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An Overview of Selected Theories about Student Learning

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Abstract

Engineering educators are often not familiar with the theories and research findings of educational psychology, adult development, curriculum design, and instruction design. Even the published research in engineering/computing education does not sufficiently leverage this body of knowledge. Often in the educational reports and recommendations by professional agencies like ACM and IEEE, there is no or insufficient reference to educational models or theories. Rich corpus of classical as well as contemporary theories of learning can be leveraged to review and transform the educational processes for all groups of learners. The engineering educators can innovatively adapt many of these theories to redesign pedagogic engagements for their students in their courses.

1. Background

The mechanism of learning has been attracting the attention of thinkers in philosophy, psychology, education, and also computer science. *Neuroscience* ascribes 'learning' to the brain's ability to change its structure. *Behaviorists* see learning as a relatively permanent change in behavior due to experience, and concentrate on control of the external environment. *Cognitive psychologists* perceive it as a relatively permanent change in mental associations due to experience, and believe that humans are capable of insight, perception, and attributing meaning. *Social psychologists* view it as a social enterprise, depending upon interaction between learner and his/her socio-cultural environment. *Humanists* emphasize the development of the whole person, and place emphasis on the affective domain. *Constructivism* stresses that all knowledge is context bound, and that individuals make personal meaning of their learning experiences through internal construction of reality. Table 1 provides a chronological list of theories related to learning and the closely associated issues of intelligence, thinking, human development, curriculum design, etc. readers are encouraged to study these theories.

Table 1.1: A chronological list of some important theories about human learning, intelligence, and thinking (pre 1990)

1. Connectionism (Thorndike, 1913)
2. Genetic epistemology (Piaget, 1915)
3. Theory of Curriculum (Bobbit, 1918)
4. Social development theory (Vygotsky, 1920s)
5. Gestalt theory (Wertheimer, 1924).
6. Theory of cognitive development (Piaget, 1930s onwards)
7. Contiguity theory (Guthrie, 1938)
8. Fluid and crystallized intelligence (Cattell, 1941)
9. A theory of human motivation (Maslow, 1943)
10. Theory of inventive problem solving (TRIZ/TIPS) (Altshuller, 1946)
11. Phenomenology (Rogers, 1951),
12. Information processing theory (Miller, 1956)
13. Taxonomy of educational objectives (Bloom, 1956)
14. Cognitive dissonance theory (Festinger, 1957)
15. Motivation to work (Herzber, 1959)
16. Two cultures (Snow, 1959)
17. Originality (Maltzman, 1960)
18. Conditions of learning (Gagne, 1962)
19. Systems thinking (Emery and Trist, 1965)
20. Constructivist theory (Bruner, 1966)
21. Structure of intellect (Guilford, 1967)
22. Lateral thinking (Edward de Bono, 1967)
23. Experiential learning (Rogers, 1960s)
24. Sub-sumption theory (Ausubel, 1960s)
25. The stage theory (Atkinson and Shiffrin 1968)
26. ERG theory (Alderfer, 1969)
27. Intellectual and ethical development (Perry, 1970)
28. Androgogy (Knowles, 1970)
29. Levels of processing (Craik and Lockart, 1970s)
30. Framework of reflective activities (Borton, 1970)
31. Conscious competence theory (Gordon Institute, early 1970s)
32. Classification of disciplines (Biglan, 1973)
33. Attribution theory (Weiner, 1974)
34. Conversation theory (Pask, 1976)
35. Double loop learning (Chris Argyris, 1976)
36. Approaches to learning (Marton and Saljo, 1976)
37. Social learning theory (Bandura, 1977)
38. Theory of tri-archic intelligence (Sternberg, 1977)
39. Script theory (Schank, 1970s and 80s)
40. Modes of learning (Norman and Rumelhart, 1978)
41. Logical categories of learning (Bateson, 1979)
42. Flow theory of motivation (Csikszentmihalyi 1979)
43. Four quadrant model of the brain (Herrmann's 1979)
44. Repair theory (Brown and VanLehn, 1980)
45. Self determination theory (Deci and Ryan, 1980 onwards)
46. Adult learning theory (Cross, 1981)
47. Structure of the Observed Learning Outcomes (SOLO) Taxonomy (Biggs and Collis, 1982)
48. Multiple intelligence theory (Gardner, 1983)
49. Component display theory (Merrill, 1983)
50. Tri-archaic theory of intelligence (Sternberg, 1970s and 80s)
51. Learning style and experiential learning theory (Kolb, 1984)
52. Concept mapping and Vee mapping (Novak and Gowin, 1984)
53. Nature of moral stages (Kohlberg, 1984)
54. Mathematical problem solving (Schoenfeld, 1985)
55. Intellectual functioning in three levels (Costa, 1985)
56. Levels of professional expertise (Dreyfus brothers, 1985)
57. Women's 5 ways of knowing (Belenky et al, 1986)
58. Cognitive load theory (Sweller, 1988)
59. Cognitive apprenticeship (Collins et al, 1987)
60. Four perspectives on professional expertise (Kennedy, 1987)
61. Knowing in action (Schön, 1987)
62. 3P model (Biggs, 1987-99)
63. Dimensions of learning (Marzano, 1988)
64. Mental self-government learning theory (Sternberg, 1988)
65. Style of learning and teaching (Entwistle, 1988)
66. Framework for reflection (Gibbs, 1988)
67. Cognitive load theory (J. Sweller, 1988)
68. Framework for reflection on action (Smyth, 1989)

