the learners related knowledge and the cognitive demands of the task. For novices, seemingly simple overt actions may have significant cognitive requirements (Solso, 1991). In physics, for example, predicting a value which best approximates the force of one object on another requires considerable estimation, computation, and comparison. The physical response (entering a numeric value) is quite modest, but the associated cognitive requirements are substantial for the novice. In other cases, however, relatively complex physical responses are required for tasks requiring only nominal cognitive processing. Some tasks, such as making a left-hand turn across traffic in an automobile, are largely automated and can be completed with little conscious effort by most seasoned drivers.

Symbols and Codes. The nature of the information (e.g., points, alphanumerics, frequencies, colors) presented to the learner can be thought of in terms of symbolic codes (Goodman, 1976; Salomon, 1976, 1979). Technologies vary in the symbolic codes they support, and individuals demonstrate varying degrees of learning when employing these technologies. The success of interactions, therefore, is influenced by both the availability (technology dependent) and use (design dependent) of these symbols and codes.

Interactions can be designed to vary both the number and type of available symbols used to convey information. According to the dual code hypothesis, information can be coded in verbal (meaning), imaginal (pictures), or both verbal and imaginal codes, and stored in either or both systems (Paivio, 1971). These representations retain dominant properties such as shape, size, and detail. According to Paivio, memory functions best when both semantic and image representations can be cross-referenced. Interactions that support multiple, related representations provide complimentary support for both encoding and retrieving.

Another difference among interaction strategies is the relationship between the external code used during instruction and the internal code used by subjects. Salomon (1979) contends that learning is influenced

to the extent that the external symbol system employed during instruction is compatible with the internal representations of the learner. In some cases, interactions featuring visual symbols such as illustrations may help to organize a host of semantic concepts; in others, verbal information might be necessary to understand relationships coded visually.

Considerable research has been published on the effects of compatibility among presentation codes suggesting that poorly selected codes can be detrimental to learning. Stroop (1935), in his classic study, found that subjects took significantly longer to read words referring to a given color (e.g., "blue") but written in a different color ("blue" written in red ink) than when the color and term were identical. Decoding the verbal codes (words) was complicated by the incongruent presence of image (colors) codes. More recently, Cowan and Barron (1987) found that subjects who listened to random color words performed poorer than those who listened to non-color words or music. Students who listened to nothing while identifying color words performed best, suggesting that learning is hindered to the extent that codes conflict.

Similar findings have been reported for contextual learning tasks. Pictures have been found to support learning when they overlap with textual content, are congruent with evolving semantic meaning, and provide either redundant information or organization of textual content (Haring & Fry, 1989). Hannafin (1988) studied the effects of pictorial, oral-aural, and combined presentation codes on the learning and mislearning of explicitly depictable (concrete) versus difficult to depict (abstract) lesson content. Concrete concepts were learned comparably via either visual or verbal presentations, but pictures alone were ineffective in conveying abstract lesson concepts. Combinations of pictures and oral-aural, however, yielded both the greatest learning, and the fewest misunderstandings, of both concrete and abstract content.

Research suggests that the codes used during interaction can either facilitate or hinder learning. Learning will be facilitated to the extent that the information supports, and does not interfere with, appropriate

processing. When very abstract codes or a poor combination of codes have been chosen, the ability to process the information decreases.

Functional Perspectives

Functional views emphasize how interaction is used, and the varied roles it plays in learning systems. Hannafin (1989) identified five functions of interaction: supporting lesson pacing, providing the opportunity to elaborate, confirming the accuracy of responses, navigating within or across lessons or lesson segments, and supporting inquiries from students.

Pacing. Pacing refers to the metering of information as students move through a lesson or activity. Pacing is more often related to lesson flow than to the achievement of instructional objectives. Although metacognitive judgements are presumably made by individuals, both the nature of the physical response and the associated cognitive requirements tend to be minimal.

Simple pacing interactions often take the form of instructions to "press any key to continue." It serves to meter the rate of information flow according to individual dictates, allowing the student to reread, study, or release information from view. However, pacing interactions may also affect the start, stop, and suspension of ongoing information flow, as individuals seek to speed up, slow down, or terminate lesson activities.

