A Review of Research on Constructivist-Based Strategies for Large Lecture Science Classes

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Introduction

Modern theories of learning claim the construction of knowledge occurs as students build understanding in light of experiences occurring in the world. Experience can occur within the context of various pedagogic modes within a classroom setting; moreover, the development of deep conceptual understanding of content and the processes of science – as informed by constructivist models of learning – stress the active participation of students in the process of constructing knowledge. This can occur when students are engaged in learning tasks which tacitly or explicitly make them aware of this construction with deference to prior knowledge structures. Large lecture interactive engagement teaching strategies are designed to permit this sort of learning (Students are not tacitly given an opportunity to simply memorize bits of knowledge pre-arranged by a content expert, rather they are actively engaged in the construction of new knowledge.). Still, why do many science faculty members continue to exclusively lecture in large enrollment courses?

Institutional constraints may make successful implementation of proven strategies difficult even when faculty acknowledge the advantages of active learning approaches. These constraints include physical considerations, such as the number of students in the class, fixed seating arrangements, and the amount of time available for instruction. They also include systematic factors, such as the relationship of the class to other courses, the identification of course objectives solely in terms of content, a general lack of teaching experience and training among content faculty, and the lack of incentives (as well as the presence of disincentives) to focusing on the improvement of one's teaching. Beyond all this, however, we have found that a major detriment to successful implementation is a lack of familiarity with relevant science education literature, difficulties science faculty may have in interpreting the results of education research, and problems simply figuring out how to translate even practical techniques offered by other authors to their own teaching contexts.

*Enlist, Equip, Empower is an NSF sponsored grant (no. 0202923) aimed at better preparing and supporting future middle school teachers of science at Western

Michigan University. The construction of this bibliography was initially supported by E3, and has been used to inform instructional modifications in large enrollment chemistry, biology, and earth science courses.

The following list of resources has been compiled to aide science instructors of large lecture courses who may not be familiar with the work of science educators that can contribute to the development of teaching strategies and skills. It has been organized to cogently present samples of material that should be reviewed by instructors of large lecture courses who wish to incorporate into their courses pedagogical strategies which aide students' active construction of knowledge versus passive instructor-centered dissemination of lectured content. The first section of this bibliography addresses constructivism, a theoretical model of learning underlying this work. The subsequent sections provide examples from reform efforts and provides research finding regarding various strategies as employed in disparate disciplines of science.

Constructivism --Theoretical Perspectives:

Constructivism can be understood as a theory of learning: students construct knowledge in the process of learning through interaction with phenomenon, as they develop shared-meaning of a phenomenon via interactions within a social context (i.e. culture). Though the particulars of constructivist-focused learning theory are often contested among Science Educators, it is generally agreed that students learn by making sense of phenomenon as they experience it, evaluate it's evidentiary merits, and attempt to make sense of it within a socially acceptable context in light of prior knowledge. Some constructivists stress the role of social interactions in this process, while others do not. Most constructivists agree learning occurs when individuals assimilate new information into existing mental models of the world, or construct – as a result of discrepant insights – new models that can accommodate both old and new insights gained from experience. All would agree the building of knowledge structures on the part of a student requires she or he be actively engaged in the process of learning.

Students of large lectures, therefore, should not be regarded at automatons capable of learning by passive modes of oral dissemination of content, rather as individuals requiring the social and active construction of knowledge, as participants in a process that has as a goal the construction of knowledge as useful product. Furthermore, due to the way in which philosophers of science now think of the nature of science and construction of scientific knowledge, educators of science have changed how they view knowledge [1, 2, 3].

Knowledge is fluid, not static; therefore, instructional practices reiterating knowledge as static should not be promulgated as sole efficacious pedagogy, because such instructional practices serve to tacitly inform future generations of ill-conceived notions regarding science and knowledge of the world within the disciplines it encompasses. Pedagogy permitting the dissemination of facts as knowledge to be passively absorbed by an audience (i.e. traditional lecture practice) reiterates naïve notions of the processes of science and scientific knowledge of material phenomenon. Although the extent to which lectures inspire and permit the passive construction of knowledge may be disputed, claims that other instructional strategies exist that permit the active construction of student knowledge within large lecture environments cannot be disputed. Such modes of teaching and learning may not seem like typical lectures, but they may be arrived at with few major changes to current lecture practice. In addition, they promote the efficient construction of knowledge structures in the minds of our students.