Table 1.2: A chronological list of some important theories about human learning, intelligence, and thinking (1990 onwards)

69. Minimalism (Carrol, 1990) 70. Situated learning (Lave and Wenger, 1991) 71. Investment theory of creativity (Sternberg, 1991) 72. Curriculum integration (Fogarty, 1991) 73. Staged Self Directed Learning Model (Grow, 1991) 74. Cognitive flexibility theory (Spiro et al, 1992) 75. Capability (Stephenson, 1992) 76. Model of critical thinking (APA, 1992-2006) 77. Epistemological reflection model (Baxter-Magolda, 1992) 78. Value inventory (Schwartz, 1992) 79. Learner managed learning (Graves, 1993) 80. Reflective judgment model (King and Kitchener, 1994) 81. Learning by design (Kolodner et al, 1995-2004) 82. Model of critical thinking (Paul, 1996) 83. Work-based learning (Gattegno, 1996; Hase, 1998). 84. CHC theory (McGrew 1997, Flanagan 1998) 85. Intelligence as developing expertise (Sternberg, 1997) 86. Framework of learning style (Vermunt, 1998) 87. Socialisation, Externalisation, Combination, and Internatisation (SECI) (Noanaka &Takeuchi, 1998) 88. Action learning (Kemmis & McTaggart, 1998) 89. Propulsion theory of creativity (Sternberg, 1999) 90. Ergonagy (Tanaka and Evers, 1999) 91. Constructivist alignment (Biggs, 1999) 92. Phases in critical reflective inquiry (Kim,1999)	93. Collaborative learning (Dillenbourg, 1999) 94. Heutagogy (Hase and Kenyon, 2000) 95. Taxonomy of learning (Marzano, 2000) 96. Framework of critical thinking (Minger, 2000) 97. Taxonomy of Curriculum Integration (Harden 2000) 98. Learning Style (Entwistle, 2001) 99. Bloom's revised taxonomy (Anderson & Krathwohl, 2001) 100. Story centered curriculum (Schank, 2002) 101. Models of interplay between emotions and learning (Kort, 2001) 102. Balance theory of wisdom (Sternberg, 2003) 103. Community of practice ellipse (Medeni, 2004) 104. Spiral of experience based action learning (SEAL) (Medeni, 2004) 105. Taxonomy of knowledge Types (Carson, 2004) 106. Theory of successful intelligence, (Sternberg, 2005) 107. Framework for information and information processing of learning systems (Rauterberg, 2005) 108. Six factors of psychological well-being (Ryff & Singer, 2006) 109. Fixed and Growth Mindsets (Carol Dweck, 2006) 110. Teaching for wisdom, intelligence, creativity, and success (Sternberg et al, 2009) 111. A framework of pedagogical engagements (Sanjay Goel, 2010)

2. Two Core Principles about Learning

Out of the above mentioned theories, two principles can be identified as core principles about learning. I first briefly discuss these principles – cognitive dissonance and cognitive flexibility.