Elaboration. Another function of interaction is to encourage elaboration on the information presented. Elaboration strategies may or may not require physical responses, depending on the nature of the task and the biases of the designers. Students might, for example, be encouraged to either consider mentally how a new concept shares similarities with previously learned concepts, or type a brief response that relates lesson information to individual experiences, or both. Where no physical response is required, students may be asked to focus attention on specific issues and generate meaningful relationships that are, hopefully, congruent with the instructional objectives.

With emerging technologies, the range of elaboration options is quite diverse. Elaborations might be accomplished via embedded notetaking tools which permit the individual to write ideas and thoughts during the lesson. Interactions can also permit access to supporting on-line resources and utilities through which the student can seek additional information related to the topic at hand. Finally, annotation tools might be provided which permit the individual to make notations within computerized lessons.

Confirmation. A third function of interaction is to confirm the accuracy of student responses to problems posed during the lesson. In many cases, students respond to textual questions in the form of a simple multiple choice keystroke or short typewritten answers. The response is subsequently evaluated against certain established criteria, and the lesson proceeds accordingly.

However, confirmation can also be provided during real-time, natural image simulations such as emergency room simulations. Students might recommend particular procedures and examine the impact of the intervention. Alternatively, students might be expected to respond in ways identified as "ideal" as in expert-referenced problem solving. The interaction provides confirmation of the accuracy (or desirability) of student knowledge.

Navigation. Interaction can also be used to support student navigation during a lesson. Navigation interactions are often manifested via menu systems, either explicitly presented or implicitly defined. On one hand, lessons might be explicitly structured into sections (introduction, rules, examples), or supporting activities (glossaries, help) which provide on-demand access to available activities. On the other, control can also be accomplished by selecting and touching a given area of a monitor, where navigation logic is implicitly defined. Hypertext, nonsequential access to educational resources, poses unique interaction problems. Hypertext may be structured in a more or less explicit manner, or can be navigated dynamically. Structured links can be created among all individual elements contained in the lesson, structured selectively based upon particular linking paradigms (e.g., hierarchies, nodes), or defined dynamically by the interactions of individual users.

Inquiry. Inquiry emphasizes methods that permit the user to directly address the contents of a lesson, system, or knowledge base. In some instances, the inquiry might be related to individual performance information, such as the status of test performance. However, in other, more sophisticated circumstances, the individual might engage in a dialog such as with a medical expert system designed to assist in diagnosis. Through inquiry, the student might be able to trace the etiology of a disease or recommend treatment. In both cases, the individual assumes the initiative to address the system and for structuring the nature of the inquiry.

Open-ended inquiries are perhaps the most difficult interactions to accommodate. The system itself may strictly structure the available inquiry options such as a series of structured queries within which the student must respond. On the other hand, some systems rely on parsing algorithms to interpret inquiries. The systems possess a limited capacity to reconcile ambiguities and interpret the key elements of an inquiry in order to supply the desired information.

Integrated Perspectives

Clearly, there are different types of interaction, each of which varies not only according to the function of the interaction but to the nature of the learning task. Each has different cognitive requirements, employs varied response formats, provides feedback of different kinds, and uses different combinations of symbols and codes. Invariably, the manner in which the operational elements are implemented varies dramatically both within, and across, various functions.

At the center of this problem may be inadequate definition. Traditional definitions (i.e., physical response, feedback, mental response) emphasize observable elements, but fail to reflect the presumed cognitive consequences. Using traditional definitions, all elements can be provided, yet yield none of the desired cognitive activities. Alternately, a few elements might be provided, yet yield exceptional learning. Working definitions of interaction, therefore, must focus on cognitive requirements and consequences.

From an integrated, emerging technology perspective, interaction can be defined as an educational process designed to assist learners in acquiring or restructuring knowledge by initiating or mediating an investment of effort and/or brokering one's cognitive resources. An important aspect of this definition is that a physical response, by itself, is neither a necessary nor sufficient condition for interaction. The critical factors are intentionality in design, investment of effort by the learner, and associated effects on knowledge acquisition and restructuring. Still, while interaction necessarily involves a cognitive rather than a physical response, the importance of physical responses cannot be easily discounted in eliciting or guiding cognitive processes. Learners are required to invest effort differentially, so the degree to which physical responses engender requisite cognitive processing is critical.

