Introduction to the Model of Hierarchical Complexity

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The Model of Hierarchical Complexity presents a framework for scoring reasoning stages in any domain as well as in any cross cultural setting. The scoring is based not upon the content or the participant material, but instead on the mathematical complexity of the hierarchical organization of information. The participant's performance on a task of a given complexity represents the stage of developmental complexity. This paper presents an elaboration of the concepts underlying the Model of Hierarchical Complexity (MHC), discusses the range on applications that have been researched to this point, and summarizes the papers in the rest of the special issue.

This special issue presents a collection of papers based on the Model of Hierarchical Complexity, a non-mentalistic model of developmental stages. The model is different from previous proposals about developmental stage (e.g., Inhelder & Piaget, 1958). Instead of explaining behavior change across age as being due to the development of mental structures or schema, this model instead posits that task sequences form hierarchies that become increasingly complex. Because less complex tasks must be completed and practiced before more complex tasks can be acquired, this accounts for the developmental changes seen. Furthermore, previous theories of stage have confounded the stimulus and response in assessing stage by simply scoring responses and ignoring the task or stimulus. The Model of Hierarchical Complexity separates the task or stimulus from the performance. This short introduction to the special issue will describe this model in some detail, as each of the papers to follow will rely on it.

Tasks

One major basis for this developmental theory is task analysis. The study of ideal tasks, including their instantiation in the real world, has been the basis of the branch of stimulus control called Psychophysics. Tasks are defined as sequences of contingencies, each presenting stimuli and each requiring a behavior or a sequence of behaviors that must occur in some non-arbitrary fashion. In the present use of task analysis, the complexity of behaviors necessary to complete a task can be specified using the complexity definitions described below. One examines behavior with respect to the analytically known complexity of the task.

Model of Hierarchical Complexity

The Model of Hierarchical Complexity (MHC) developed by Commons (Commons, Trudeau, Stein, Richards, & Krause, 1998) quantifies the order of hierarchical complexity of a task based on mathematical principles of how the information is organized (Coombs, Dawes, & Tversky, 1970), and of information science (Commons & Richards, 1984a, 1984b; Lindsay & Norman, 1977; Commons & Rodriguez, 1990, 1993). Specifically, hierarchical complexity refers to the mathematical complexity of the task presented to the participant, but not directly to the complexity of the participant's performance that will successfully complete the given task.

Every task contains a multitude of subtasks (Overton, 1990). When the subtasks are carried out by the participant in a required order, the task in question is successfully completed. Therefore, the model asserts that all tasks fit in some sequence of tasks, making it possible to precisely determine the hierarchical order of task complexity. Tasks vary in complexity in two ways: either as *horizontal* (involving classical information); or as *vertical* (involving hierarchical information).

Horizontal (Classical Information) Complexity

Classical information describes the number of "yes-no" questions it takes to do a task. For example, if one asked a person across the room whether a penny came up heads when they flipped it, their saying "heads" would transmit 1 bit of "horizontal" information. If there were 2 pennies, one would have to ask at least two questions, one about each penny. Hence, each additional 1-bit question would add another bit. Let us say they had a four-faced top with the faces numbered 1, 2, 3, and 4. Instead of spinning it, they tossed it against a backboard as one does with dice in a game. Again, there would be 2 bits. One could ask them whether the face had an even number. If it did, one would then ask if it were a 2. *Horizontal complexity*, then, is the sum of bits required by just such tasks as this.

Vertical (Hierarchical) Complexity

Hierarchical complexity refers to the number of recursions that the coordinating actions must perform on a set of primary elements. Actions at a *higher order of hierarchical complexity:* (a) are *defined* in terms of actions at the *next lower* order of hierarchical complexity; (b) *organize* and *transform* the lower-order actions (see Figure 1); (c) produce organizations of lower-order actions that are new and *not arbitrary,* and cannot be accomplished by those lower-order actions alone. Once these conditions have been met, we say the higher-order action *coordinates* the actions of the next lower order.

