

LEARNING-BY-TEACHING AS A PEDAGOGICAL APPROACH AND ITS
IMPLICATIONS ON ENGINEERING EDUCATION

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INTRODUCTION

Learning and teaching are by nature intertwined. The traditional relationship between learning and teaching has always been viewed as unidirectional; professors and teachers (experts) responsible for teaching, students (novices) responsible for learning. As new pedagogies have been developed around the concept of active learning, these assumed roles have blurred. For instances classified as *learning-by-teaching*, teachers are offering students a chance to take on a teaching role to take advantage of activities implicit in teaching. Such opportunities do not work for all learning situations, but when used appropriately, students are afforded a unique chance to develop both socially and cognitively (Gartner, Kohler, & Riessman, 1971).

The purpose of the following review is to perform an analysis of what occurs when a student is learning-by-teaching. First, learning-by-teaching will be concretely defined to identify precisely what is meant by the term. Secondly, an analysis of the activities involved in the teaching process will be used to describe why teaching is a beneficial mechanism to elicit learning in the teacher. Theoretical underpinnings associated with such learning approaches will be discussed to construct a framework to support the mechanism. Third, a description of various learning-by-teaching approaches with research support will be shown to describe how learning-by-teaching has been used and what the benefits and drawbacks are to such approaches. Appropriate contexts for use of learning-by-teaching approaches will be included. The concluding discussion will describe the implications that learning-by-teaching can have in engineering education.

LEARNING-BY-TEACHING

Learning-by-teaching has a long history in the United States. Student teaching was used as a component of the traditional schoolhouse and continues to be a staple of the Montessori approach (Lillard & Else-Quest, 2006). Learning-by-teaching is present outside the classroom when explaining rules of a game to a sibling or coaching an athlete. Teaching nearly always provides opportunities to learn with the caveat that the impact is dependent on the accuracy of the information taught and the appropriateness of teaching as the learning tool.

Current depictions of what learning-by-teaching represents have not changed from how it was defined in the past. Gartner, Kohler, and Riessman (1971) connect learning-by-teaching to self-help literature. Their argument aligns with what Riessman (1965) calls the 'Helper' Therapy Principle. This principle surmises that when one individual helps another, the helper benefits more. Examples of this principle in action today include the former drug addict who mentors current drug addicts or the former dieter who instructs others on how to diet. The helper – the one formerly receiving assistance – in both instances is the one who benefits the most from the interaction. When a student engages in teaching as a form of helping, s/he is given an opportunity to learn how to learn through the teaching process. This connection has not changed over time and is the cornerstone upon which learning-by-teaching is built.

TEACHING ACTIVITIES

The activities required of a teacher in practice have concomitant cognitive benefits for that teacher. These activities identified by the seminal work in the field

include review and preparation, organization, presentation (demonstration and explanation), analysis, reflection and discussion, reformulation, and observation (Bargh & Schul, 1980; Gartner et al., 1971; Okita & Schwartz, 2006).

Review and Preparation

Teaching requires at a minimum a basic understanding of the material to be taught and a plan for conveying the material. To ensure understanding before presentation, teachers often learn by reviewing through the development of important explanatory structures in the domain (Artzt & Armour-Thomas, 1999; Bransford, Brown, & Cocking, 2000). *Learning-by-reviewing* encompasses a broad range of instances a teacher works with the material while preparing to teach another (Gartner et al., 1971). When reviewing is conducted as preparation for a teaching role, there are several qualitative differences, which are not seen when simply being taught and studying materials for personal gain (Bargh & Schul, 1980; Hufnagel, 1984). The first difference is the reviewer's shift in content-specific gain from learning for a test to being capable of explaining that same information to another. When the goal is to pass a test, learners tend to memorize the material for the purposes of short-term recall and a subsequent passing grade. Reviewing for the purposes of teaching shifts learning toward a means of elaborating material in a meaningful way.

The second qualitative difference is a teacher's use of reformulation. *Learning-by-reformulation* leads to a deeper grasp and understanding of the material because it encourages organization and the seeking out of basic structures (Gartner et al., 1971). Organization in such a manner encourages the teacher to code the content in a meaningful

way by associating it with what is already known; making the subject matter more accessible in the memory (Zajonc, 1960). Self-organization facilitates a personal understanding of the relationships between facts revealing the underlying structures within the material to be taught. By identifying the character of a concept, the teacher learns how things relate rather than memorizing the facts with no context (Katona, 1940).

Lastly, preparation for teaching places a powerful responsibility on the teacher to succeed so that his or her students do not fail. Metacognitive motivation concerning someone else's wellbeing drives teachers to remedy their misunderstandings in case a student needs clarification later on. Teachers never want to be embarrassed by not knowing the answer (Lambiotte et al., 1987). Such motivation encourages the teacher to pay more attention to the material to be learned, enhancing cognitive processing and increasing attention for the task (Annis, 1983; Benware & Deci, 1984).

Presentation

When a teacher is sufficiently prepared to teach, the next step is to present the material. Presenting to an audience contains the possible drawback of anxiety induced by speaking in front of an audience. Zajonc (1966) calls this anxiety an "audience effect". In such a case, the benefits outweigh the possible fear. The benefit is the opportunity to enhance student engagement in the learning process through verbalization. Verbalization allows students to talk about content in a meaningful way instead of passively contemplating what is being told to them (Chi, De Leeuw, Chiu, & Lavancher, 1994). The teacher is also afforded the opportunity to mentally record reactions of the audience on what they are preparing, supplying a base for future reflection.

Reflection and Observation

The final two activities implicit in teaching are reflection and observation. Together these activities supply opportunities for a teacher to analyze personal performance and gain insight into personal understanding of the material. Reflection can be triggered by both internal and external cues. Internal cues occur naturally when the teacher presents and discovers a personal deficiency in understanding.

