Transfer of Learning: Foundation for Engineering Outcomes

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Abstract

Ultimately, engineering graduates are asked to apply their learning in contexts different from those in which they learned the material. Their ability to transfer their learning to new contexts is the basis for desired learning outcomes such as problem solving, design, analysis of socio-cultural contexts, and lifelong learning. However, results from research and experience have given rise to a wide range of judgments about the ease and likelihood with which transfer occurs. Without clearer understanding of transfer, efforts to improve crucial engineering outcomes such as problem solving, design, integration, and analysis of global and societal impacts of proposed solutions may lack a firm theoretical foundation. To stimulate further conversations and research on transfer in engineering education initiatives, the paper will examine research on transfer and address three issues. How might transfer be defined? How might transfer be assessed? How might transfer be facilitated?

Introduction

To create engineering designs, solve problems, analyze technical and socio-cultural contexts, and more, engineering graduates will be expected to apply their skills and knowledge in diverse, unpredictable contexts. That is, they will be expected to transfer what they learned before graduation in classroom contexts to many different contexts, including the workplace, government, and international forums. Ideally, research on transfer of learning would provide principles and examples that engineering educators might apply in creating assessment and learning activities that would help graduates enhance their capabilities to transfer their learning. However, results from research and experience have given rise to a wide range of judgments about the ease and likelihood with which transfer occurs. For example, Detterman states "there is very little empirical evidence showing meaningful transfer to occur and much less evidence showing it under experimental control"[1]. On the other hand, everyday experience suggests that transfer occurs routinely and Haskell offers "deep-context teaching" as an approach to teach for transfer[2]. Despite the different positions, the importance of transfer is clear. "The sole reason why we have schools and universities, that is formal settings designed for learning activities is that we expect that learning will transfer"[3]. Without clearer understanding of transfer, efforts to improve crucial engineering outcomes such as problem solving, design, integration, and analysis of global and societal impacts of proposed solutions may lack a firm theoretical foundation.

To stimulate further conversations and research on transfer in engineering education initiatives, the paper will examine research on transfer and address four issues.

- How might transfer be defined? Definition of transfer is crucial, because the likelihood of transfer often depends on its definition. Many definitions of transfer have been offered and results about the likelihood of transfer often depend on the definition. In addition, recent research has offered descriptions of transfer as preparation for future learning and of how past learning can affect future task performance. These more recent definitions may be more applicable to integration, problem solving, and design.

- How might transfer be assessed? Assessment is dependent on definition of the intended learning outcome. Existing approaches to assessment of transfer will be examined.
- How might transfer be facilitated? Learning activities can be designed to increase the likelihood that learners will be able to transfer their learning beyond its original context. For example, lectures may be redesigned to encourage engagement in effective processing, particular discourse mechanisms may be used to promote deep learning/comprehension, and assessment may be based on the theory of successful intelligence.

After these issues are addressed, potential directions for future research in engineering education will be offered.

Defining Transfer of Learning

Transfer of learning implies the ability to use what was learned in an original context to contexts that are different from the original. Although easily and succinctly stated, the previous simple definition raises more questions. First, the original context and the application context might be very similar or very different. As McKeachie states "We talk about 'transfer of learning' when … learning is displayed in a situation somewhat different from that in which the original learning occurred. If the transfer situation is so different that the use of learning encounters some barrier of difficulty we speak of 'problem solving.' When the situation is greatly different and the distance of transfer need is greater still, we speak of creativity"[4]. Recognizing that differences in the original and application contexts might result in differences in the ability to transfer learning, two types of transfer were recognized: near transfer, when the original and application contexts were similar, and far transfer, when the original and application contexts were very different. Although near and far transfer attempt to capture some of the variations between original and application contexts, Barnett and Ceci[5] present a case that the two-category taxonomy does not begin to explain differences in the massive literature on transfer that has been published. Then, they offer a more elaborate taxonomy that addresses two questions. The first question is "What is expected to be transferred?" They break down the question into three dimensions: learned skill, performance change, and memory demands and provide three anchors for each dimension that describe the potential spectrum for each of the three dimensions. The second question is "How different are the original and application contexts?" For the second question, they offer six dimensions in which differences between the two contexts can be measured: knowledge domain, physical context, temporal context, functional context, social context, and modality. For each of the six dimensions, they provide five anchors that describe the potential spectrum for the six dimensions. Although Barnett and Ceci concede that their taxonomy may not be the final answer, they suggest that it provide a better framework in which to address questions about transfer than simply the distinction between near and far transfer.