To illustrate how lower actions get organized into more hierarchically complex actions, let us turn to a simple example. Completing the entire operation 3 x (4 + 1) constitutes a task requiring the distributive act. That act non-arbitrarily orders adding and multiplying to coordinate them. The distributive act is therefore one order more hierarchically complex than the acts of adding and multiplying alone; it indicates the singular proper sequence of the simpler actions. Although simply adding results in the same answer, people who can do both display a greater freedom of mental functioning. Thus, the order of complexity of the task is determined through analyzing the demands of each task by breaking it down into its constituent parts.

Figure 1. Order of Hierarchical Complexity Tree. Each higher order action organizes two or more lower order actions.

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      ∧            Stage n
    a   b
   ∧     ∧         Stage n - 1
  a b   a b
 ∧  ∧  ∧  ∧        Stage n - 2
a b a b a b a b
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The hierarchical complexity of a task refers to the number of concatenation operations it contains, that is, what is the number of recursions that the coordinating actions must perform? An order-three task has three concatenation operations. A task of order three operates on a task of order two and a task of order two operates on a task of order one (a simple task).

Tasks are also quantal in nature. They are either completed correctly or not completed at all. There is no intermediate state. For this reason, the Model characterizes all stages as hard and distinct. The orders of hierarchical complexity are stepped like the rings around the nucleus. Each task difficulty has an order of hierarchical complexity required to complete it correctly. Since tasks of a given order of hierarchical complexity require actions of a given order of hierarchical complexity to perform them, the stage of the participant's performance is equivalent to the order of complexity of the successfully completed task. The quantal feature of tasks is thus particularly instrumental in stage assessment because the scores obtained for stages are likewise discrete.

Stages

The notion of stages is fundamental in the description of human, organism, and machine evolution. Previously it has been defined in some ad hoc ways. Here we describe it formally in terms of the model of hierarchical complexity. Since actions are defined inductively, so is the function *h*, known as the order of the hierarchical complexity. To each action *A*, we wish to associate a notion of that action's hierarchical complexity, *h(A)*. Given a collection of actions A and a participant *S* performing A, the *stage of performance* of *S* on A is the highest order of the actions in A completed successfully at least once, i.e., it is

stage(*S*, A) = max{*h(A)* | *A* 0 A and *A* completed successfully by *S*}.

Thus, the notion of stage is discontinuous, having the same gaps as the orders of hierarchical complexity. This is in agreement with previous definitions (Commons et al., 1998; Commons & Miller, 2001; Commons & Pekker, 2007).

Stages of Development

The MHC specifies 14 orders of hierarchical complexity and their corresponding stages, showing that each of Piaget's sub-stages, in fact, are hard stages. Commons also adds three postformal stages. The sequence is as follows: (0) computory, (1) sensory & motor, (2) circular sensory-motor, (3) sensory-motor, (4) nominal, (5) sentential, (6) preoperational, (7) primary, (8) concrete, (9) abstract, (10) formal, (11) systematic, (12) metasystematic, (13) paradigmatic, and (14) cross-paradigmatic. The first four stages (0-3) correspond to Piaget's sensorimotor stage at which infants and very young children perform. The sentential stage was added at Fischer's suggestion (1981, personal communication). Adolescents and adults can perform at any of the subsequent stages. MHC stages 4 through 5 correspond to Piaget's pre-operational stage; 6 through 8 correspond to his concrete operational stage; and 9 through 11 correspond to his formal operational stage.

The three highest stages in the MHC are not represented in Piaget's model. Few individuals perform at stages above formal operations. More complex behaviors characterize multiple system models (Kallio, 1995; Kallio & Helkama, 1991). Some adults are said to develop alternatives to, and perspectives on, formal operations. They use formal operations within a "higher" system of operations and transcend the limitations of formal operations. In any case, these are all ways in which these theories argue for and present converging evidence that adults are using forms of reasoning that are more complex than formal operations with which Piaget's model ended.

Because MHC stages are conceptualized in terms of the hierarchical complexity of tasks rather than in terms of mental representations (as are Piaget's stages), the highest stage represents successful performances on the most hierarchically complex tasks rather than intellectual maturity. Table 1 gives descriptions of each stage.