The references listed in this section have been collected to present 1) the theory of learning that underlies research done in improving large lecture pedagogy, and 2) general information about what is known of lecturing as traditionally practiced as it relates to this theory of learning. In addition, the first reference provides a picture of the context in which contemporary scholarly work in Science Education is taking place. The section concludes with a listing that is used by many Science Educators as a tool of reference; and, though it is not comprehensively devoted to constructivism, it is a worthwhile inclusion in any bibliography in Science Education, as it represents a thorough description of the concerns of the discipline as a whole.

Lopez, R.E., & Schultz, T. (2001). Two Revolutions in K-8 Science Education. *Physics Today*, 54(9), 44-49.

The article describes contemporary goals and objective of the Science Education community at large (as scene through the eyes of two Physics Educators).

Bligh, D. A. (2000). What's the Use of Lectures? San Francisco: Jossey-Bass.

The book is a thorough examination of what lectures can and can not do in terms of student learning. Research findings are discussed that inform the reader of when lectures should be employed, as well as what the instructor can expect outcomes in student learning and content retention to be as a result of having lectured. Of particular note - aside from the review of psychological research findings concerned with student memory, attention and motivation during lectures (chapters 2, 3 and 4 respectively) - are chapters 17-19 and 20-22. The author discusses alternatives to lecturing and the preparation of lectures in those chapters, respectively.

Mintzes, J.J., Wandersee, J.H., & Novack, J.D. (1998). Teaching Science for Understanding: A Human Constructivist View. San Diego: Academic Press.

The book outlines a constructivist viewpoint of teaching and learning that is commented on by the authors and widely shared within the Science Education community. The book is organized into three parts: 1) theory and research foundations for constructivism, 2) teaching/learning intervention strategies of the human constructivist perspective, and 3) an epilogue covering the implications for "meaningful learning, knowledge restructuring, and conceptual change: on ways of teaching science for understanding."

Lord, T.R. (1997). A Comparison Between Traditional and Constructivist Teaching in College Biology. *Innovative Higher Education*, 21(3), 197-216.

The article reports the findings of a study that assessed the learning of identical course content in two individual group treatments: one group receiving traditional instruction (n=86) and another receiving student-centered constructivist instruction. It is found that the constructivist treated group out-performed the traditionally taught cohort on identical evaluations.

Fosnot, C. T. (Ed.) (1996). *Constructivism: Theory, Perspective, and Practice.* New York: Teachers College Press.

The book is a compilation of articles exploring modern constructivism. Although many aspects of constructivism are approached, the first three chapters explore in detail where, when, and how constructivism developed. It provides a reader with a clear picture of what is meant by the modern term "constructivism."

Gabel, D.L. (Ed.) (1994). *Handbook of Research on Science Teaching and Learning.* New York: Macmillian.

The manual serves as a starting point for practicing researchers in Science Education and those who become interested in Science Education in determining what the research community has written about various topics pertaining to science teaching and learning. The manual is composed of chapters, written by various authors, devoted to thematic subtopics within overarching parts: Part I - Teaching; Part II - Learning; Part III - Problem Solving; Part IV - Curriculum; and, Part V - Context.

III. Informative Studies in Biology, Chemistry, Geosciences and Physics Teaching

Many studies have been performed in the last two decades that attempted to characterize and assess the impact of active learning strategies upon student learning in large lecture settings. Some studies have concentrated upon interactive engagement strategies employing techniques to evoke individual participation in the lecture process, while others have examined the effects of cooperative or peer learning upon student performance.

