COGNITIVE AND SOCIAL ASPECTS OF ENGAGEMENT IN ACTIVE LEARNING

Milo D. Koretsky
Oregon State University • Corvallis, OR 97331-2702

There is strong research evidence that active learning positively increases several important student outcomes in undergraduate STEM education when compared to traditional lecture, including: conceptual understanding, self-esteem, and persistence.[1,2] The effectiveness of active learning has been demonstrated through large quantitative meta-analyses,[3,4] controlled classroom experiments,[5] and in-depth qualitative investigations.[6] While traditional lecture settings foreground the transmission of knowledge from master to student, active learning encompasses pedagogies that engage students in activities in which they are asked to process the content to make meaning of it for themselves through thinking and reasoning.[7]

In this article, students' conceptions as to what helps them learn in one active learning setting are analyzed using Chi's Interactive-Constructive-Active-Passive (ICAP) model[8,9] and Hammer and colleagues[10] resource-based framework. In the ICAP model, Chi[8,9] defines three modes of active learning: (i) active (students doing something rather than receiving information passively); (ii) constructive (students generating ideas that go beyond the information that is presented); and (iii) interactive (students engaged with each other to make meaning through dialog). She argues "that interactive activities are most likely to be better than constructive activities, which in turn might be better than active activities, which are better than being passive" (page 73). Hammer, et al.[10] present a resources-based framework which posits that a student's ability to correctly answer conceptually challenging problems involves activating multiple resources. They view "learning an idea not as the acquisition or formation of a cognitive object, but rather as a cognitive state the learner enters or forms at the moment, involving the activation of multiple resources" (page 94). This activation of the resources depends on both the social and physical environment of activity. When viewed from this perspective, incorrect answers arise from a student's inability to activate the appropriate resources even though they may be resources that she has been able to activate in other settings.

Milo Koretsky is a professor in the School of Chemical, Biological, and Environmental Engineering at Oregon State University. He received his B.S. and M.S. degrees from UC San Diego and his Ph.D. from UC Berkeley, all in chemical engineering. He is interested in integrating technology into effective educational practices and in promoting the use of higher-level cognitive and social skills in engineering problem solving. His research interests particularly focus on what prevents students from being able to integrate and extend the knowledge developed in specific courses in the core curriculum to the more complex, authentic problems and projects they face as professionals.

Using these lenses, student-written reflections of what helped them learn were analyzed. The context studied includes four different sophomore- and junior-level courses in a studio-based program-level curricular reform initiative.[11] The small-enrollment, activity-based studios are interspersed between large-enrollment lecture classes. The activities are designed to allow students to make connections to concepts and procedures presented in lecture by reasoning through challenging concept-based questions and numerical problems while talking to one another. Critical in these environments is for instructors to explain and model norms of social interactions and evidentiary reasoning processes.[12]

In principle, the studio active learning environment aligns well to Chi's interactive mode. In this paper, I ask, "do students perceive it that way?" The data source is a mid-quarter survey where students responded to a prompt that asked them to identify what about the studio environment helped them learn. I use analysis of these data to answer the following research questions:

1. *What aspects of an active learning studio environment do students think helps them learn?*

2. *To what degree do students view learning in studio in terms of cognitive processes? In terms of social processes?*

STUDIO ARCHITECTURE AND IMPLEMENTATION DESIGN

In the studio-based curriculum design, large enrollment courses are organized to include smaller studio sections interspersed between lectures.[11] Studios are entirely activity based. Students spend the class period working in small teams to answer a series of conceptual and numerical questions. The studios are designed to be small enough (typically 24 students) so that a graduate teaching assistant (GTA) or instructor can circulate around the room, and interact with students and teams through asking types of questions that help them get unstuck and promote learning. We have also begun to insert undergraduate learning assistants (LAs), based on the University of Colorado LA Alliance Model,[13] to provide a near peer for instructional support. The social interaction between students themselves and the student and instructors is viewed as critical and is strongly encouraged. The intent is to shift emphasis from having students obtain the "correct" answer to developing their thinking process and skills about the concepts and problems and to relating their activity to the content in lecture. Directive feedback is used only as a last resort.