Bransford and Schwartz[6] suggest that entirely new approach to transfer is necessary. Instead of asking whether learners can apply what they learned in one context to another context, they suggest asking whether learning experiences have equipped learners to be better prepared for future learning. Hatano and Greeno[7] have questioned the authenticity of sequestered testing, which is the norm for transfer studies. Instead, they suggest that in most situations in which transfer of learning will be expected, learners will have access to external resources. Therefore, transfer might reconceptualized as the degree to which learners can make productive use of the external resources that they can access. De Corte summarizes the shift as "a strong tendency toward reconceptualizing transfer, emphasizing the broad, productive, and supported use of acquired knowledge, skills, and motivations, as opposed to the direct and sequestered application of skills from one situation to another"[8].

Assessing Transfer of Learning

Assessment of transfer of learning will depend upon the definition of transfer that is used. As the previous section has shown, transfer of learning remains a critical learning goal in flux. Assessment will require collecting data in a context that differs from the context in which learning occurred. Beyond that perhaps difficult to implement challenge, several questions may need to be addressed in assessing transfer of learning:

- What is to be transferred? Using the four dimensions of knowledge in the revised Bloom's taxonomy[9], will the study examine transfer of factual knowledge, conceptual knowledge, procedural knowledge, or metacognitive knowledge?
- How will transfer be recognized? Will learners demonstrate transfer through greater facility in problem solving; construction of concept maps; performance on examinations in courses downstream in a prerequisite chain from the course in which original learning occurred; greater facility in learning new, but related concepts, etc?
- In what ways will the context of the environment in which transfer is to be demonstrated differ from the context in which original learning occurred? Barnett and Ceci[5] have already elaborated six dimensions along which the original and application contexts may differ and choices for each of the six dimensions would be appropriate.

Potential models for assessment might be found in studies by Chen and Klahr[10], Gick and Holyoak[11], and Fong et al.[12]. It would be helpful to provide more constructive information on assessment of transfer of learning, but the literature that was examined for this paper does not support additional propositions.

Enhancing Transfer of Learning

Since serious questions remain about the nature of transfer and how meaningful data on the extent to which transfer occurs might be collected and analyzed, definitive recommendations to enhance transfer are difficult to construct. However, examination of the literature has yielded several different sets of recommendations from researchers. Synthesis of these recommendations should provide useful guidelines until further research provides a more solid base for empirically supported practices. Haskell[2] offers the following eleven principles.

Haskell Principle #1. Acquire a large primary knowledge base in the area in which transfer is required
Haskell Principle #2. Acquire some level of knowledge base in subjects outside the primary area
Haskell Principle #3. Understand what transfer of learning is and how it works
Haskell Principle #4. Understand the history in the area(s) that transfer is wanted
Haskell Principle #5. Acquire motivation, or more specifically, a "spirit of transfer"
Haskell Principle #6. Develop an orientation to think and encode learning in transfer terms
Haskell Principle #7. Create cultures of transfer or support systems
Haskell Principle #8. Understand the theory underlying the area(s) in which we want to transfer
Haskell Principle #9. Engage in hours of practice and drill
Haskell Principle #10. Allow time for the learning to incubate
Haskell Principle #11. Observe and read the works of people who are exemplars and masters of transfer thinking

De Corte[8] in his examination of changes in definitions of transfer provides five recommended guidelines that are supported by existing research.

De Corte Principle #1. First, learning environments should encourage "productive use of knowledge, skills, and motivations … [to] support constructive learning processes in all students"[8].

De Corte Principle #2. Second, "powerful learning environments should enhance students' cognitive and motivational self-regulation"[8]. Self-regulation is required for lifelong learning and self-regulation requires that students become more aware and adept with processes through which they transfer knowledge and skills.