External cues are supplied to the teacher through observed student reactions including non-verbal reactions, student questions, and student assessments. Non-verbal reactions are involuntary cues that a teacher can use to gain insight into whether students are grasping the material. Being cognizant of student expressions allows the teacher to receive instant feedback on their teaching.

Student questions are more direct. When a student asks a question, the teacher's understanding is tested. This prompts non-scripted verbalization shown to promote achievement (Webb, 1991, 1992). Student questions can also serve as opportunities for the teacher to reflect upon their own knowledge. Student confusion makes the teacher cognizant of possible conceptual gaps and discrepancies that may exist within the students' understanding. Gaps in student understanding may correspond to a weak area within the teacher's knowledge (Bargh & Schul, 1980; Lin, Schwartz, & Hatano, 2005). Reflection of student questions leads to reorganization and clarification of the material improving their own fundamental understanding and improving future learning sessions. (Chi, Silver, Jeong, Yamauchi, & Hausmann, 2001; Lin et al., 2005).

Additionally, teachers can enhance personal understanding through observations of students on assessment tasks. Student assessment allows the teacher to see how their

students use the taught knowledge and whether they are truly grasping the material (Chi et al., 2001; Graesser, Person, & Magliano, 1995; Palinscar & Brown, 1984). When someone has some understanding of what they are observing, observation can trigger reflection not produced when analyzing student questions or looking at student work (Okita & Schwartz, 2006). Assessment is also a difficult part of teaching because of the required content knowledge for appropriate assessment.

Summary

The combination of activities possible in the teaching process has the capability of being an effective means for a student who teaches to learn and understand content. Teaching with the intention to learn affects not only content-specific gain, but also allows the student experiencing the teaching to learn how to learn. Learning how to learn develops the ability to relate material quicker and easier, facilitating generalized gain (Novak & Gowan, 1984; Postman, Keppel, & Zacks, 1968). The next section of this review describes a group of studies identifying the specific effects of the teaching process on students who participate in a teaching experience.

CONSEQUENCES OF LEARNING-BY-TEACHING

A number of studies have investigated the overarching effects of learning-by-teaching methods. The earliest and most highly referenced study was conducted by Bargh and Schul (1980). Bargh and Schul's experiment analyzed the effects of *expecting to teach* on student cognitive gain. Two groups were formed in a closed experiment; one expecting to teach and the other preparing to be examined. The group expecting to teach

did not actually teach, but were misled to keep up appearances. Post-test performance scores for both groups – adjusted to remove the effect of pretest performance scores – showed that the group with the teaching expectancy ($M = 0.649$) significantly outperformed the group expecting to be examined ($M = 0.569$). Bargh and Schul hypothesized that these results were an effect of student anticipation to have to teach, rather than the actual act of teaching. The study does not analyze a group that actually taught.

Following Bargh and Schul's study, Annis (1983) conducted an experiment measuring achievement on content-specific and generalized cognitive gains for a total of five different groups: *read*, *read to teach*, *read and teach*, *be taught*, *read and be taught* in order to analyze every stakeholder in a learning-by-teaching environment. The *read* group represented a control group of individuals who simply read an excerpt for the purpose of being examined on it later with no teaching involved. The *read to teach* and *read and teach* groups represented tutors. *Read to teach* looked at the effects of reading with the intent to prepare to teach, but with no actual teaching involved. The *read and teach* group represented the students who prepare and actually did teach. The remaining two groups, *taught* and *read and taught* represented the tutees. In the *be taught* group, the learner had no background information about what they were taught, while the *read and be taught* group previously read the excerpt before being taught about it. The analysis looked at the effects of teaching expectancy, exposure to teaching, and teaching experience. Analysis of these five groups showed that those students in the *read and teach* ($M = 6.31$) group significantly outperformed all other groups in knowledge (*read*, $M = 4.0$; *read to teach*, $M = 4.81$; *be taught*, $M = 3.35$; *read and be taught*, $M = 5.08$). In

addition, the *read* and *be taught* groups significantly outscored the *be taught* and *read* groups, and the *read to teach* students significantly outscored the students who were in the *be taught* group. Annis's results clarify the work of Bargh & Schul by showing that actively being engaged in teaching, rather than being passively exposed to material – reading alone or just preparing to teach without the actual experience – is the most beneficial avenue for learning within a learning-by-teaching environment.

Ehly, Keith, and Bratton (1987) performed an experiment producing contrasting results. Their analysis consisted of measuring posttest scores for five different groups: *Teach I*, *Teach II*, *Study*, *Learn*, and *Control*. Both the *Teach I* & *II* groups were given lesson content in advance. The *Teach II* group was identical to Bargh and Schul's group of students expecting to teach, but with no actual teaching opportunity; while the *Teach I* group represented students both expecting to teach and who actually had the opportunity to teach. Students who learned from the *Teach I* group formed the *Learn* group. The final two groups, the *Study* and *Control* groups, represented students who expected to be examined and students with zero exposure to the material before being tested, respectively. While analyzing the effects of teaching expectancy and the differences between studying to tutor and studying to take a test, they concluded that expectancy did not sufficiently produce mastery of the content. Although the study recognizes an undeniable impact of expectancy, students in the *Teach I* ($M = 25.63$) and *Learn* ($M = 25.67$) groups outscored the *Teach II* ($M = 19.62$) group on a post-test (means adjusted for variable study times). The researchers concluded that knowledge of content was more influential than simple exposure to materials – being given the materials before the study – in a teaching role.