The studio design is described in more detail elsewhere.[11] Some defining features of CBEE's studio sections are:

1. ***Focused on activity-based small-group work:*** *Students spend the entire studio time working in small groups (typically three students) while actively engaged in assigned questions, problems, experiments, and analyses. Assignments are structured to explicitly encourage students to collaborate as they work. For example, assignments commonly ask students to individually make predictions based on their own intuitions; discuss their predictions with their group mates; conduct an experiment, model, or analysis to test their prediction; and reflect on any differences between their prediction and the more rigorously derived result. To provide space for this type of social interaction, assessment is based primarily on attendance and engagement.*

2. ***Limited to 24 students:*** *The smaller class sizes are necessary to allow the studio instructors to provide sufficient attention and feedback to each student group. The 24-student cap is based on five years of experience with different sized studio sections. The increased contact and sense of connection with studio instructors is an intentional outcome of the smaller class sizes, and further supports students' motivation and ability to actively engage studios while they struggle to make meaning of challenging content.*

3. ***Discursive pedagogical practices:*** *We emphasize a set of practices borrowed from ambitious teaching in science and mathematics.[14,15] GTAs and LAs are coached to attend to student questions in a facilitative manner, encouraging the students' own thinking and interactions with one another, a practice that further supports the student's role in active learning. The instructors use techniques such as re-voicing a student's response, asking students to explain their own reasoning and provide evidence or to restate a group mates reasoning, and providing a counterexample for discussion. Such near-peer interactions have been shown to support active learning.[16]*

4. ***Supported programmatically:*** *Each term, we convene regular meetings (three to four per quarter) inviting all GTAs and course instructors involved in studio sections. In some cases, graduate students who expect to run studio sections in the future also attend. In these meetings, GTAs discuss challenges and successes in their own sections. Through these meetings, the overall pedagogy and goals of the studio environment can be continuously maintained. These meetings also reinforce the commonality of structure across all 10 studio courses.*

METHOD

The studio structure was implemented in the 2011-2012 academic year and currently encompasses 10 core courses in our program. The sample for the analysis in this paper draws from four studio courses over a two-year time span. The purposive sample was taken from a representative subset of all the studio courses and includes one course at the sophomore level and three at the junior level. Four hundred and three students majoring in chemical engineering (73%), bioengineering (18%), and environmental engineering (9%) participated in the study. Their participation ranged from responding to a survey in a single course to responding in all four courses in the study. Participants identified as 65% male and 35% female. The Institutional Review Board approved the research and participants signed informed consent forms.

At the midpoint of each quarter, students in studio were asked to complete a survey to provide their perceptions of the studio experience. The survey consisted of three fixed-scale items and two free-response items. The free response items asked students to:

(1) Write down one thing about the studios that helps you learn; and

(2) Write down one thing that could improve the studio.

Results of one of the fixed-scale items and coded data from the first free-response item ("Write down one thing about the studios that helps you learn") form the basis of the analysis in this paper. A more comprehensive analysis of the fixed-scale items is reported elsewhere.[11] An open-coding approach was taken to analyze the free-response (written) data, by which we identified emergent categories in the data. First, two researchers identified important themes by examining responses from each of the courses. The categories showed general similarity, but had different labels. Both researchers and one of the studio coordinators then met and reached consensus on code categories and definitions for each category. The researchers then coded a set of 359 responses independently with these common code definitions and achieved an interrater reliability of 0.82 using Cohen's kappa statistic. This value indicates suitable reliability in the coding process. The remaining data were coded by a single researcher.

Table 1 shows the six code categories developed and analyzed. Included are the definition used for coding and an example student excerpt. While students were specifically asked to identify "one thing" that helped them learn, often responses showed elements from multiple categories. In such cases, multiple codes were assigned to the response. To answer the research questions, the code categories identified in Table 1 were arranged in general classes of cognitive (connection to lecture; conceptual understanding; practice problem solving) or social (guidance from TA; small group; help from others). One code (worksheets) did not fit in either class and is labeled as other.

