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A Theoretical Review: The Role of Knowledge-Based Symmetry in Engineering Student Collaboration

Mr. Jack Elliott, Utah State University

Jack Elliott is a concurrent M.S. (Mechanical Engineering) and Ph.D. (Engineering Education) graduate student at Utah State University. His M.S. research is in experimental fluid dynamics, his Ph.D. work examines student social support networks in engineering education, and his other research activities include developing low-cost technology-based tools for improving fluid dynamics education.

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Introduction

The purpose of this theory paper is to describe the role of knowledge-based symmetry on co-regulation and co-construction of learners in formal group settings. To motivate this purpose, this paper begins by describing the practicality of these topics in modern engineering education including how co-regulation and co-construction are crucial aspects of group learning activities. With the chosen topics incentivized, this paper introduces the necessary foundations of symmetry, cognitive constructivism, co-construction, self-regulation, and co-regulation. Following the description of these principles in cognition and a discussion of their relationship to each other, this paper proposes a framework regarding the mediating role of knowledge symmetry (i.e., how similar two individual's knowledge levels are) in the co-construction and co-regulation of learners, which (to the author's knowledge) has yet to be synthesized for curricular design in the relevant literature. Finally, this paper provides a framework-based discussion to benefit educators seeking collaboration in the classroom.

Background

As an engineer and educator, the author's work in engineering education has focused on identifying variables related to learning for the purpose of improvement. To date, the author's experience has led them to the epistemological understanding that the learner and other individuals are inseparable variables when accomplishing this purpose. Specifically, a large amount of information is considered *indirect* knowledge, or knowledge only reasonably accessible to a learner through social contact [1]. Further, within the learning context, interactions are adapted reciprocally by the learning environment and learner [2]. These and related foundations indicate that understanding the social aspect(s) of the learning environment is essential for understanding and improving learning.

To identify and optimize social variables related to student learning, recent engineering education literature shows a growing awareness of and interest in peer support. These observations of student interactions and outcomes indicate improved learning, motivation, and self-efficacy due to student peer support networks [3], [4]. Among the efforts to incorporate those peer supports in learning; formal (in-class) group work plays a key role [5]–[8]. Studies regarding formal engineering group work are extensive enough that Kalaian and colleagues [5] were able to conduct a meta-analysis exploring the highest likelihood of individual student grade achievement according to varied group structures. Among the group structures assessed (i.e., self-selecting, random assignment, and knowledge-based grouping), *knowledge-based groups* (i.e., groups which place students together based on an estimate of their course-work relevant knowledge) showed the lowest overall effect size [5]. However, recent authors have observed significant improvements from knowledge-based grouping in individual studies [9].

These conflicting results may be a result of misalignment between group designs and instructor's pedagogical goals. Specifically, some instructors seek peer *scaffolding*, where one peer supplements the knowledge of another [10], [11]. However, other instructors seek peer *collaboration*, where each group member contributes equally [12]–[14]. While each strategy has substantial merit, misalignment between the implications of each strategy and the instructor's group assignment methods may have confounded the meta-analysis results regarding knowledge-based grouping. To address this issue, this paper will first describe the necessary cognition topics for group interactions: constructivism, co-construction, self-regulation, and co-regulation. After discussing these foundational group interaction topics, this paper will synthesize the literature regarding these topics through the lens of knowledge-based symmetry.

Symmetry

Symmetry, in the context of social interactions, describes the existence and propagation of knowledge and status-based differences through interactions between two or more individuals [12], [13]. For example, two individuals who have the same level of knowledge on a given topic have a high level of (topic related) knowledge symmetry. When one individual has a different level of knowledge or status (e.g., teacher and student), the relationship is along that trait, asymmetric. How the status and knowledge-based symmetry between two individuals manifests in interactions is specifically referred to by Barron [13] as *mutuality*. High mutuality is characterized by each individual in a group realizing and constructing a joint solution space equally. Low mutuality is characterized by a dominant constructor of the joint space.

Deploying these definitions, knowledge symmetry has potential to mediate the mutuality between individuals and be subverted by other socially-negotiated asymmetries in the context of co-construction. To demonstrate these conclusions, this paper will elaborate A) co-construction between learners, B) co-regulation between learners, C) the role of knowledge-based symmetry on co-construction between learners, then D) the role of knowledge-based symmetry on the co-regulation between learners.

Constructivism and Co-Construction

Constructivism, as described by Yilmaz [15], describes knowledge as something relative, held in the mind, and developed (or *constructed*) by the learner. Across the detailed definitions of constructivism (i.e., sociological, psychological, and radical; varied by the role of culture, social interactions, and epistemology), the constructivist philosophy generally describes that learning is a process which requires a foundation of knowledge to build on, and new information is added to the learner's existing knowledge through conceptual change [16].