De Corte Principle #3. Third, socio-cultural supports for learning, such as interaction and collaboration, can help students broaden their understanding of cognitive tools and motivational qualities that are acquired in initially narrow contexts[7,13].

De Corte Principle #4. Fourth, the "situated character of learning also means that preparation for future learning can be fostered by confronting students with meaningful, [realistic, challenging] … problems that are representative of tasks they will encounter in the future"[8].

De Corte Principle #5. Fifth, learning activities should induce "students to articulate and to reflect on their cognitive and motivational processes during learning and problem solving. Indeed, to become productive and self-regulated users of their cognitive and motivational potentials, students should be aware of them, and believe that they are worthwhile and useful"[8].

Extensive work on a pedagogical approach for open-ended problems referred to as Model Eliciting Activities (MEA) has generated six principles in developing a MEA[14-16]. Since the approach is intended to promote several important educational goals, these guidelines should be considered in looking for ways to enhance transfer.

MEA Principle #1. The *Model-Construction Principle* requires learning activities in which students construct a mathematical model, which includes explanations of the product and process as well as mathematical artifacts such as functions and equations, for a significant problem. Applying the principle encourages students to engage in thought processes in which they create a product in addition to applying existing products and concepts.

MEA Principle #2. The *Reality Principle* requires learning activities begin with an actual context so learners can connect their activities to real-life applications.

MEA Principle #3. The *Self-Assessment Principle* requires learning activities that include criteria with which learners can evaluate the ideas that they generate during the process and modify their ideas to improve scores with respect to the criteria.

MEA Principle #4. The *Model-Documentation Principle* requires that learners document not only the results of their work but also document the process through which they are constructing their results. Making the process and the product explicit helps creates greater awareness of thought processes and may open opportunities to help students improve their metacognitive skills. In many MEAs, the documentation has taken the form of a memo to the client. This principle yields information for instructors about students' conceptual understandings and provides the materials for assessment of student learning.

MEA Principle #5. The *Share-Ability and Re-Usability (or Generalizability) Principle* requires students construct results that can shared with others and that others can adopt and adapt for their requirements. Students must begin to think about how others might use their results and craft the results in forms that promote applications by others. If learners work in teams, application of the principle may encourage greater communication as team members talk about how to promote sharing and reuse.

MEA Principle #6. The *Effective Prototype Principle* requires that learners construct a solution that addresses the problem statement.

Halpern and Hakel[17] offer ten empirically-based principles for constructing learning environments that enhance transfer.

Halpern and Hakel Principle #1. The single most important variable in promoting long-term retention and transfer is "practice at retrieval."

Halpern and Hakel Principle #2. Varying the conditions under which learning takes place makes learning harder for learners but results in better learning.

Halpern and Hakel Principle #3. Learning is generally enhanced when learners are required to take information that is presented in one format and "re-represent" it in an alternative format.

Halpern and Hakel Principle #4. What and how much is learned in any situation depends heavily on prior knowledge and experience.
Halpern and Hakel Principle #5. Learning is influenced by both our students' and our own epistemologies.
Halpern and Hakel Principle #6. Experience alone is a poor teacher.
Halpern and Hakel Principle #7. Lectures work well for learning assessed with recognition tests, but work badly for understanding.
Halpern and Hakel Principle #8. The act of remembering itself influences what learners will and will not remember in the future.
Halpern and Hakel Principle #9. Less is more, especially when we think about long-term retention and transfer. "The amount of detail that learners will need at [a] future, unknown time and place should guide decisions about how deeply a particular element of content should be learned and what level of detail is important"[17].
Halpern and Hakel Principle #10. What learners do determines what and how much is learned, how well it will be remembered, and the conditions under which it will be recalled.