TABLE 1
Cognitive and social code definitions and example excerpts

Class	Code	Definition	Example Excerpt
Cognitive	Connection to Lecture	Explicitly relates activity in studio to the same content when it was covered in lecture—apply what was covered in class	"I reviewed what I have learned in class. Sometime using experiments helped me to understand the lecture."
	Conceptual Understanding	Identification of specific conceptual learning or scientific principles. An indication that studios help process, apply, or understand concepts.	"We apply the concepts we learn in class to real-world situations, which helps to develop a basis for gut-checks. Also, the depth at which we twist and turn a concept helps for later applications on tests and whatnot."
	Practice Problem Solving	Emphasis on the role of studio in providing practice to problem solving.	"You actually solve problems instead of just getting equations. You get to apply it in ways similar to homework and tests."
Social	Guidance from TA	Indications that the teaching assistant (TA) is available to help when students get stuck and point them in the right direction.	"Talking with the TAs, and getting instant help."
	Small Group	Statements that indicate that working in small groups allows them to get help from fellow students and/or exposes them to different perspectives.	"Working with other students is great, I like to get new perspectives and try to work through problems with a new group of people. When you work with the same ppl all the time, you get stuck in your role, but with new people sometimes you can explain things."
	Help from Others	This code is used when the statement describes being helped by others, but it is unclear if it is the GTA, the group, or both, *i.e.*, the TA or group is not defined ("getting one-on-one help with the concepts"). If the others are plural—it is assumed to be group interaction.	"Trying to solve problems on my own and if I get stuck there is someone there to help me."

RESULTS

Figure 1 shows responses to the fixed-response survey question that asked students to evaluate whether they believed lectures or studios were more productive in helping them learn. The data shown are aggregated across courses at each academic level and over the years of the study. However, other than the year of enrollment (sophomore or junior), there was little difference in the data. Eighty percent of the sophomores and 93% of the juniors viewed the studios as more helpful. While these data are based on perception and do not measure actual learning gains, at least from the students' perspective, studios provide a productive environment to help them learn. This result is more pronounced in the more challenging junior-year courses.

Table 2 shows the number of respondents for each course and the percentage of responses for each of the code categories. Results are presented by code class (cognitive, social, or other) in descending order. A total of 55% of the responses corresponded to the "Cognitive" class, where students most often cited "Practice Problem Solving" as being useful to help them learn (29%), but also cited "Connection to Lecture" (15%) and "Conceptual Understanding" (11%). The Junior 2 course is explicitly taught using what the instructor describes as "concept-based active learning" and the students in this course perceived that emphasis ("Conceptual Understanding"; 23%). A total of 42% of the responses corresponded to the "Social" class, where students cited both interactions with their group mates ("Small Group Interactions"; 23%) and with the instructor facilitating learning ("Guidance and Help from TA"; 17%). The code "Help from Others" (2%) was used when it was unclear from the response if the assistance came from group mates, from the TA, or from both. The studio worksheets themselves were identified by a few students (3%), and were classified as "Other." In general, the frequency of coded responses within a course is consistent between years. The course listed "Junior 2" only has one year of data since it did not utilize the studio model in Year 1 of the study. A redesign of studio activities between years in Junior 1 led to students reporting a greater connection to lecture (14% to 26%).

As stated earlier, while students were asked to write down "one thing" about studio that helped them learn, those responses frequently contained references to multiple codes. Table 3 (next page) provides examples of student-written responses that were coded into multiple categories. If both codes were from the Cognitive class (see the first response in the table), we label it a cognitive-cognitive couple. Similarly examples of social-social, social-cognitive, and social-social-cognitive are shown in Table 3.