As an interesting and important depiction of constructivism, prior knowledge then acts as a requirement and barrier for correct knowledge acquisition and structure [16]. That is, learners may assimilate and/or accommodate new information with existing knowledge whether the new information and/or existing knowledge are correct. The resolution of new information conflicting with prior knowledge leads to the learner restructuring existing knowledge to include the new information *or* adapting/rejecting the new information to reinforce the existing knowledge [17].

An extension of the understanding that knowledge is actively constructed in the learner's mind, co-construction involves the creation of a new "joint space" which may or may not be a part of each individual learner's conception. For example, as stated by Jacoby and Ochs [18] an argument between two individuals without resolution is still co-constructed, despite each constructor holding different knowledge. However, rather than separate knowledge from the mind, note that the co-construct is created only due to the intersection of two or more individuals. Furthering this discussion, the belonging of the co-construction to the mind and/or society determines the attribution to the several sub-categories of sociological, psychological, or radical constructivism. For the purposes of this paper, these nuances are less important than the understanding that the co-constructed space is A) a result of the intersection of two or more learners, and B) an opportunity for each learner to actively access and deploy new information. As a result, this unique information access and retrieval is the aspect of co-construction to be optimized by symmetry.

As described by Barron [19], social quasi-experiments have found that a co-constructed space can improve and extend the potential exhibited by each individual learner (i.e., a co-constructing group may be greater than the sum of its parts [20], [21]). Further, Barron's [19] studies found that among similar knowledge level learners, the joint solution(s) from unsuccessful groups were of lower quality than the individual group members' solutions. In this way, some groups were worse than the sum of their parts. While Barron [19] describes that the learning of individuals in the low-performing groups was not damaged, as a means of deliberate practice [22], poor co-construction intended for collaboration should be considered a loss of learning opportunity.

To identify then mitigate the variables leading to unsuccessful group work, Barron [19] first found that the successful and unsuccessful groups had equal frequency of correct solution proposals in the joint space. However, the successful groups had a higher number of accepting and discussing responses with a lower number of rejecting and neglecting responses than the low performing groups. These findings indicate that co-construction relies on the ability of the individuals to communicate their individual model(s) of the solution space and engage with the co-constructed space (i.e., *discourse* [18], [23]). Within small groups (two or more individuals), discourse relies on each individual's mutual understanding of the joint space and access to verbally and non-verbally communicate in the group [24]. As a result, social and cognitive regulating factors are also an important determinant for a group of individuals to effectively engage in discourse (and thereby co-construct).

Self-Regulation and Co-Regulation

Prior to co-regulation, one or more individuals co-constructing must engage in at least some self-regulation. Self-regulation, as described by Zimmerman [25], [26] is a cyclical process composed of three phases: *forethought* (including analyzing the task, and acting according to goals/motivation), *performance* (including deploying strategies and making intermediate steps observable), and *reflection* (including evaluating the processes and results, and determining further courses of action). Individual learners' self-regulation relates to performance outcomes, is learnable, and is mediated by social interactions [25].

When describing the mediation of self-regulation by others, however, the issue of "self" becomes too disparate from the term. Rather, co-regulation in the literature generally refers to regulation of a task and solution between two or more individuals [27]. Within the general concept of co-regulation, Moreno et al.'s review [28] identified three epistemological views: sociocultural, sociocognitive, and systemic, which stem from modern interpretations of Vygotsky [29], Bandura [2], and Zimmerman's [26] works.

The sociocultural view of co-regulation is rooted in Vygotsky's [29] work including the "Zone of Proximal Development" (ZPD) which traditionally describes the body of knowledge which is accessible to a learner through interactions with a separate individual who holds the necessary knowledge; a *more knowledgeable other*. This idea, however, extends beyond knowledge acquisition into the idea of *for* regulation where the learner's regulation is scaffolded by the more knowledgeable other. The sociocultural view specifically depicts this co-regulation as an "authoritative" regulation of the task and solution by the more knowledgeable other scaffolding the problem-solving and self-regulatory processes of the less-knowledgeable learner.

Extending beyond the idea of an instructor *for* regulating a learner, the sociocognitive view of co-regulation, stemming from Bandura [2] and Zimmerman [26], includes three separate levels of co-regulation. These levels include other, co-, and shared regulation [28]. Other regulation involves the same traits as the sociocultural view where the teacher regulates *for* the learner while the learner self-regulates and develops. Co-regulation in the sociocognitive view is seen as a near-peer acting in a conditionally stable regulating role of the other learner(s). Finally, shared regulation refers to regulation which is symmetric, and the learners have mutual responsibility for the regulation. Moreno and colleagues [28] argue that the shared regulation is optimal among the sociocognitive views. Through these descriptions, the three levels of sociocognitive regulation descend through three purportedly distinct levels of regulation asymmetry.