Interaction tasks are defined in terms of physical, or overt, responses deemed relevant to better understanding the skills or concepts at hand and the cognitive elements which, though essential, are frequently underemphasized.

Response Requirements: Cognitive. Cognitive requirements emphasize the individual's task in processing and understanding. This dimension reflects certain aspects of Salomon's (1981) concept of Amount of Invested Mental Effort (AIME). Salomon defined AIME as the number of nonautomatic elaborations applied to a unit of material. In the present context, mental effort refers to the learner's conscious efforts to process lesson information purposefully. In general, increases in purposeful mental effort should improve learning while decreases should hamper learning in proportion to the effort invested.

However, simply increasing the amount of purposeful processing activity does not ensure successful learning. Norman and Bobrow (1975) examined factors that influence cognitive processing, and distinguished between data-limited and resource-limited processes. In the present context, data-limited processes are those in which the investment of additional processing resources, by itself, does not improve learning. Data limitations derive from two basic sources: external and internal. Some data-limited processes indicate individual

knowledge deficiencies (internal). For example, despite good external organization, lesson content may be too advanced or complex, or the learner may lack the requisite knowledge or skills. Additional effort will not likely improve learning, and may result in considerable frustration. Other data limitations might reflect deficiencies in the organization of to-be-learned content (external). Resource-limited processes are based upon strategic manipulations of the data themselves and are more amenable to improvement through additional effort.

Some lessons are poorly organized or presented, obscuring important information and complicating the task for otherwise capable learners. Resource-limited processes, therefore, are influenced by the ability of the learner to invoke (internal), or the learning system (external) to supply, activities that aid the learner in processing lesson content. In some cases, individuals may possess content-free strategies, such as spontaneously generated individual elaborations, to remember essential lesson information. In other cases, the system may prompt the individual to form mental images. Resource-limited processes improve performance to the extent that strategies are appropriate for the processing requirements and they do not compete for the same cognitive resources. Learning is stimulated when individuals both have the required resources *and* invest the effort necessary to allocate their resources appropriately. For interaction purposes, the merging of the mental effort and multiple resource perspectives yields four possible scenarios.

Scenario 1: The student has neither access to "clean" data, possesses the resources available to process data, nor invests mental effort in the task. Of particular interest are learner resource deficiencies. This is evident in many disenfranchised adolescents, who demonstrate significant achievement deficits and acutely negative attitudes towards learning. Students lack not only the basic data (knowledge) required to process lesson content, but are also disinclined to invest the mental effort required to overcome the deficits. In certain cases, the data themselves are sufficiently "noisy" as to render them uninterpretable, and learners possess neither the inclination nor the ability to understand them. The potential for interaction to support learning is, of course, weakest under these circumstances.

Scenario 2: The student neither possesses, nor has available, the required resources but attempts to invest mental effort. This situation arises with learners who invest considerable energy trying to understand, but are unable to comprehend due to limitations in either the enabling knowledge or the strategies required to process the information. When students attempt to understand a severely distorted message (e.g., an overseas radio transmission), they might invest considerable effort to interpret the poor data. Unless the message retains sufficiently intelligible information, it is uninterpretable. In this case, the invested mental effort will yield comparatively little value, and may eventually lead to frustration.

Scenario 3: Students possess the required resources but do not invest the mental effort. This is typically seen among bright, underachieving students. They often possess both significant related knowledge and complimentary learning strategies, but fail to invest the effort required to comprehend. Learning of otherwise intelligible information would not be expected since, while the data are appropriately organized, the willingness to engage the material is lacking.

Scenario 4: Learners have the resources available and invest sufficient mental effort to appropriately process the data. This is the ideal scenario, and one which interactions are designed to promote successful engagement. Lesson data are appropriately organized, learners engage lesson content appropriately and apply both previous knowledge and metacognitive strategies to the learning task.