Lambiotte et al. (1987) clarified this discrepancy by analyzing different interactions between students during a student-taught lesson. Four groups were analyzed: *cooperative teaching in the teaching role*, *cooperative teaching in the learning role*, *cooperative learning*, and *cooperative microteaching*. These four conditions varied in what each partner read, taught, and learned. They concluded that preparing for and teaching information to a naïve learner (*cooperative teaching in the teaching role*, $M = 8.69$) resulted in the highest gross overall scores on recall (*cooperative teaching in the learning role*, $M = 5.46$; *cooperative learning*, $M = 3.95$; *cooperative microteaching*, $M = 4.80$) even when each group was exposed to the same materials. Lambiotte et al. suggest that it is differing amounts of effort, demand characteristics, different social factors, and variable metacognitive activity that account for these differences, not exposure to the materials.

Benware & Deci (1984) conducted another experiment analyzing not only conceptual understanding, but also intrinsic motivation. The experiment consisted of two groups: *reading to learn for a test (control)* and *reading to learn to teach a peer (experimental)*. Both groups when examined performed equally well on rote learning (*control*, $M = 16.24$; *experimental*, $M = 18.21$), but *the learn to teach* group outperformed the *learn for a test* group on conceptual understanding (*control*, $M = 10.76$; *experimental*, $M = 18.84$). The study confirms the previous results on active engagement with the material. In addition, the study identifies that teaching facilitated significantly high levels of interest (*control*, $M = 4.43$; *experimental*, $M = 7.13$) and enjoyment (*control*, $M = 4.67$; *experimental*, $M = 7.00$) brought about by a sense of competence and self-determination not seen among those who learn only to be tested. This suggests that

learning for the purposes of teaching intrinsically motivates students more than learning for the purpose of being examined.

Benware & Deci's results were contrasted in a study by Renkl (1995). Renkl's study performed an analysis of students studying worked-out examples. Students performing the task in preparation to teach displayed significantly lower levels of intrinsic motivation (*experimental*, $M = 2.60$) than students expecting to be tested (*control*, $M = 3.27$). Students preparing to teach also performed the task with somewhat more anxiety (*control*, $M = 2.34$; *experimental*, $M = 2.72$). Renkl's intrinsic motivation results are in question as direct effects of low levels of competence and self-determinism of the participants possibly skewed the data. Renkl's identification of high levels of anxiety, however, were paralleled in a study by Ross & DiVesta (1976). Students were analyzed when they both verbalized answers (representative of the teacher) and when they observed someone else verbalizing (representative of the student). A comparison anxiety brought on when students verbalized their answers ($M = 31.81$) and when they observed ($M = 21.19$) resulted in significantly increased levels of anxiety when students were engaged in verbalization activities. The study concludes that teaching expectancy can foster learning, but can be hampered by the anxiety of having to speak to a group. Such detrimental effects can be explained as stress brought on by negative audience arousal (Zajonc, 1966).

Summary

The results of these studies suggest that exposure to teaching opportunities can afford students both cognitive and emotional benefits not seen when the only option is to

be passively taught. The one caveat is that these benefits may be hampered by the possibility of some individuals' becoming anxious based on an audience effect. As learning-by-teaching is not the best fit for all learning environments, the following section will delve into the theoretical underpinnings of why learning-by-teaching can allow students in certain situations to obtain a greater mastery of the content.

THEORETICAL FRAMEWORK

There are numerous different ways to theoretically explain why and how learning-by-teaching works in certain situations. One feature is the inherently social nature of learning-by-teaching. The social nature of learning-by-teaching is important because social interactions between a teacher and a learner are the essence of what makes teaching a learning tool. Hartman (1990) theorizes that social interactions induced by teaching can produce valuable cognitive benefits toward personal development that are not seen through any other form of learning. The conceived benefits to cognitive skills (perceiving, differentiating, selecting, storing, interfering, applying, combining, justifying, and responding), meta-cognitive skills (planning, monitoring, and evaluating), and the associated use of declarative, procedural, and contextual knowledge, suggest that an integral and inseparable aspect of learning-by-teaching is the social nature in which it occurs. If removed from a social context, the learning is no longer teaching.

A search of the social learning literature leads to the discovery that no one theory has the full capability of explaining why it is that learning-by-teaching is advantageous. For this review, the following sections will construct a compilation of multiple theoretical

ideas woven into a theoretical framework. The final framework will elaborate on the cognitive, behavioral, and environmental factors driving learning-by teaching.

Development Through Social Interaction and Conflict

The theoretical support of learning-by-teaching's social nature starts with an individual's personal development. Two theories keying into this point are Piaget's Theory of Cognitive Development and Vygotsky's Social Development Theory.

Theory of Cognitive Development - According to Piaget's Theory of Cognitive Development* (1985), self-exploration of the world is the main guide to an individual's understandings. Self-exploration (i.e. self-teaching) causes constant internal conflicts triggering intellectual reconstruction and cognitive change through assimilation and accommodation. These processes force an individual into a state of disequilibrium until new knowledge is constructed.

The limiting factor to self-exploration is the world each individual explores. Enhancing understanding gained through self-exploration are social interactions, in the form of social conflicts. These secondary affects develop socio-cognitive skills not achieved through self-exploration. For example, when two individuals have a disagreement, a social and cognitive conflict occurs within each of their current knowledge sets. Both become aware for the first time that others may have varying points of view that do not agree with their own. This realization encourages each individual to examine and reflect upon their point of view, reassessing their view's validity. Validity is

* Although developed specifically for young children, Piaget's theory is often applied to learners of all ages.

established when they can determine how to justify their view so that others may accept it as valid. Justifying their ideas consequentially forces them to work out their understanding in order to express their views convincingly. Ultimately they teach themselves and one another.

Learners involved in learning-by-teaching incorporate self-exploration when reviewing and preparing, but more importantly use social conflict when the prepared content is presented. The assumption is that social interactions, as opposed to self-exploration, supply a greater impact on the benefits of learning-by-teaching. The assumption can be made because learning-by-teaching broadens the world in which the student learns. Take for instance when a student questions what the teacher presents. The teacher enters a state of disequilibrium, reflecting and reassessing their view to determine why the student asked the question. There might not have been any errors in the material presented by the teacher, but the questioning of the presented material elicits reflection directed toward their understanding and method of presentation. The social interaction imposed upon the teacher enhances what might otherwise have been overlooked.