Recognizing the consistencies in the sociocultural and sociocognitive views of regulation, the systemic view of regulation considers the spectrum of roles a co-regulator may take (regulating others and/or learning to regulate the self). However, this view also considers the systemic sources of asymmetry and regulatory actions as a necessary consideration for "social" regulation. Specifically, *status* is a term which indicates each learner's socially negotiated influence [30] and application of this influence may also be considered co-regulation. As learning groups are unique systems situated in a larger system, these groups are a separate entity from the individuals the group is composed of [19]. Effectively, the systemic view incorporates both the sociocultural and sociocognitive views by pointing to the fact that the co-occurrence is the intersection of systems and individuals. Adopting this systemic view of co-regulation as necessary for the implications of systemic practices on symmetry and reverting to the general language of "co-regulation" for what Moreno [28] describes briefly as social regulation, this paper will now discuss the implications of these ideas for the role of knowledge-based symmetry on group work.

Symmetry and Co-Construction

The role of knowledge-based symmetry on co-regulation includes the socially negotiated expectation that in asymmetric contexts, the more knowledgeable other will scaffold the less knowledgeable learner to maintain the correctness of the joint solution space. This reduces the likelihood of persistent misconceptions [17]. In symmetric contexts with a minimum level of knowledge, scaffolding is not required, and the co-construction is developed in a "shared" manner. A primary issue for symmetry in co-construction is then to ensure that within and outside collaboration, the joint problem space adopts the correct (if possible) representation of new information while providing all individuals the maximum potential to contribute and realize the joint space. At the end of this process, group members have successfully co-constructed the knowledge if they all realize and adopt the correct knowledge representation for future use [16].

The ability and requirement to scaffold then becomes the determinant of collaborative or scaffolded learning. To illustrate this point, Figure 1 demonstrates the combined role of knowledge asymmetry and shared vs. guided knowledge co-construction in collaboration, scaffolding, and sub-optimal strategies.

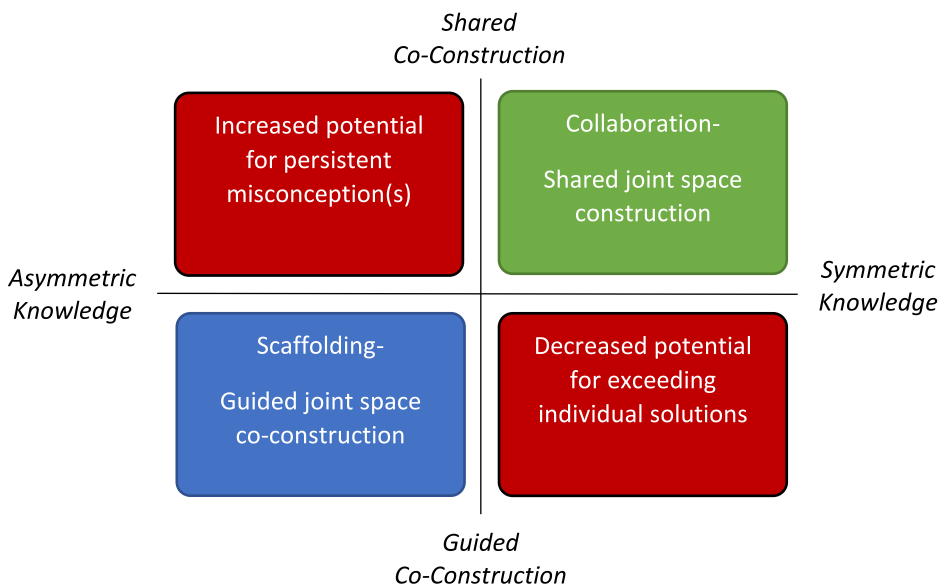

Figure 1. Proposed model of the role of symmetry and shared vs. guided co-construction levels on collaboration (green), scaffolding (blue), and sub-optimal strategies (red).

Recognizing the importance of how guided or shared co-construction (i.e., aspects of co-regulation) facilitate learning, knowledge asymmetries then determine how to properly maximize the collaboration potential for realizing a high level of mutuality and joint space co-construction while maintaining correct knowledge in the joint space.