Response Requirements: Physical. Individuals routinely act in observable, physical ways that do little to stimulate, clarify, or strengthen understanding. Everyday examples of routinized "passive-active" responding include switching TV channels via remote devices as well as automated processes such as riding bicycles. While some cognitive activity is involved in each of these examples, both the physical responses and associated cognition are largely automatic in nature and require minimal investment of mental effort. For physical responses to be integral to the success of the interaction, they must cause individuals to alter their processing activities and effort in meaningful ways.

Physical responses can be either purposeful or nonpurposeful. Purposeful responses reflect learner decisions to consciously examine associated consequences (cf Hannafin, Hannafin, & Dalton, in press). A typed response to an embedded question, for example, generally indicates awareness and intentionality by the learner. It is the product of active processing and construction of a particular response. Nonpurposeful responses represent little or no active processing by the learner. In some cases, they are largely unconscious, "mindless" responses, such as thoughtlessly scanning a magazine or turning pages with little or no active mediation.

The relationship between the physical response and mental effort is bidirectional. Mental effort may be the impetus for, the product of, or both the impetus for and product of physical responses. Upon observing that a simulated airplane will crash if its attitude is not corrected, for instance, learners attempt to adjust the flight plane of the aircraft. Mental effort provided the impetus for a purposeful physical response. In contrast, responses themselves, whether intentional or unintentional, may supply the impetus for subsequent processing activities. An individual might absentmindedly and inadvertently break a flask of highly corrosive acid, requiring the rapid development and implementation of a plan to control the potential damage. The physical response, in this example unintentional, triggered associated cognitive activities.

As noted previously, physical responses do not always support learning and may on occasion hamper learning (Baggett, 1988). From multiple resource and mental effort perspectives, physical responses hamper learning when they compete for resources required to successfully process knowledge (Gopher, Weil, & Siegel, 1989; Wickens, 1992). Important data may go undetected due to response requirements that misdirect attention (e.g., responses focusing on unimportant information or concepts; interruptions in continuity) or significantly mismatch lesson versus actual performance requirements (e.g., complex typing requirements for simple response needs; simple touchscreen responses approximating the tactile resistance of turning an automobile). Cognitive resources may become overtaxed by disproportionately high processing requirements associated with

the physical response itself (e.g., complex, nonessential procedures for responding). Conversely, physical responses prove beneficial when they assist in directing attention, provide complementary stimulation or information to the individual, supplement existing lesson resources with unavailable information, meter the flow of information, illustrate and clarify sequential concepts, and approximate the sensory aspects of a task. Finally, while physical responses may initially interfere with learning, they often increase in effectiveness through usage. As the physical response becomes automatized, competition for resources is reduced thereby freeing the individual to process information more effectively. The procedural requirements for complex computer simulations may require effort which initially limits the cognitive resources available for learning lesson content. As individuals become familiar, however, the resource requirements decrease while the productive value of the physical response increases.

Design Factors: Quality. Quality of interaction refers to the richness and appropriateness with which resources are invested, and the role of both cognitive and physical responses in promoting relevant processing. It emphasizes the ability to invoke those cognitive processes most beneficial to the individual. As a rule, increased interaction quality improves learning.

Low-quality interactions promote cognitive activity that is insufficient, ineffective, inefficient, inappropriate, or counterproductive to learning. The interaction fails to engage the learner cognitively in appropriate processes. Often the interaction causes the individual to attend to unimportant or irrelevant information. Perhaps the interaction activities are not well suited to the types of processing desired, causing the individual to misallocate cognitive resources. In either case, the interaction strategy failed to stimulate high-quality processing.

Quality can be further differentiated according to different perspectives: designer versus learner. Value may be assigned by the designer based upon external factors such as the presence of multiple, complimentary coding mechanisms or the integration of apparently related concepts. Alternatively, quality is interpreted by

the individual based upon internal factors such as the perceived relevance of the interaction. To the extent that the criteria of both internal and external sources are addressed, interaction strategies should be of high quality.