Of interest is the degree to which these different aspects group together. Figure 2 (next page) presents a network diagram that illustrates such couplings. The nodes in Figure 2 correspond to cognitive or social codes. The lines connecting the nodes are indicated by a solid line (cognitive-social), large dashes (cognitive-cognitive), and small dashes (social-social). The number above each connecter indicates the number of student responses that includes both codes, and the line thickness is proportional to that number. For example, 96 responses contained both "Practice Problems" and "Connection to Lecture" (cognitive-cognitive) and 70 responses contained both "Connection to Lecture" and "Small Group" (cognitive-social). Likewise, these are the two thickest lines on the network diagram. Apparently both working on the problems and interacting with group mates can help students make meaning of the lecture. Summing the connectors, we see the most common coupling is cognitive-social (296 counts or 73%

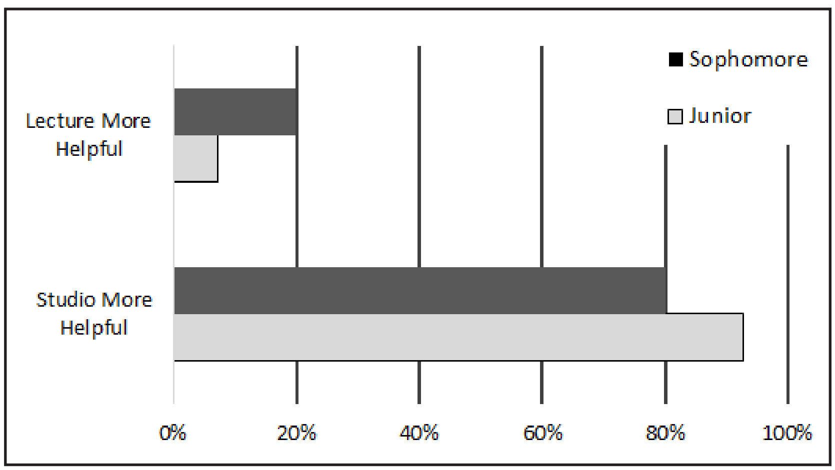

Figure 1. *Responses for sophomore (n = 185) and junior (n = 642) students aggregated across courses and years of the study.*

TABLE 2

Percentage of coded responses for four different courses, over two years. Not all columns add up to 100% due to round off.

		Sophomore 1		Junior 1		Junior 2	Junior 3		Total
		Year 1 (n=92)	Year 2 (n=93)	Year 1 (n=114)	Year 2 (n=137)	Year 2 (n=102)	Year 1 (n=147)	Year 2 (n=142)	
Cognitive	Practice Problem Solving	37%	39%	28%	21%	26%	27%	28%	29%
	Connection to Lecture	12%	11%	14%	26%	9%	13%	18%	15%
	Conceptual Understanding	14%	8%	12%	11%	23%	6%	4%	11%
Social	Small Group Interactions	21%	22%	22%	24%	19%	31%	24%	23%
	Guidance and Help from TA	13%	13%	18%	13%	16%	22%	22%	17%
	Help from Others	4%	4%	3%	3%	4%	0%	0%	2%
Other	Worksheets	0%	4%	3%	4%	3%	1%	4%	3%

TABLE 3 Examples excerpts of connections between codes		
Coupling	**Code Categories Connected**	**Student-Written Response**
Cognitive – cognitive	Conceptual Understanding Practice Problem Solving	“Doing problems that apply the concepts that we are learning is very helpful because it helps later on the homework.”
Social – social	Guidance from TA Small Group	“Working in groups to solve problems while having a TA that can circulate to answer questions that might be harder to answer in a large lecture hall.”
Social – cognitive	Small Group Conceptual Understanding	“Being able to converse with other students about the assumptions we can make in certain situations and better understand concepts by defending our thoughts.”
Social - cognitive - cognitive	Small Group Connection to Lecture Practice Problem Solving	“Studio is a great time to work together and solve harder problems that we could potentially see on tests and cement ideas that we learned in the lecture prior.”

of students), then cognitive-cognitive (179, 44%), and finally social-social (21, 5%).