The shortcoming of social conflict as the initiator for learning is the possibility of misinformation or misconception misguiding the learning. When an inaccurate idea is accepted based on a lack of total understanding, learning is inhibited rather than enhanced. The learner should always consider the source of information to judge the reliability of the social conflict.

Social Development Theory - Vygotsky's Social Development Theory (1978) is driven by the effects of social interactions on cognitive structures. According to Vygotsky, social

interaction is fundamental and primary for full cognitive development. Interaction through expert guidance and peer collaboration allows the learner to observe and model behaviors, attitudes, and emotional reactions (interpsychological). These observations encourage internalization of social and cognitive processes (intrapsychological) leading to the development of higher-order functions for later individual use. This concept is illustrated clearly in Vygotsky's Zone of Proximal Development (ZPD). The ZPD is a shifting range that identifies an individual's real-time array of capabilities. The lower bound is defined by an individual's ability to solve a problem alone, while the upper bound is defined by the ability to solve a problem with help from an "expert". Social interactions and the advancement of individual ability are dictated by shifts in ZPD through experiences with experts and peers. Individuals are always more capable when working with someone who knows more than they do.

Learning-by-teaching views Vygotsky's theory from the perspective of the expert. Implications of this theory on peer learning have been discussed (Hogan & Tudge, 1999), but to date, no research has been conducted specifically looking at how, if at all, an expert's ZPD changes through interactions with novices. The literal theory would presume that the expert would in no way learn from interactions with novices because novice interaction does not produce a variable upper bound for the expert. Anecdotally it is recognized that peer interactions with novices lead to expert learning. The ZPD model can be used to attempt an illustration of what an expert's range might look like. For instance, when novices probe the expert to explain what they know alone (lower bound of the ZPD), a variable upper bound for the expert may result. This upper bound for the expert could be defined by the ability to reason a problem for the purposes of explaining

them to a novice. Examples would include a master further perfecting their trade through work with an apprentice or a teacher being asked a question. In situations where the teacher's upper bound is challenged by a question, the teacher and student switch roles. This causes the teacher to become the "novice", shifting the upper bound of his or her ZPD. The consequences of such a role reversal could be dire. If the expert does not know the answer it could entice them to propagate misconception to avoid embarrassment. Inappropriate reactions can hamper learning rather than enhance it. Neither ZPD-like model for expert learning is extremely convincing. Perhaps due to accuracy discrepancies and the fact that the ZPD was developed for the learning of the novice, a ZPD-like model for expert learning is simply not appropriate.

What can be taken from both developmental theories is a base upon which a theoretical framework supporting learning-by-teaching can be built. It is recognized from the developmental theories that social interactions can motivate an individual to abandon misconception in order to search for better answers. Better answers allow for the learner to master both social (participation and argumentation) and cognitive (verification and criticism) processes (Damon, 1984). Because both Piaget and Vygotsky's theories are limited to a focus of novice (or child) development, it is pertinent to extend this theoretical framework to include the cognitive, behavioral, and environmental influences related to social learning.

Social Learning and Cognitive Theory

Social learning extends beyond simply working with others and establishing differing points of view. Social learning incorporates cognitive, behavioral, and

environmental influences that affect both teaching and learning. These influences are the basis for why it can be assumed that learning socially and subsequently learning-by-teaching: 1) sometimes produces a richer experience than learning by oneself, 2) encourages individuals to make their thoughts explicit rather than implicit, and 3) supplies a context for building arguments differently from those one would build independently (Kafai & Harel, 1991).

Social learning theory derives from Tarde's (1890, 1962) proposition that social learning occurs through four stages of imitation: close contact with an expert, mimicking, understanding concepts, and role model behavior. As a behavioral learning theory, Tarde's assumption was that an individual's environment causes an individual to behave in a certain way.

Bandura's Social Learning Theory (1977) and Social Cognitive Theory (1986) suggest that psychosocial functioning is the result of a reciprocal interplay between cognitive, behavioral, and environmental factors or *triadic reciprocal causation* (depicted in Figure 1). This model asserts that thought, action, and emotions are functions of the interaction between behavior, personal cognitive factors, and external environmental factors rather than being mutually exclusive. Individuals develop cognitive, social, and behavioral competencies through mastery learning elicited through not only imitation, but also through observation and modeling of behaviors, attitudes, and emotional reactions. Effective social learning through these mechanisms is accomplished when the individual observes attentively, retains information in a meaningful way, reproduces accurately, cultivates beliefs in their capabilities, motivates through goal setting, and possesses high self-efficacy toward the task.