2.1. Cognitive Dissonance

Curiosity is the most fundamental requirement for 'learning.' Incongruity, contradictions, novelty, surprise, complexity, and uncertainty can arouse curiosity. Cognitive Dissonance Theory [1] postulates the following:

1. Humans are sensitive to inconsistencies between actions and beliefs.

2. Recognition of an inconsistency results in cognitive dissonance, and motivates an individual to resolve the dissonance.
3. Dissonance can be resolved in one of three ways: change in beliefs, change actions, or change perception of actions.

The traditional teacher-centric education does not create much dissonance among learners. However, instruction can be designed to create short term dissonance. This dissonance facilitates the learners to first recognize the need to change attitude, and then they should be guided through progressive changes to resolve the dissonance. Non-threatening levels of perceived meaning-deficits generate manageable cognitive load, an enabling flow of emotions, and positive incongruence. When the positive incongruence is within an individual's 'threshold,' it supports learners to sustain their motivation, enjoyment, and efforts. This 'threshold' depends upon the learner, learning context, culture, and community. Hence, in order to help the learners to develop their ability to learn, and also the ability to solve ill-defined unfamiliar problems, the prime aim of higher education has to be to increase this threshold.

2.2. Cognitive Flexibility

The ability to 'transfer' what learners have learned in a context, to different, even unique situations is referred to as 'cognitive flexibility' [2]. Cognitive Flexibility Theory posits that the traditional linear teaching may be ineffective for ill-structured knowledge domains. Spiro and Jehng suggested that learners need to develop their own knowledge representations to adapt knowledge for future use in different types of situations. This and other related theories like 'Aptitude-Treatment Interaction' and 'Random Access Instruction' recommend that for developing cognitive flexibility, especially for ill-structured domains, over-simplification, compartmentalization, and transmission of knowledge should be avoided. Instead instruction should support context dependence, multiple representations, construction, and interconnectedness of knowledge.

3. Some Important Theories about Learning

3.1 Perry's model of epistemological development

Perry [3] proposed a nine stage model of cognitive and moral development. The initial five stages are purely cognitive, whereas ethical aspects also get integrated in the later four stages. These nine micro level stages are also broadly grouped into four macro level stages. At the level of 'dualism,' people believe things are right or wrong and have faith and commitment to truth and knowledge as stated by genuine authorities. At the second macro level stage of 'multiplicity,' the diversity in thinking is recognized, but the person does not feel the need to commit to any specific belief or mode of thinking. The third macro-stage is 'relativism.' At this stage, the person sees the context sensitivity of knowledge. The final macro-stage is 'commitment,' at which the learners feel the need to take positions and commit to them.

As per Perry's model, the movement through this stage is not automatic and progressive. One can undergo a long term pause at some position, or escape the progression by developing competence in some specific field, or even regress to lower position without one's awareness. Studies have shown that engineering education failed to elevate a significant number of students to level 5 as per Perry's nine-level model, and the average growth after four years of college was only one level, with most of the change occurring in the last year. We can certainly do better in this regard by suitably leveraging the finding of education research.

3.2 Andragogy

Initially proposed by Knowles [4], Andragogy refers to learner-focused education. It postulated that as learners mature, their motivation as well as perspective shift from external to internal and from postponed application of knowledge to immediacy of application respectively. The andragogic model asserts that following issues must drive the education processes:

1. Learners need to know why they need to learn something.
2. Adults need to learn experientially.
3. Adults approach learning as problem-solving.
4. Adults learn best when the topic is of immediate value.

3.3 Bloom's Taxonomy and a proposed revision

Benjamin Bloom [5] classified the cognitive process into six major levels arranged in a hierarchical order. Beginning with the simplest level and increasing in complexity, the cognitive levels are: Knowledge, Comprehension, Application, Analysis, Synthesis and Evaluation.

Anderson and Krathwohl [6] modified Bloom's taxonomy by adding another dimension of knowledge types: factual, conceptual, procedural, and meta-cognitive. They renamed the earlier hierarchy of levels from nouns to verbs. They also swapped the position of the uppermost two levels. Using Bloom's taxonomy in its original or revised form for deciding the learning objectives of school education is perfectly fine. Recently, a lot of engineering or engineering education research also has been based on these models. For example, on December 20th, 2009, ACM Digital library showed 407 papers referring to Bloom's taxonomy out of which 214 papers were published 2007 onwards.