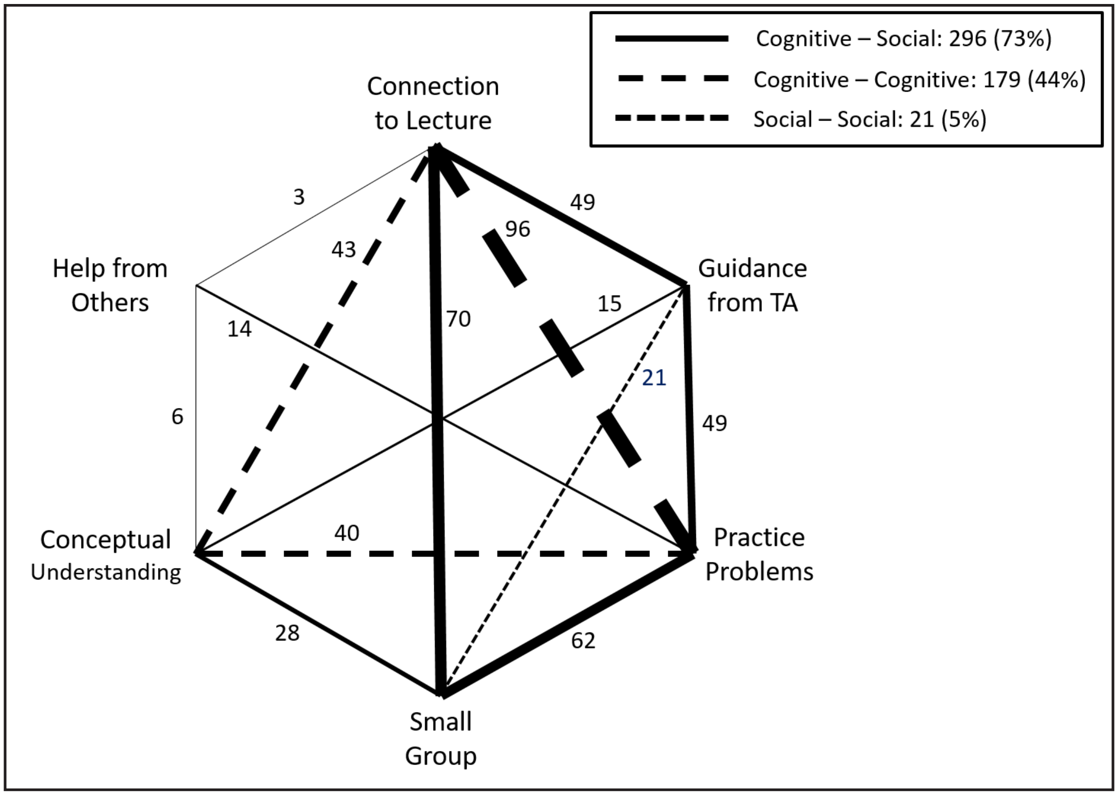

Figure 2. Network diagram of coded responses. The nodes represent code categories and the numbers above the connectors indicate the number of student responses with both categories. The thickness of each connector line is proportional to the number of responses.

DISCUSSION

The context for this study is a coordinated implementation of studio-based active learning in 10 core courses in our chemical, biological, and environmental engineering programs. In this endeavor, we have sought to create a community around studio instruction consisting of faculty teaching these courses and the GTAs and LAs working with the students in the studios to facilitate learning. Both cognitive and social aspects are considered important for student engagement and learning. Cognitively, we seek to have our students participate in activities that develop and refine their thinking processes and where they can safely confront the inevitable confusion that is the precursor to deep learning.[17] In this way, studios can form a “bridge” between concepts and content provided in lecture and the ability to apply this knowledge on homework and exams. Socially, we seek to provide a collaborative environment where students can develop and test ideas with their peers, and also get punctuated support in the form of coaching from the instructors. In this role, the instructors seek to build on the ideas that students bring to the activity, push the students for justification and explicit reasoning, and encourage students to regulate their own and one another’s thinking.