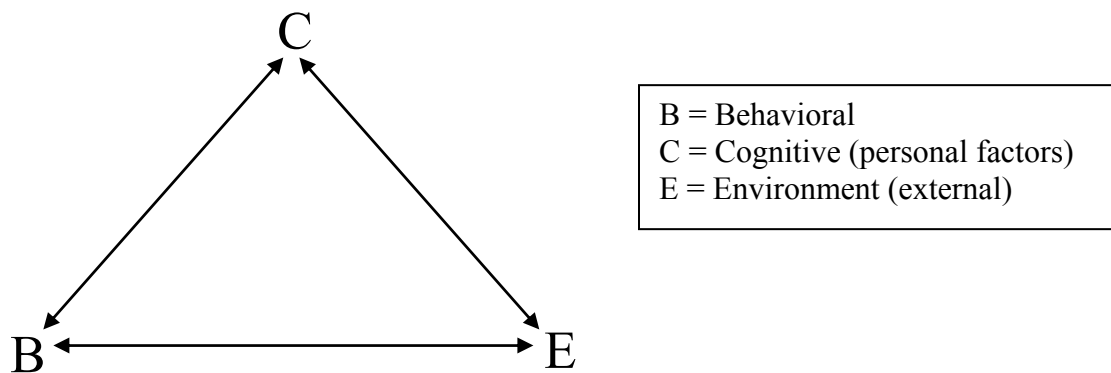


Figure 1: Triadic reciprocal causation. Psychosocial Functioning = $f(BCE)$

Learning-by-teaching capitalizes on the power of social learning theory when used in conjunction with cognitive apprenticeship approaches (Collins, Brown, & Holum, 1991). A teacher in a cognitive apprenticeship plays the role of a visible model to be observed and imitated. When the teacher prompts the student to become the model, they are given an opportunity to take on responsibility for the task by displaying how well they attained, retained, and can reproduce the models they learned from.

Social learning theory describes the importance of cognitive, behavioral, and environmental influences on learning-by-teaching. As determined by the theory, a teaching experience – framed as a mastery experience – can have more of an effect on learning than a vicarious experience in a classroom. For learning-by-teaching to capitalize on the benefits of social learning theory, it must occur within an appropriate environment. The final addition to the theoretical framework will expand upon the social learning process to include situated cognition.

Situated Cognition

Situated cognition, or situativity theory of cognition, is the idea that learning is not a result of random thoughts, but rather a function of the activity, context, and culture (Brown, Collins, & Duguid, 1989; Greeno, 1998; Lave & Wenger, 1991). Considering context and culture incorporates two vital aspects of social learning. The context of an activity supplies insight into the particular set of circumstances that surround a given application. Culture incorporates the characteristics of a particular social group into the activity. Learning shifts from being abstract and decontextualized to being a social process when context and culture are considered. This is the basis for the pedagogical approach known as situated learning (Lave & Wenger, 1991). Situated learning is a established when tasks are undertaken in situations normally involving the subject-matter knowledge. Students fully understand how to make sense of novel contexts through co-construction of knowledge (Brown et al., 1989; Greeno, Collins, & Resnick, 1996).

Learning-by-teaching incorporates situated cognition theory in a unique way. Learning in a learning-by-teaching environment transforms classroom learning into an authentic context. The activity is by default culturally situated within the student's classroom. The real world activity then becomes the act of teaching. A teaching experience as situated learning provides the learner with an opportunity to take the knowledge they have learned as a student in that same classroom and affect their environment through a different role. The knowledge is made visible through the role reversal.

Summary

The benefits and reasoning why to use learning-by-teaching can be theoretically supported through a theoretical framework of cognitive developmental theory, social developmental theory, social cognition and learning, and situated cognition. Taken together, these theories address three important aspects crucial to the effectiveness of learning-by-teaching: 1) social interaction and conflict between learners of all abilities benefits both the teacher and learner, 2) cognitive, behavioral, and environmental influences on social interactions impact why some teaching experiences can lead to learning, and 3) learning is more affective when performed in a situated environment. Learning-by-teaching supplies the learner with an opportunity to experience social interactions with peers and teachers, while modeling what they know about teaching in an appropriate learning environment.

LEARNING-BY-TEACHING APPROACHES

There are a plethora of existing learning-by-teaching approaches. Varieties have been comprised and used at all levels of education to extract the benefits and combat the difficulties. These approaches include, but are not confined, peer assisted learning, cooperative learning, clinical experiences for pre-service teachers, and teachable agents. Each category has been used and supported through research to positively impact learning outcomes (Aronson, Blaney, Stephan, Sikes, & Snapp, 1978; Damon, 1984; D.W. Johnson & Johnson, 1981; Slavin, 1982). The following sections will elaborate on the four learning-by-teaching approaches. Each approach will be discussed to provide an

overview, specific methods, and research identifying the positive and negative affects on the classroom and the students.

Peer-Assisted Learning

Peer-assisted learning is a form of learning-by-teaching that uses advanced students to assist those having difficulty grasping the material. Advanced students – high in-class achievers or students who have mastered the material previously – provide struggling students with a peer resource to assist their development of understanding. Both participants construct knowledge together through their social interactions. Varieties of peer-assisted learning exist including peer tutoring and teaching assistantships. The following subsections elaborate on these two specific methods.

Peer Tutoring - The most prevalent form of peer-assisted learning is peer tutoring. Tutoring can be defined as ‘a system of instruction in which learners help each other and learn (themselves) by teaching’ (Goodlad & Hirst, 1989). Typically in a peer tutoring environment, one student playing the role of tutor, teacher, or expert (someone who already has the knowledge or skills) supplies guidance to others who play the role of tutee, learner, or novice (Damon & Phelps, 1989). The goals of peer tutoring are to: 1) stimulate tutors, 2) provide academic and motivational help for tutees, and 3) develop relationships between students (Topping, 1988).

Cross-age and same-year peer tutoring are two forms of fixed-role peer tutoring. Affective use of each approach relies on the tutor and a tutee being designated in fixed roles. Cross-age peer tutoring employs high-achieving students who have already gained

the knowledge as tutors, while same-year tutoring employs high-achieving students in the same class as the low achieving students. Another form of peer tutoring is called reciprocal peer tutoring. Reciprocal peer tutoring differs from fixed-role tutoring by using fluid roles. Fluid roles allow each student to take a turn acting as both the tutor and tutee as part of the pedagogical approach. Reciprocal peer tutoring is a pedagogical approach rather than a supplement for high and low-achieving students.