Table 1. Stages described in the Model of Hierarchical Complexity

	Order or Stage	What they do	How they do it	End result
0	calculatory	Exact–no generalization, computer computations	Human made program manipulate 0, 1	None
1	sensory or motor	Discriminate in a rote fashion, stimuli generalization, move	Move limbs, lips, eyes, head View objects or move	Discriminative and condition stimuli
2	circular sensory-motor	Form open-ended classes	Reach, touch, grab, shake objects, babble	Open ended classes, phonemes
3	sensory-motor	Form concepts	Respond to stimuli in a class successfully	Morphemes, concepts
4	nominal	Find relations among concepts Use names	Use names and other words as successful commands	Single words: ejaculatives & exclamations, verbs, nouns, number names, letter names

	Order or Stage	What they do	How they do it	End result
5	sentential	Imitate and acquire sequences Follows short sequential acts	Generalize match-dependent task actions. Chain words	Pronouns: my, mine, I; yours, you; we, ours; they, them
6	preoperational	Make simple deductions Follows lists of sequential acts Tell stories	Count random events and objects Combine numbers and simple propositions	Connectives: as, when, then, why, before; products of simple operations
7	primary	Simple logical deduction and empirical rules involving time sequence Simple arithmetic	Adds, subtracts, multiplies, divides, counts, proves, does series of tasks on own	Times, places, counts acts, actors, arithmetic outcome from calculation
8	concrete	Carry out full arithmetic, form cliques, plan deals	Does long division, follows complex social rules, takes and coordinates perspective of other and self	Interrelations, social events, what happened among others, reasonable deals,
9	abstract	Discriminate variables such as Stereotypes; logical quantification; (none, some, all)	Form variables out of finite classes Make and quantify propositions	Variable time, place, act, actor, state, type; quantifiers (all, none, some); categorical assertions (e.g., "We all die")
10	formal	Argue using empirical or logical evidence Logic is linear, 1 dimensional	Solve problems with one unknown using algebra, logic and empiricism	Relationships are formed out of variables; words: linear, logical, one dimensional, if then, thus, therefore, because; correct scientific solutions
11	systematic	Construct multivariate systems and matrices	Coordinates more than one variable as input Consider relationships in contexts	Events and concepts situated in a multivariate context; systems are formed out of relations; systems: legal, societal, corporate, economic, national
12	metasystematic	Construct multi-systems and metasystems out of disparate systems	Create metasystems out of systems Compare systems and perspectives Name properties of systems: e.g. homomorphic, isomorphic, complete, consistent, commensurable	Metasystems and supersystems are formed out of systems of relationships
13	paradigmatic	Fit metasystems together to form new paradigms	Synthesize metasystems	Paradigms are formed out of multiple metasystems
14	cross-paradigmatic	Fit paradigms together to form new fields	Form new fields by crossing paradigms	New fields are formed out of multiple paradigms

Relationship Between Piaget's Theory and Notions From the Model of Hierarchical Complexity

There are some commonalities between the Piagetian and Commons' notions of stage and many more that are different. In both one finds:

1. Higher order actions defined in terms of lower order actions. This forces the hierarchical nature of the relations and makes the higher order tasks include the lower ones
2. Higher order of complexity actions organize those lower order actions. This makes them more powerful

What Commons et al. (1998) have added includes:

3. Higher order of complexity actions organize those lower order actions in an non-arbitrary way.

This makes it possible for the organization to meet real world requirements, including the empirical and analytic.

1. Task and performance are separated
2. All tasks have an order of hierarchical complexity
3. There is only one sequence of orders of hierarchical complexity.
4. Hence, there is structure of the whole for ideal task actions
5. There are gaps between the orders of hierarchical complexity
6. Stage is defined as the most hierarchically complex task solved.
7. There are gaps in Rasch Scaled Stage of Performance.
8. Performance stage is different task area to task area.
9. There is no structure of the whole—horizontal decaláge—for performance. It is not inconsistency in thinking within a developmental stage. Decalágе is the normal modal state of affairs.