As Table 2 shows, students identified both cognitive and social aspects to studio that helped them learn. In addition, the social and cognitive aspects are often coupled in the same student response (Figure 2). These findings align with Chi’s interactive mode that advocates for classroom learning activities where students engage with each other to make meaning through dialog. It is consistent with a social constructivist view that learning is socially mediated and intimately influenced by the culture and activities in which the learning is situated.[18] Through a process of scientific explanation and argumentation,[14] students have the opportunity to compare and contrast their thinking with their peers', and, consequentially, build on one another's ideas to construct richer understanding than they would be able to alone. From the perspective of Hammer's resource-based framework,[10] the intra-group and instructor-student interactions allow greater opportunity for students to identify and activate resources needed to approach complex engineering work. Indeed, we have observed different sociocognitive processes to activate resources, such as engaging the questions of peers, working through analogous representations of an idea or phenomenon, testing and revising models, and inquiring what approaches are reasonable and valid. In these ways, interactive learning environments such as the studios studied here ask students to activate resources in a way that resembles the practices of professional engineers. While social interactions have been shown to be effective in promoting conceptual change,[19] we advocate that importantly they also better prepare students socially for their interactions with others in professional practice.

The benefits students identify are consistent with the intent of the studio design. In addition to small group interactions, the studios provide structure that allows for guidance and help from the GTA. A few student statements indicated that the studio environment enhances their self-efficacy by increasing their confidence that they can be successful engineers. This final factor may be particularly important for students from underrepresented groups.[20]

This study has several limitations. First, while student perceptions align with the studio design principles and with Chi's ICAP theory, we do not measure learning outcomes or gains. This limitation is mitigated in part by anecdotal observations in the studio classroom. We have observed students interacting with their group mates and with the GTA and LA facilitators in ways that are centered around meaning making and evidentiary reasoning and that are intellectually generative. While such observations are consistent with the student perceptions reported in this study, it would be useful to develop a systematic observation protocol or collect and analyze video data to understand the interplay between the cognitive and social aspects of learning. Second, in the studio design, the GTAs and LAs have great responsibility in their role to facilitate learning. This pedagogically complex environment requires these student instructors to make a variety of quick decisions as they interpret the technical progress and social interplay in the groups. While we have instituted pedagogical training for both GTAs and LAs, its scope is limited. Using Hammer's framework, GTAs and LAs too need to activate teaching resources as they interact with students in this environment. We have observed a wide range of choices, both positive and negative, that the facilitators employ. Of particular interest in the cases where the GTA or LA appears to be able to identify a pedagogical principle outside of the studio (in the pedagogy training or in an instructional team meeting), but then makes instructional choices antithetical to the principle in studio. More research is needed to understand how these student instructors' prior experiences and notions of knowledge and learning interact with the work they do with students in the studio classroom. We could then use that understanding to build more productive ways to develop their teaching practice.

IMPLICATIONS

This article describes one specific learning environment designed to stimulate interactive engagement and provide students resources for their thinking. While acknowledging limitations in the study, general principles have emerged for instructors to consider as they develop or modify activities, structures, and environments for their courses. Instructional designers should consider the types of thinking and reasoning they seek to elicit in an activity. For example, students should be asked to make meaning of content, relate different representations of a phenomenon, or apply concepts in situations they have not seen before. Equally important are the social resources available to support these types of thinking. Students should be encouraged and supported to work in ways where they can be a resource for one another to provide alternative ideas and elicit thinking through explanation and argumentation. In this type of learning environment, instructors should be aware of their role in the social process of learning by noticing where a student's thinking is at and how it relates to the thinking of others in the group. Based on this information, the instructor then needs to interact with students and groups in productive ways that move the group's thinking forward in disciplinarily productive ways.

CONCLUSION

The results in this study showed that students believed that they learned more in the studio-based active-learning environment than they would in the equivalent time in lecture. An analysis of written responses about what students think helps them to learn in studio was then presented. Students value both cognitive and social aspects. Fifty-five percent of the responses were coded in cognitive categories of practice problem solving; connection to lecture; and conceptual understanding. Forty-two percent were coded in social categories that related to small group interactions and guidance and help from the TA. Importantly, many responses contained several codes, and the most common contained both cognitive and social aspects. These perceptions align with Chi's ICAP theory that asserts that interactive engagement is the most productive for learning. It is suggested that social interactions are critical for activating resources in students as they do complex engineering work. Instructors in active-learning environments should pay critical attention to helping students activate resources. This includes explaining and modeling norms of social interactions and evidentiary reasoning processes and encouraging students' own thinking and productive interactions with one another. Useful techniques include re-voicing a student's response, asking students to explain their own reasoning and provide evidence, asking students to restate a group mate's reasoning, or providing a counterexample for discussion.