Numerous research studies have been conducted analyzing the different types of peer tutoring. The general conclusion for tutors is that they benefit as much socially and cognitively from the interaction as their tutees (Beasley, 1997; Chi et al., 2001; Graesser et al., 1995; Webb, 1983). A number of reviews support this claim. Early reviews on tutoring programs concluded that a tutoring experience does affect cognitive gain for tutees and might contribute to the academic growth of the students who provide the tutoring (Devin-Sheehan, Feldman, & Allen, 1976; Ellson, 1976; Rosenshine & Furst, 1969). The limiting factor on these analyses was the unsystematic approach taken by most researchers in their early analysis of these programs. The reviews note that the studies included in their analysis only show benefits when the program was well structured, when students were trained properly to be tutors, and when the type of student who could benefit from being a tutor was appropriately matched with those who could benefit from being a tutee. Hindrances related to the structure, training, and types of students often lead to the downfall of such programs.

Later reviews by Sharpley & Sharpley (1981) and Cohen, Kulik, & Kulik (1982) performed more statistically significant meta-analyses of tutoring programs. Sharpley & Sharpley's meta-analysis of 82 peer tutoring studies reported substantial cognitive gains

for both tutors and tutees. Cohen et al. analyzed 65 studies – only 38 of which studied the effects on tutors – to determine the overall educational outcomes of tutoring in regards to achievement, self-concept, and attitudes. Cohen et al. concluded that students who tutored generally performed better on examinations than control students with no teaching experience (33 of 38 studies), displayed a small positive change in self-concept (12 of 16 studies), and displayed increased positive subject-matter attitudes (4 of 5 studies). These two meta-analyses combined conclude that tutors gain a better mastery of and develop positive attitudes toward the subject matter when given a tutoring opportunity. Self-esteem was unaffected.

Missing from the meta-analyses are additional benefits outside the realm of greater understanding of content. These benefits include increased confidence, refined communication and social skills, changes in attitudes and motivation toward school, working faster, having a higher sense of personal responsibility, and simply enjoying their learning experience more (Cloward, 1967; S. W. Ehly & Larsen, 1980; Fantuzzo, Dimeff, & Fox, 1989; Fuchs, Fuchs, Karns, & Hamlett, 1996; Gartner et al., 1971; Goldschmid & Goldschmid, 1976; Greenwood, 1984; Mathur & Rutherford, 1991; Slavin, 1987; Topping, 1996). For low-achieving tutors, these experiences have also decreased dropout rates, truancy, and tardiness (Cardenas, Harris, del Refugio Robledo, & Supik, 1991).

Teaching Assistantships - Another form of peer-assisted learning is the use of teaching assistants at the university level. Teaching assistantships occur as cross-year small-group learning. Many institutions award teaching assistantships (TAs) to graduate and

undergraduate students to supplement large collegiate classes. Graduate students in many cases are even required to perform a TA as it is deemed an aid in the student's own mastery of the field (McKeachie & Kulik, 1975) and helps to prepare them for a possible professorship (Moust & Schmidt, 1994; Nyquist, Abbott, Wulff, & Sprague, 1991). TA roles vary among institutions and classes, but typically include leading small subsections of the larger lecture, guiding student laboratory assignments, and grading student assignments. Very little research has been conducted on the specific effects of a TA for the teaching assistant. Most research on TAs is primarily focused on how such experiences hinder graduate student graduation rates. The most relevant study is a comparative analysis of research assistantships (RA) and teaching assistantships. Ethington & Pisani (1993) analyzed all the graduate students at a single university who participated in both or either an RA and a TA during their graduate school tenure. Those who participated in both a TA and an RA self-reported that they benefited the most. Those who just had a TA experience were perceived to benefit far less than those participating in both or just an RA. These results are not surprising considering the high emphasis on research over teaching in major research universities, where TAs are most common.

A few other studies indirectly studying TAs as cross-year small-group tutoring have produced some subjective feedback data from participating TAs. These studies indicated that tutors reported improved communication skills, increases in confidence, and improved knowledge of the subject (Arneman & Prosser, 1993; Bobko, 1984; American River College, 1993; Moody & McCrae, 1994). Johansen et al. (1992) also

reported that TAs were rather anxious. More work is needed to fully understand the overall effects of a TA on the teaching assistant.

Cooperative Learning

Cooperative learning is a broad categorization of in-class learning approaches used to enhance academic performance, increase self-esteem, and encourage positive social relationships (Greenwood, 1984; Sharan, 1980; Slavin, 1983). Learning is achieved in a cooperative learning environment by promoting learning together through positive interdependence, face-to-face interactions, individual and group accountability, interpersonal and small-group skills, and group processing (D.W. Johnson & Johnson, 1983; D. W. Johnson, Johnson, & Smith, 1991; Slavin, 1983, 1995; Smith, 1996).

Cooperative learning drives each student in the group to be responsible for their own learning and the overall understanding of the group members. Some students within the group will take on a teaching role. Different content areas will call for different group members to teach, maintaining high quality explanations vital to learning (Webb, 1989; Webb, 1991, 1992). Group sharing of the responsibility allows for the overall group to be imparted with a deeper and more sympathetic understanding of the content (Damon, 1984; O'Donnell & O'Kelly, 1994). Cooperative learning, therefore, allows for students of all abilities to use teamwork to accomplish academic tasks and improve their understanding of a subject.

A number of research studies have been conducted on cooperative learning. A 1989 review by Johnson & Johnson reported that more than 875 studies had been conducted on cooperative learning environments. With copious research comes copious

variation. Variation exists not only in the age of the students or the subject being taught, but with the variety of cooperative learning methods that have been developed. Some examples include the Jigsaw method (Aronson et al., 1978) reciprocal teaching (A. L. Brown & Campione, 1990; Palincsar & Herrenkohl, 2002; Palinscar & Brown, 1984), Think-Pair-Share (Lyman, 1981), Roundtable Brainstorming (Osborne, 1963), Teams-Games-Tournament (DeVries & Edwards, 1973; DeVries & Slavin, 1978), Student-Teams and Achievement Division (Slavin, 1978, 1986), and Group-Investigation (Sharan & Hertz-Lazarowitz, 1980). The studies performed on these cooperative learning approaches have analyzed variables ranging from achievement and creativity to interpersonal relationships, ethnic relations, and self-esteem.