Our studies [7] showed that engineering students report more effective learning when they are engaged in higher order cognitive activities. Even in the opinion of professional engineers, faculty should engage students in higher level cognitive activities like *analyse, design, develop, implement* and so on. However, most of the engineering faculty give assignments and activities that engage students in lower level cognitive activities like *calculate, explain, prove (studied theorem, studied method), define (studied definitions)* and so on. In a survey, our respondents from software industry recommended that more than 70% pedagogic engagements of computing students should be at upper three levels.

A revised version wrt engineering education

The level of evaluation involves (i) designing of criteria and also (ii) considerations of larger context, human values, and ethics. Hence, it is appropriate to keep it at the highest level. In fact, some ‘create’ activities may require lower cognitive effort than ‘evaluate,’ whereas some of them will be based upon serious evaluation. Hence, in order to avoid simplistic hierarchy, I propose to keep ‘create’ and ‘evaluate’ at the same level. I have proposed a further extension of Bloom’s taxonomy by adding the next higher level of ‘mentoring’ in this ladder. A brief summary of the adaption and extension of Bloom’s taxonomy for the purpose of engineering education is as follows:

1. Remember: recognizing, recalling
2. Understand: interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining
3. Apply: executing, implementing
4. Analyze: differentiating, organizing, attributing, checking, critiquing using existing criteria

5A. Create: generate, plan, and produce

5B. Evaluate: Critiquing based on self-designed criteria, Deciding in the light of larger context, human values and ethics

6. Mentor: coaching juniors for skills and providing guidance in their projects

There is a need to further refine the upper levels (3-6) in order to enhance engineering educators’ understanding of the pedagogic possibilities. I feel that such an expansion of these levels into sub-ladders will help the engineering educators design appropriate learning objectives and instructional interventions for their courses [7]. The proposed expansion of two most important levels in this ladder – ‘Analyze’ and ‘Create’ are outlines here. The sub-levels for ‘Analyze’ are proposed as follows:

a. Analyze data
b. Analyze problems
c. Analyze complex ill defined problems
d. Analyze systems

With reference to the expansion of the level of ‘create’ from a single level into a sub-ladder, I find Sternberg’s taxonomy of creative contributions as a useful source that can be used by engineering educators. This taxonomy has not yet been used by engineering education researchers. These sub-levels for ‘Create’ are follows:

a. Paradigm preserving: replication, adaption
b. Paradigm forwarding: forward incrementation, advance forward incrementation
c. Paradigm rejecting by paradigm redirection and reconstruction,
d. Paradigm rejecting by paradigm re-initiation

3.4 Kolb’s Learning Styles

Kolb [8] identified four main learning styles and also discovered prominent patterns of correlation of the styles with respect to domains, and also with concerned persons’ functions. These four styles are given below:

1. Divergent: involves reflection on concrete experience, requires abilities of concrete experience as well as reflective observation. This style is associated with valuing skills: relationship, helping others, and sense making. Effective communication and relation building requires this style.

2. Convergent: involves active experimentation to test/apply abstractions, requires abilities of abstract conceptualization as well as active experimentation. This style is associated with decision skills like quantitative analysis, use of technology, and goal setting.
3. Accommodative: involves active experimentation on concrete experiences, requires abilities of concrete experience as well as active experimentation. This style encompasses a set of competencies that can best be termed acting skills: leadership, initiative, and action. Decision making in uncertain situations requires this style.
4. Assimilative: involves reflection on abstractions; requires abilities of abstract conceptualization as well as reflective observation. This style is related to thinking skills: information gathering, information analysis, and theory building. Planning and research activities require this style.

Rather than following the commonly popular perspective that subjects are linked with specific learning styles, I take a position, that different styles are relatively more suitable for learning different aspects of a single subject. Hence, an integration of these styles enhances learners' ability to learn different aspects of any domain. Kolb also proposed 'experiential learning cycle' for facilitating deeper learning. Consequently, engineering students' educational engagements must ensure a good mix of *convergent, assimilative, divergent, and accommodative* activities.

3.5 SOLO Taxonomy

Biggs and Collis [9] proposed a five-level Structure of the Observed Learning Outcome (SOLO) Taxonomy in terms of increasing complexity. As per this taxonomy, the lower three levels: 'pre-structural,' 'uni-structural,' and 'multi-structural' are about quantitative increase in details of the response. The upper two levels: 'relational' and 'extended abstraction' are about its qualitative transformation through integration, extension, and abstraction. The first level indicates complete lack of comprehension and understanding.