ACKNOWLEDGMENTS

The author gratefully acknowledges partial support from the National Science Foundation under the grant NSF DUE 1347817. The rich interactions, spirited discussion, and general camaraderie of the students and faculty on the studio team are very much appreciated. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

1. National Research Council, *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*, National Academies Press (2012)
2. Prince, M., "Does Active Learning Work? A Review of the Research," *J. Eng. Ed.*, **93**(3), 223 (2004)
3. Hake, R.R., "Interactive-Engagement Versus Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses," *American J. Physics*, **66**(1), 64 (1998)
4. Freeman, S., S. L. Eddy, M. McDonough, M.K. Smith, N. Okoroafor, H. Jordt, and M.P. Wenderoth, "Active Learning Increases Student Performance in Science, Engineering, and Mathematics," *Proceedings of the National Academy of Sciences*, **111**(23), 8410 (2014)
5. Deslauriers, L., E. Schelew, and C. Wieman, "Improved Learning in a Large-Enrollment Physics Class," *Science*, **332**(6031), 862 (2011)
6. Lising, L., and A. Elby, "The impact of Epistemology on Learning: A Case Study From Introductory Physics," *American J. Physics*, **73**(4), 372 (2005)
7. Smith, K.A., S.D. Sheppard, D.W. Johnson, and R.T. Johnson, "Pedagogies of Engagement: Classroom-Based Practices," *J. Eng. Ed.*, **94**(1), 87 (2005)
8. Chi, M.T.H., "Active-Constructive-Interactive: A Conceptual Framework for Differentiating Learning Activities," *Topics in Cognitive Science*, **1**, 73 (2009)
9. Chi, M.T., and R. Wylie, "The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes," *Educational Psychologist*, **49**(4), 219 (2014)
10. Hammer, D., A. Elby, R.E. Scherr, and E.F. Redish, "Resources, Framing, and Transfer," in: Mestre, J.P. (ed.) *Transfer of Learning: Research and Perspective*, Information Age Publishing, Greenwich (2004)
11. Koretsky, M.D., "Program-Level Curriculum Reform at Scale: Using Studios to Flip the Classroom," *Chem. Eng. Ed.*, **49**(1), 47 (2015)
12. Osborne, J., "Arguing to Learn Science: The Role of Collaborative, Critical Discourse," *Science*, **328**, 463 (2010)
13. Otero, V., S. Pollock, and N. Finkelstein, "A Physics Department's Role in Preparing Physics Teachers: The Colorado Learning Assistant Model," *American J. Physics*, **78**(11), 1218 (2010)
14. Windschitl, M., and A. Calabrese Barton, "Rigor and Equity by Design: Seeking a Core of Practices for the Science Education Community," in D.H. Gitomer & C.A. Bell (eds.), *AERA Handbook of Research on Teaching*, 5th ed. (pp. 1099–1158), Washington, DC: American Educational Research Association (2016)
15. Sohmer, R., S. Michaels, M.C. O'Connor, and L. Resnick, "Guided Construction of Knowledge in the Classroom: Teacher, Talk, Task, and Tools," in *Transformation of Knowledge Through Classroom Interaction* (pp. 105–129), edited by: B. Schwarz, T. Dreyfus, and R. Hershkowitz, London, UK: Routledge (2009)
16. Crouch, C.H., and E. Mazur, "Peer instruction: Ten Years of Experience and Results," *American J. Physics*, **69**(9), 970 (2001)
17. Horn, I.S., *Strength in Numbers: Collaborative Learning in Secondary Mathematics*, Reston, VA: National Council of Teachers of Mathematics (2012)
18. Wertsch, J.V., *Voices of the Mind: A Sociocultural Approach To Mediated Action*, Harvard University Press, Cambridge (1991)
19. Pea, R.D., "Learning Scientific Concepts Through Material and Social Activities: Conversational Analysis Meets Conceptual Change," *Educational Psychologist*, **28**(3), 265 (1993)
20. National Research Council, *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads*, National Academies Press: Washington, D.C. (2011) ❒