Empirical Research Using the Model of Hierarchical Complexity

The MHC has a broad range of applicability. The mathematical foundation of the model makes it an excellent research tool to be used by anyone examining performance that is organized into stages. It is designed simply to assess development based on the order of complexity which the individual utilizes to organize information. The MHC offers a singular mathematical method of measuring stages in any domain because the tasks presented can contain any kind of information. The model thus allows for a standard quantitative analysis of developmental complexity in any cultural setting. Other advantages of this model include its avoidance of mentalistic or contextual explanations, as well as its use of purely quantitative principles which are universally applicable in any context. Cross-cultural developmentalists and animal developmentalists; evolutionary psychologists, organizational psychologists, and developmental political psychologists; learning theorists, perception researchers, and history of science historians; as well as educators, therapists, and anthropologists can use the MHC to quantitatively assess developmental stages.

Table 2 shows the large range of domains to which the model has been applied. In one representative study, Commons, Goodheart, and Dawson (1997) found, using Rasch (1980) analysis, that hierarchical complexity of a given task predicts stage of a performance, the correlation being *r* = .92. Correlations of similar magnitude have been found in a number of the studies.

Table 2. Examples of tasks studied using the Model of Hierarchical Complexity or Fischer's Skill Theory (1980)

Algebra (Commons, in preparation)	Language stages (Commons, et al., 2007)
Animal stages (Commons & Miller, 2004)	Leadership before and after crises (Oliver, 2004)
Atheism (Commons-Miller, 2005)	Loevinger=s Sentence Completion task (Cook-Greuter, 1990)
Attachment and Loss (Commons, 1991; Miller & Lee, 2000)	Moral Judgment, (Armon & Dawson, 1997; Dawson, 2000)
Balance beam and pendulum (Commons, Goodheart, & Bresette, 1995; Commons, Pekker, et al, 2007)	Music (Beethoven) (Funk, 1989)
Contingencies of reinforcement (Commons, in preparation)	Orienteering (Commons, in preparation)
Counselor stages (Lovell, 2004)	Physics tasks (Inhelder & Piaget, 1958)
Empathy of Hominids (Commons & Wolfsont, 2002)	Political development (Sonnert & Commons, 1994)
Epistemology (Kitchener & King, 1990; Kitchener & Fischer, 1990)	Relationships (Armon, 1984a, 1984b)
Evaluative reasoning (Dawson, 2000)	Report patient=s prior crimes (Commons, Lee, Gutheil, et. al., 1995)
Four Story problem (Commons, Richards & Kuhn, 1982; Kallio & Helkama, 1991)	Social perspective-taking (Commons & Rodriguez, 1990; 1993)
Good Education (Dawson-Tunik, 2004)	Spirituality (Miller & Cook-Greuter, 2000)
Good Interpersonal (Armon, 1989)	Tool Making of Hominids (Commons & Miller 2002)
Good Work (Armon, 1993)	Views of the Agood life@ (Armon, 1984c; Danaher, 1993; Dawson, 2000; Lam, 1995)
Honesty and Kindness (Lamborn, Fischer & Pipp, 1994)	Workplace culture (Commons, Krause, Fayer, & Meaney, 1993)
Informed consent (Commons & Rodriguez, 1990, 1993; Commons, Goodheart, Rodriguez, & Gutheil, 2006; Commons, Rodriguez, Adams, Goodheart, Gutheil, & Cyr, 2007).	Workplace organization (Bowman, 1996a, 1996b)
	Writing (Commons & DeVos, 1985)

Conclusion

In the current issue, the Model of Hierarchical Complexity is applied to a variety of domains: (a) the development of attachment, both in terms of what are the expected, normative developments and in terms of what outcomes might result from negative, abusive or traumatic early experiences, (b) the development of game playing and social interaction skills in infants, (c) a description of how processes of acquisition of new skills differ across developmental stages, (d) an application of the model to teaching and teacher behavior, (e) an explanation of the influence of hierarchical complexity within organizations, and (f) a comparison of two different models of complexity, showing how each can be used to assess college students' behavior. The choice of this wide range of applications is designed to show, most importantly, that the model of hierarchical complexity can be applied in a very large range of domains. It is not limited to problem solving, or to cognition, but also explains social and emotional development, and behavior within organizations.

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