Johnson & Johnson's (1981, 1989) review is a comprehensive analysis generalizing the average student in a cooperative learning environment. Their conclusion was that students who learned cooperatively typically produced greater achievement gains than students in individualistic or competitive situations. Students also displayed higher levels of self-esteem. Cooperative learning also typically promotes greater cognitive and affective perspective taking shown through increased linking among students (D.W. Johnson & Johnson, 1983) and helps to develop creative thinking (Triandis, Bass, Ewen, & Mikesell, 1963). Each approach varies on its effectiveness within these realms. Also, it must be noted that not everything that appears to be cooperative learning is actually cooperative learning. Cooperative learning does not occur just by placing students in groups with no structure. Having a group of novice students without guidance will most likely lead to negative consequences and numerous

propagated misconceptions. When used as designed, most cooperative learning approaches will positively effect education through learning-by-teaching.

Preservice Teacher Clinical Experiences

Practicums and internships are forms of experiential learning that are used to complement campus-based studies. These clinical experiences are not implicitly learning-by-teaching approaches, except for when they are integrated into the learning of a preservice teacher. The practicum for preservice teachers is the actual form of the student's future profession. ** Pre-service teacher practicums are opportunities to apply and connect knowledge, skills, and attitudes developed in class to a real world experience. Practice experiences before entering the professional world of teaching maximize exposure to the realities of the profession preventing teachers from entering into a 'sink or swim' situation (Titley, 1984).

There are three theories accepted in the education community pertaining to the purpose of using a practicum or internship for preservice teachers. The traditional theory is that such experiences grant future teachers a situation to link theory with practice within a regularly structured and supervised situation. Here the argument is that students learn theory within their classes and then apply it to practice. The second theory argues that the role of a practicum or internship is to raise problems and issues used to trigger the investigation of related theory and pedagogical knowledge (Schon, 1990). This argument reverses the role of theory and practice so that practice is the guiding tool. The third alternative theory argues that the crucial factor involved in a practicum or internship

** This is not to say that teaching does not occur in every profession, but teaching is the everyday explicit work in the life of a teacher.

is the opportunity to reflect on or to examine experience in the light of the individual's current knowledge and understanding (Boud, Keogh, & Walker, 1985). The focus of this argument is on what enables learners to turn experience into learning in order to gain maximum benefit from the situation.

In a review of studies looking at preservice teacher clinical experiences, reports have resulted in positive and negative images. Levine (2006) and Whitcomb, Borko, & Liston (2007) identify that some clinical experiences have helped to prepare teachers, but problems in the integration of theory and practice have hindered the effectiveness. Negative impressions are due in part to recurring weaknesses regarding inconsistency, disconnects from university coursework, limited success in developing reflection and self-evaluation skills, and lack of quality from supervisors (Neville, Sherman, & Cohen, 2005; Ralph, 1994-1995; Ralph, Walker, & Wimmer, 2007). However, most students still find the practicum an essential part of their preservice education. In a study by Ryan, Toohey, & Hughes (1996), preservice teachers self-report to see the practicum as a central part of their teacher education. The practicum was seen as the most important, satisfying, relevant, practical, worthwhile feature of their pre-service education based on what they gain toward their future vocation. Johnson, Ratsoy, Holdaway, & Friesen (1993) similarly report that beginning teachers saw the internship as a valuable induction scheme. The practicum eliminates the disjunction between the theory and professional practice, while easing the stressful transition into a full time teaching position. The caveat from these two studies is that the experience was only worthwhile when organized and properly supervised.

Intelligent Tutoring Systems: Teachable Agents

A technological approach to putting a student in the role of teacher is to use intelligent tutoring systems (ITS). An ITS is a form of artificial intelligence that provides direct customized instruction or feedback to students performing a task. The advantage is that students can work with these expert systems without the intervention of another human being (Psotka, Massey, & Mutter, 1988). The expert system simulates aspects of a human tutor morphing social interaction into a digital interaction.

Most intelligent tutoring systems consist of four modules: interface, expert, student, and tutor. The combination of these modules supplies the student with a reference guided computer-based interaction. Student responses signal the system to react, signaling subsequent corrective action. These actions develop a cognitive model of a student as s/he interacts with the program. An example is the Cognitive Tutor developed by Carnegie Learning (Koedinger & Corbett, 2006).

Teachable agents (Brophy, Biswas, Katzlberger, Bransford, & Schwartz, 2000) differ in that they are intelligent tutoring systems designed to elicit learning-by-teaching. Students who use a teachable agent are given the task of teaching a computer playing the role of the student. The advantage of such a platform is that teachable agents develop structured networks of knowledge similar in nature to how a student would develop knowledge when taught. The student teaching the computer learns how to take on responsibility (as a teacher), while learning how to prepare for future learning (Biswas, Leelawong, Schwartz, & Vye, 2005).

One example of a teachable agent is Betty's Brain (Leelawong, et al., 2002; see Blair & Schwartz, 2004 for another example). Betty exists as a virtual person capable of

being taught, queried, and quizzed. Each of the three activities included affords the student a real teaching experience as previously identified. The process begins by having a student impart, or teach, knowledge to the computer. That content is stored in Betty's Brain so that the computer can answer subsequent questions. When the computer is quizzed, the student can observe and evaluate how well they taught the computer. When queried, the student is allowed to ask the computer questions to determine what the computer has learned.

Early research studies conducted on the effectiveness of teachable agents indicate benefits toward student learning and transfer of knowledge (Brophy et al., 2000).