An overlap exists regarding the goals of such strategies, yet these disparate strategies attempt to meet their organizational goals by various means. Interactive engagement strategies, for example, tend to elicit individual student engagement/ participation during lecture in an attempt to provide real-time assessment of student understanding as a lecture unfolds. Accordingly, students may provide feedback to instructors during a lecture via responses to an organized series of questions through the use of coordinated hand held flashcard or electronic device (see Meltzer, D.E., & Manivann, K. (2002), below). In contrast, cooperative and peer learning strategies stress the construction of knowledge in groups comprised of lecture participants (see Paulson, D.R. (1999), below). For example, students may form small groups periodically during lecture and attempt to solve a question posed by an instructor at critical junctures in the presentation of lectured material. Then, students are given an opportunity to share their work – and potentially gain useful feedback – via a variety of methods ranging from simple in-class presentations to organized assignments.

The articles presented in this section are organized according to discipline: biology, chemistry, geosciences, and physics. The included article serve one of two possible functions: 1) inform the reader of studies published in peer-reviewed science education research journals that have examined the use of active learning strategies in large lecture classroom environments in each of the four discipline areas, and 2) provide the reader with examples and/or guiding principle concerning the implementation of such strategies in their classrooms. A brief description of each article has been included to aide the reader in discovering the intent of an included article. It should be noted that the works cited below represent formal research, action-oriented research published in practitioner journals, and opinion pieces appearing in various resources. Although, the latter may not be regarded as appropriate for affirming the claims made by those who support the inclusion of interactive engagement strategies in large enrollment courses they have been included for the sake of modeling appropriate strategies.

a. Biology

Udovic, D., Morris, D., Dickman, A., Postlethwait, J., & Wetherwax, P. (2002). Workshop Biology: Demonstrating the effectiveness of Active Learning in an Introductory Biology Course. *BioScience*, 52(3), 272-281.

The article describes a program designed for increasing science literacy rates among non-majors of science at the University of Oregon. Findings are discussed in brief, but it is shown that inquiry-based instructional strategies did aide student learning.

Francis, J.W. (2000). Use of Internet Resources in the Biology Lecture Classroom. *American Biology Teacher,* 62(2), 90-93.

The author discusses several ways in which internet resources are being used in the teaching of large lecture biology courses.

Switzer, P.V., & Shriner, W.M. (2000). Mimicking the Scientific Process in the Upper-Division Laboratory. *BioScience*, 50(2), 157-162.

In this article two professors of an introductory biology courses discuss the implementation and assessment of inquiry-based learning strategies in their large lecture classrooms and associated labs. They present an argument that supports claims of researchers who suggest that the inclusion of such strategies aides student understanding of course content.

Sutcliffe, R.G, Codgell, B, Hansel, M.H, & McAteer, E. (1999). Active Learning in a Large First Year Biology Class: a Collaborative Resource-based Study Project on AIDS in Science and Society. *Innovations in Education and Training*, 36(1), 53-64.

The authors provide a descriptive assessment of the implementation of a inquiry-based (i.e. “resource-based”) student projects, and alternative perspectives are discussed. Both students and tutors of the program enjoyed the program; and, student work was found to be acceptable when examined using pre-intervention standards.

Lord, T. (1998). Cooperative Learning that Really Works in Biology Teaching: Using Constructivist-Based Activities to Challenge Student Teams. *The American Biology Teacher,* 60(8), 580-588.

This paper offers guidance in the development of constructivist, inquiry-based activities within classes utilizing team learning. A review of relevant literature offers advice regarding the use of constructivist approaches for teaching in biology, cooperative learning, the development of useful inquiry-sensitive curricula, the management of cooperative learning, and the grading of cooperative learning tasks. Of note, useful lecture questioning strategies are discussed.

Ebert-May, D, Brewer, C., & Allred, S. (1997). Innovation in Large Lectures - Teaching for Active Learning. *BioScience*, 47(9), 601-607.

The authors describes results of a study designed to test the affects of the inclusion of peer instruction strategies upon student understanding within large lecture introductory biology course. It was found that the implemented strategies aided student understanding and learning, as measured by performance on standardized

assessments between control and experimental groups at two public universities.

Lunsford, B.E, & Herzog, M.J. (1997). Active Learning in Anatomy and Physiology: Student Reactions & Outcomes in a Nontraditional AP Course. *The American Biology Teacher*, 59(2), 80-84.