Symmetry and Co-Regulation

Within collaborative and scaffolding strategies, the shared vs. guided co-construction relates specifically to the level of the individuals regulating themselves (self-regulation), to be regulated by the other individual(s) (*by* regulation), and to regulate the other individual(s) (*for* regulation). Without instructor intervention, perceived knowledge asymmetry is socially negotiated into influence/status and can determine levels of each co-regulation type [30] culminating into high or low mutuality. For example, a teacher in a traditional scaffolding classroom, due to the likely knowledge asymmetries from the students, is often expected to regulate the students, to regulate themselves, and to be minimally regulated by the students (i.e., to lead the class authoritatively). Reciprocally, the student may expect to be regulated by the teacher and regulate themselves (to varying degrees [12]). However, the relationship of knowledge symmetry and resulting level of mutuality, indicated by equal levels of self, by, and for regulation, is not deterministic. For example, a teacher employing active learning with the students may take a high mutuality approach (with decreased instructor *for* regulation of the students) despite the levels of knowledge and status asymmetry. This method can increase openness and student engagement due to the high mutuality [31].

Among symmetric regulators, the levels of self, *by*, and *for* regulation are approximately equal (i.e., symmetric) across individuals. For example, collaborative learning groups composed of high knowledge and status symmetry members are more likely to exhibit symmetric co-regulatory processes. In near-symmetric knowledge dyads conducive to collaboration, however, small differences in knowledge symmetry have produced persistent and dynamic asymmetries of regulation [12], [32]. Arvaja [12] attributes the differences in these experiences to non-knowledge-based status. Corroborating this result, Azmitia and Montgomery [33] and Hartup [34] found that collaboration between friends lead to more transactive discourse than collaboration between acquaintances. That is, the willingness to co-regulate when knowledge asymmetry existed was more likely among friends. Azmitia and Montgomery [33] further explored this phenomenon and recognized that among acquaintances, group members were likely to be “too positive”, and group harmony (an unwillingness to critically co-regulate) was overprioritized. This furthers the findings by Barron [19], that elaboration and discussion were predictors of group success. In all, knowledge and status symmetry then predict levels of co-regulation, but in the case of asymmetric knowledge and status, the choice of the dominant individual to engage in a prescribed level of for-regulation determines the mutuality of interactions.

The purpose of collaborative work as defined here is to provide learners an opportunity to co-construct a joint solution space which is greater than the sum of individual solutions [12], [19]. As discussed, the level(s) of co-regulation relate to the ability of the students to achieve this goal. Thus, co-regulation plays an essential role in learners’ solution co-construction during a problem-solving activity and the role of instructors includes fostering the co-construction process (through *for* regulation).

Implications for Pedagogy

An important note for Figure 1, while many authors consider collaborative activities as the general goal, situations with low overall knowledge levels or low co-regulation among the learners may require a less-symmetric regulation strategy [12], [32], [35]. Consider the situation when the correct knowledge (held by a highly knowledgeable instructor) encounters incorrect co-constructed knowledge of a student learner group and persists [17]. The more knowledgeable peer/instructor then may need to present counterexamples of the incorrect co-construction in a guiding manner. This guidance does not require action as an authoritative figure (where high mutuality is still important), but as a scaffolding figure to aid the incorrect joint space toward constructing the correct representation of the knowledge.

For instructors seeking collaborative activities, symmetric knowledge groupings are likely to facilitate symmetric co-construction and co-regulation. However, within knowledge symmetric groups, asymmetric status may still subvert collaborative, shared co-regulation. To reduce this issue, prior research shows that friendship (i.e., group member comfort level) and instructor interventions reduce the impact of other status asymmetries. To realize this benefit then, knowledge symmetric groups will need time to establish reciprocity for effective collaboration [36]. Further, knowledge symmetric groups will likely result in each individual group varying along the spectrum of shared vs. guided co-construction requirements from Figure 1. To avoid the negative impact quadrants (Figure 1, red) instructors will need to actively assess and scaffold the co-constructed and individual solution spaces of groups. In all, the potential for symmetric grouping correctly implemented is for the co-constructed knowledge to exceed the potential for each individual learner's construction.

Conclusion

This paper explored the role of knowledge-based symmetry in two important cognitive aspects of social learning: co-regulation and co-construction. Prior research indicates knowledge and status asymmetry act as predictors of the co-constructive and co-regulatory processes in social learning. Specifically, that the relationships within and across self-, *for* other, and *by* other regulation are influenced by knowledge and status asymmetry of each co-regulating pair. Co-regulation is required to allow effective co-construction, and the asymmetry in knowledge has important implications for optimizing the co-constructed space by balancing exploration and correct conception. The proposed models of knowledge symmetry regarding co-construction and co-regulation need further refinement and appraisal. However, these models may act as a starting point for discussing the pedagogical implications of symmetry in social learning environments. Further, instructors deploying group learning pedagogies should carefully consider the mediating role of knowledge symmetry in the context of their intended group work outcomes.

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