Teachable agents are capable of capturing a student's attention, while motivating them to accomplish a goal. Further studies of teachable agents have shown that students who teach the computer develop a deeper understanding of the content and organize their ideas more efficiently than those who study the material (Leelawong et al., 2002; Leelawong et al., 2003). Interactions with the teachable agent were also shown to help students assess their teaching, implying gains in their own learning (Biswas et al., 2004; Biswas et al., 2005).

The clear limitations of teachable agents are the scope and ability of the teachable agent. Unlike human beings, a computer cannot improvise. In a study by Uresti's (2000) on computer learning companions, it is suggested that learning gains can be directly impacted if the computer confuses the student by not performing as told; however, very recent studies have begun to identify significant differences in learning performance and learning behaviors of groups working with well trained teachable agents (Leelawong & Biswas, 2008; Wagster, Tan, Wu, Biswas, & Schwartz, 2007).

Summary

The description and research of the various forms of learning-by-teaching have shown that these pedagogical methods enhance student learning if properly structured. Properly structuring these methods to ensure usefulness starts by educating teachers and students on how to appropriately work within each system. Time limitations become a factor and shortcoming. Large amounts of time are required when first implementing most learning-by-teaching learning techniques. Another hurdle for teachers to clear is gaining comfort with the chaos that ensues when students are no longer rooted to their seats. This often leads to high volumes of noise and other class management difficulties. A successful learning-by-teaching situation begins with persistence and a constant reminder that the positives outweigh the negatives. A higher influx of learning-by-teaching will occur once more teachers see the gross overall advantages.

Within engineering these approaches have seen increased use, but very little research has been conducted analyzing their effects. The nature of engineering ideally fits the use of learning-by-teaching. The following section will build off of anecdotal reports to discuss the expected implications of learning-by-teaching on engineering.

IMPLICATIONS FOR ENGINEERING EDUCATION

Engineering education is a highly criticized subject in the United States. In *Rising Above the Gathering Storm*, Augustine (2005) argues that the United States must make improvements in K-12 education, research, higher education, and economic policy if it wishes to uphold world prowess in engineering. Published reports by science and engineering groups advocate for a greater emphasis on educating students on professional

skills (i.e. teamwork, communication, and leadership) (ABET, 1999; EDC/ASEE, 1994; NSF, 1996). Making these changes starts with reforming classroom practice (J. S. Brown et al., 1989; Chickering & Gamson, 1987; Dewey, 1938; Fink, 2002; Lave & Wenger, 1991). Engineering educators need new approaches to teach about specialized bodies of knowledge, application knowledge, and professional skills (Smith, 1988). This review suggests learning-by-teaching approaches as pedagogical solutions.

Learning-by-teaching approaches have seen use within engineering classrooms (Coyle, Jamieson, & Oakes, 2005; deGrazia, Sullivan, Carlson, & Carlson, 2000; Mourtos, 2004; Portsmore, Rogers, & Pickering, 2003; Smith, 1993, 1995); however, little research has been conducted reporting the impacts of these techniques on engineering education. The most prominent results rely on student self-reported data. The earliest work by Goodlad et al. (1979), and later Saunders (1992), analyzed the specific affects of tutoring within engineering on the development of communication skills. Student self-reported data lends itself to the notion that a tutoring experience helps engineering students to improve their communication skills along with their ideas of their professional responsibilities. Magin & Churches (1995), and later Ramaswamy et al. (2001), extend Goodlad et al. and Saunders work to include an analysis on developing not only communication skills, but also a deeper understanding of the content. Students expressed an increase in content gains attributed to the consequential reformulation and reorganization of knowledge brought on by tutoring.

Cejka et al. (2005), and later Carberry et al. (2007), conducted two separate experiments on a group of undergraduate engineering students participating in K-12 engineering outreach. In Cejka et al.'s study, students were interviewed to determine the

effects of K-12 outreach on their communication skills and sense of citizenship. Students self-reported both improvement in their communication skills and an enhanced sense of the civic responsibilities embedded in being an engineer. Carberry et al.'s study extended this study to include a quantitative analysis of student gains in engineering understanding as well as changes in student attitudes and confidence toward engineering design.

Students generally displayed increased understanding of the engineering design process accompanied by positive changes in attitudes and confidence toward engineering. The outreach experience was not beneficial for all participants. The results of this study are questionable as the assessment measures were not validated.

Cooperative learning in engineering has also been investigated in two studies by Johnson et al. (1991) and Smith (1996). These studies report that students felt they learned the material while teaching each other in a team context. The cooperative learning approach accomplished the goal of building team working skills, communication skills, positive interdependence, and accountability. In addition, Felder and Brent's (1994) analysis of cooperative learning in engineering notes that student professional skills are not the only aspect impacted by cooperative learning. Students involved in cooperative learning report a deeper learning and increased positive attitudes toward engineering and themselves as a result of their cooperative learning experience.

The research results of these studies are a start to analyzing learning-by-teaching in engineering. Future work in this area should build off of this base to conduct more rigorous studies addressing engineering educator concerns about learning-by-teaching. Future results should focus on addressing the common misconception that the end impact of learning-by-teaching is not worth the effort required to implement learning-by-

teaching. Studies also need to produce quantitative results to convince quantitative-centric engineering educators. An influx of learning-by-teaching in engineering will not be undertaken until such obstacles can be cleared.

CONCLUSION

The learning-by-teaching paradigm is a well-established way of educating students in and out of the classroom within many disciplines. Although the classification of learning-by-teaching encompasses numerous approaches, each approach presented in this review can give participants an ability to grasp the underlying structure of the material. Learning-by-teaching offers the learner an opportunity to learn how to learn while playing the role of the teacher. This experience and knowledge affects how the student acts once they are pupils again. In the end, if used appropriately, learners can effectively and efficiently learn not only the content, but useful professional skills improving upon the way students learn today.

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