Quality is the primary factor affecting the value of physical interactions. Two qualitative variables influence the processing of knowledge resulting from a physical response: the complexity of the response and the specificity of the resulting information. As noted previously, complex responses initially require significant cognitive resources in order to "understand" and meet the response requirements. Considerable mental, and occasionally physical, effort must be expended in order to automate basic physical and cognitive responses. In some cases, adaptive methods are designed to adjust the conceptual difficulty of a task while holding the basic response requirements more or less fixed. In other cases, complex tasks are parsed into smaller units, such as just-in-time training and part-task training, and progressively "assembled" into more complete units of performance. This allows learning by metering cognitive resources and mental effort into manageable chunks that are progressively combined to enable more complex performances.

Design Factors: Quantity. Quantitative factors refer to how much physical (e.g., frequency, demands, timing, and density of responses) and cognitive (e.g., number of elaborations, covert repetitions, amount of processing) responding is fostered during interaction. Quantitative views emphasize factors such as frequency, motor requirements, and temporal requirements and their corresponding influence on mental effort and cognitive processing. Generally, as the quantity of task-appropriate interactions increases, the number of opportunities for producing physical responses, investing mental effort, and utilizing processing resources increases.

As noted previously, quantitative views have dominated traditional notions of interaction. It is conceivable that increases in the quantity of responses will elevate mental effort and alter the investment of cognitive resources, but the nature of the processing activities may not support learning. Depending on the quality of the interaction, mastery of instructional objectives may or may not be facilitated. If the quality of the interaction was good (encouraged appropriate investment of mental effort and cognitive resources), learning

should increase as the quantity of interaction increases. If the quality of the interaction was poor, however, learning should not increase but will often decrease as quantity increases. Responses may be mismatched with the learning task, the physical or cognitive demands may overtax the individual's processing capacity, the responses may compete for the same resources, or the activities may promote the use of multiple, non-complementary, processing resources. The effort may be misdirected, and the resources poorly allocated.

Consider quantity from multiple resource and mental effort perspectives. If the interaction invokes identical mental processes, then increases in quantity provide additional directed processing related to the task. Quantity serves to improve the automaticity of the learned skill. To the extent that lesson information has not been completely processed, resources would continue to be effectively allocated to the task. However, as learners approach mastery, less "new" information exists to be processed via interactions. If, during subsequent interactions, learners continue to invest effort and invoke resources as initially done, effort and resources would be ineffectively utilized. Fewer resources would be available for deepening understanding, and the interaction would be inefficient. Benefits would continue to diminish until either new information was presented or until mental effort and cognitive resources were focused on different tasks.

If the interaction invokes cognitive processes that are nonrepetitive but complementary (i.e., different mental processes are employed for various aspects of the task), then interaction quantity functions to develop rich knowledge structures. Effort is sustained by the diversity of the activity, and resource-based processing mechanisms can be utilized accordingly. Lesson content and concepts are processed in complementary ways to provide multiple perspectives.

If, however, interaction fails to provide sufficient opportunity for processing guidance or exceeds the individual's available processing resources, then learning will be impaired. Mental effort may be sufficient, but data, resource, or both data and resource limitations, minimize the effectiveness of the interaction. When

provided with too little interaction, individuals often fail to master or automate knowledge and skills. The production value of the resulting knowledge is inherently limited.

Clearly, the issue of "how much" is integral to interaction strategy design. However, quantity per se provides a limited and often misleading perspective. Simply increasing the frequency or physical demands of a response does little to promote learning. Instead, the role of quantity is jointly mediated by both cognitive and physical response considerations, and by the qualitative value of the response itself.

CONCLUSIONS

This paper provides a brief summary and implications of several perspectives on the design of interaction strategies. Clearly, while operational and functional perspectives are useful by themselves, each is somewhat incomplete both in terms of empirical rooting and capacity to guide interaction design. The integrated perspective provides a more inclusive and connected method for examining the psychological aspects of interaction design while reflecting the more pragmatic aspects of both the operational and functional specifications of the system. Comprehensive approaches, such as the integrated perspective, should aid designers in designing richer and more empirically supportable interaction strategies.

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