Brabrand and Dahl [10] examined intended learning objectives of more than six hundred science courses (including computer science) at two Danish Universities, and found that the average SOLO level of intended learning objectives varied from 2.8 to 3.4 for undergraduate students, and between 2.9 to 3.8 for postgraduate students. Aggregating all the disciplines, nearly 70% of courses' intended learning objectives aimed to achieve only third SOLO level. For some disciplines, this was as high as 80%. Overall, only a little more than 10% intended learning objectives targeted for fifth SOLO level, and for some disciplines this was even lesser than 5%. The realized objectives would perhaps be even lesser than the intended ones.

Hence, it can be concluded that students' most common engagement in engineering education is not only at the lower levels of Bloom's taxonomy, it is also at the lower levels of the SOLO taxonomies. In the last four years, few papers in the ACM SIGCSE, and very few in IEEE conferences have made some reference to the SOLO taxonomy.

5. Phenomenon of Learning – A Unified Explanation

Though learning is natural, it is not automatic. It is driven by voluntary and/or involuntary efforts made in response to stimulating experiences. Such stimulating experiences create 'cognitive dissonance' and 'learning contexts' by inducing recognition of inadequacy of existing meanings. These contexts catalyze the activation of operating learning processes. Learning is a natural multi-faceted process that helically progresses through making and rendition of meaning at progressively deepening levels. Meaning making and rendition processes unfold in a multi-dimensional space of physical world, community, culture, psycho-motor, cognition, emotion, attitude, and values.

Humans continuously make meanings about the external world, inner self, and the relationship of the two. Experiences are interpreted as mental objects by the human mind to create an individual's meanings. Mental objects include thoughts, ideas, concepts, impressions, percepts, rules, images, notions, scripts, schemas, and so on. The combined strength of deductive, inductive, convergent, divergent, linear, nonlinear, critical, and creative thinking processes, as well as intuition, drive this interpretation. Symbols, notations, language, diagrams, and concept-maps are used to represent and create these objects.

We create meaning at different levels in different contexts. These levels range from superficial symbolic levels to deeper conceptual and revelational levels. A disjoint ensemble of inflexible and incoherent superficial meanings results in surface learning. Deep learning requires the learners to create integrated, coherent, and trans-contextually transferable meaning at deeper conceptual and revelational levels. Ability to apply, blend, and regulate thinking processes governs coherence, accuracy, richness, interconnectedness, and representations of mental objects, and hence, the level of meanings. Deeper meanings are characterized by richer representations. At the deepest levels of learning, meanings related to self, get well integrated with the meanings related to the external world. Prior meanings may expedite, impede, or even block the progress of an individual's meaning making processes.

We render our meanings in abstract forms like models and theories, and concrete forms like artifacts, e.g., software and processes at varied levels of sophistication. Meaningful and creative renderings manifest learners' deeper integrated meanings and refined rendering skills. Meaning making continues during rendition, and rendering skills themselves are refined through practice and newer meanings. The level of meaning, and also the form and sophistication of rendering, depend upon the richness of context and strength of operating processes of learning as well as learners' nature, nurturing, and intrinsic motivation.

An individual's value orientation and interests shape his need perception. Many of our efforts made for fulfilling our needs and other experiences create 'learning contexts' by inducing recognition of inadequacy of existing meanings. An individual's value orientation, perceived needs, intrinsic motivation, and flow of emotions trigger, drive, and direct their meaning making process and efforts. Community and culture significantly influence value orientation, perceived needs, intrinsic motivation, and flow of emotions. Further, community and culture also provide the ground for creating shared meaning.

Repeatedly reinforced meanings, cultural norms, and social expectations affect the meanings about the inner self. Meanings related to inner self have strong influence on personal values, interest, attitude, intrinsic motivation, goals, and even perspective. Changes of self-related meanings affect individual's efforts, and also their meanings about external world. Consequently, a practice of critical self-reflection on self-related meanings strengthens self-regulation of meaning making, and increases the efficacy of learning processes.

Wisdom is an outcome of trans-contextual meaning integration, self-awareness, openness based on awareness of competency limitations, and a concern for collective and sustainable well-being.

6. Conclusion

In this paper, I have briefly discussed few of the most important theories related to student learning. Some revisions for few of these theories, especially Bloom's taxonomy have also been outlined wrt the specific needs of engineering education.

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