Examining these four sets of principles reveals some encouraging overlaps and connections. First, De Corte's first and fourth principles reinforce the intention of the MEA Reality Principle. Both support the use of actual contexts in designing effective learning activities. By helping students to see how what they are learning can be applied in a context with which they can relate from their experiences, learning activities that are based on realistic contexts facilitate transfer of learning to other realistic situations. However, the value of the realistic contexts is tempered by remarks connected with the sixth principle from Halpern and Hakel. "[There] is a popular belief that all learning and assessment should be 'authentic'—that is, nearly identical in content and context to the situation in which the information to be learned will be used. But what is missing from most authentic situations—and from most real-life situations as well—is systematic and corrective feedback about the consequences of various actions"[17].

Second, Haskell's third and eleventh recommendation, which are intended to promote greater understanding of the nature and practice of transfer, De Corte's second and fifth guidelines for enhancing self-regulation, and the MEA Self-Assessment and Model Documentation principles all reinforce that the proposition that transfer is enhanced to the degree that learners reflect on their learning in the process of being more self-directed learners. Self-assessment is essential for self-regulated learning and emphasizing model building processes reinforces learner focus on learning processes in addition to graded products. Haskell's recommendation that learners become more aware of transfer and more familiar with the nature of the transfer of learning reinforces the assertion by Wood et al that learning activities to promote problem solving require explicit attention to the transfer of problem solving skills that are being presented to students[18]. Matsui and De Corte[19] developed and implemented an intervention that promoted greater knowledge of two self-regulated learning skills, orienting and self-judging, among the experimental group. Assessment data from the experiment was encouraging.

Third, the MEA Model Construction Principle and De Corte's first principle both convey the importance of learning activities in which students construct products from their own synthesis of information instead of, or in addition to, applying products that have been constructed by others and presented to the students. These types of learning activities are consistent with the first, second, seventh and tenth principles from Halpern and Hakel. Self-construction aligns with the proposition by Baxter Magolda[20] that learners must move to positions of self-authorship and that pedagogies should be developed to promote self-authorship. Self-construction was also advocated by Cowan as he asked students to develop scripts for solving a specified class of engineering mechanics problems instead of solving a single problem from that class[21]. Readers are encouraging to discover and synthesize further connections among the four sets of principles.

Despite commonalities among the four sets of principles, there are some potential contradictions. For example, consider the first principle from Haskell that encourages presentation of a large domain-specific knowledge base and the ninth ("less is more") principle from Halpern and Hakel. Finding an instructional approach that is responsive to both principles appears problematical. Contradictions among principles that are being advocated to enhance transfer may limit adoption of these principles by engineering faculty members.

Conclusions

Transfer of learning is a critical issue underlying potential improvement of performance with respect to a number of important learning outcomes for engineering graduates. As shown in this analysis of the literature, much work remains to be done in order for research on transfer of learning to provide a useful theoretical foundation for proposing improvements in engineering education. First, the nature of the transfer of learning requires clarification. Several different definitions of transfer have been proposed. Regardless of the definition, questions about the degree to which transfer occurs remain unanswered. Second, methodologies for assessing transfer of learning need to be developed. Although issues that the methodologies might address have been identified, methodologies, which might be used for various studies in engineering education, do not yet exist. Definitions and assessment methodologies are precursors to providing experimentally-based principles for enhancing transfer in engineering.

Although a more solid research base is necessary, several sets of principles for enhancing transfer have been offered. Analysis of four sets of principles has revealed at least three guidelines that should support pedagogies that would lead to enhanced transfer of learning:

- **Realistic Context Principle:** Principles from several sets highlight the importance of providing authentic contexts for open-ended challenges that are offered to learners. Learners should be able to draw connections between their own experiences and the contexts that are offered. Service learning is a growing initiative that rests on this principle. However, as Halpern and Hakel point out, realistic contexts alone are insufficient. Learners, in the course of working on the challenge, must be provided with feedback that allows them to recognize and make corrections.
- **Self-regulated Learning Principle:** Learning activities that are intended to enhance transfer should promote awareness, knowledge and skills required for self-regulated learning.
- **Self-construction Principle:** Asking students to synthesize information to formulate concepts or models is a necessary activity in promoting transfer.

Although the available literature provides some support for enhanced transfer of learning, more research is required. Suggestions for further research have been offered.

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