Informally, the article reviews the work of the investigators in the teaching of anatomy and physiology. In summary they have found inquiry-based strategies, if properly implemented in the classroom, are not a detriment to future Allied Health students when they take licensing exams. Also, students favor the inclusion of such learning strategies.

Groccia, J.E., & Miller, J.E. (1996). Collegiality in the Classroom: The Use of Peer Learning Assistants in Cooperative Learning in Introductory Biology. *Innovative Higher Education*, 21(2), 87-100.

The article summarizes the findings of a study that assessed the efficacy of peer learning assistants (PLAs) in an introductory college biology course, and student attitudes concerning the employed assistants and the peer learning groups that the students participated in. It is discovered that students, as well as the PLAs and faculty benefited from the instructional practice. Also discussed is the development of the specific cooperative learning model employed in the study. Overall, students, faculty, and the PLAs were satisfied with the method.

b. Chemistry

Gutwill-Wise, J.P. (2001). The Impact of Active and Context-Based Learning in Introductory Chemistry Courses: An Early Evaluation of the Modular Approach. *Journal of Chemical Education*, 78(5), 684-690.

The author devised a study to assess a curricular approach which used modules as a primary approach to instruction. It is shown that a modular approach to study can aide student understanding (at the same level or above that scene in traditionally taught students), foster scientific thinking and conceptual understanding, and promote positive attitudes towards science. It is noted instructors implementing the modules, however, must have a clear understanding of the modular approach of learning and teaching prior to implementation.

Hinde, R.J., & Kovac, J. (2001). Student Active Learning Methods in Physical Chemistry. *Journal of Chemical Education*, 78(1), pp.93-99.

The article describes a study conducted to determine the impact of active learning strategies upon the attitudes and abilities of physical chemistry students. It is found that although students who participated in classes that were completely cooperative learning-based performed at the same level as those who participated in classes with marginal cooperative learning both groups felt that such active learning activities aided comprehension.

Bowen, C.W. (2000). A Quantitative Literature Review of Cooperative Learning Effects on High School and College Chemistry Achievement. *Journal of Chemical Education*, 77(1), 116-119.

The article elucidates how a quantitative meta-analysis of quantitative literature is performed within the discipline of Science Education. The technique is discussed, then performed. The example used concerns the effect of cooperative learning upon student understanding of science topics in high school and college level chemistry classes. It is found that students who do not participate in cooperative learning environments display lower levels of comprehension of key topics.

Kaufman, D.B., Felder, R.M., & Fuller, H. (2000). Accounting for Individual Effort in Cooperative Learning Teams. *Journal of Engineering Education*, 89(2), 133-140.

The authors discuss a method for evaluating student performance in cooperative learning groups. In general, it is found that the method employed was consistent and equitable, displaying ease in application.

Paul, T., & Walters, J.P. (2000). Role-playing in Analytical Chemistry: The Alumni Speak. *Journal of Chemical Education*, 77(8), 1019-1025.

The article reports findings of a study that addressed the use of role-playing (organized "industry" groups) in analytical chemistry courses at St. Olaf College. Survey results suggest the majority of respondents who participated in role-playing classes enjoyed the experience, felt they were prepared for jobs in the chemical industry or teaching professions, and they related an increase in their quality of life (due to a development of communication skills).

Browne, L.M., & Blackburn, E. V. (1999). Teaching Introductory Organic Chemistry: A Problem-Solving and Collaborative-Learning Approach. *Journal of Chemical Education*, 76(8), 1104-1107.

The authors review and discuss pertinent literature which informed efforts in reforming how they teach introductory organic chemistry at a Canadian university. The result of their efforts is a collaborative learning environment which includes student-driven, open inquiry and lecture. They conclude by discussing implementation and evaluation concerns.

Farrell, J.J, Moog, R.S, & Spencer, J.N. (1999). A Guided Inquiry General Chemistry Course. *Journal of Chemical Education*, 76(4), 570-574.

The authors describe the implementation and organizational concerns of a guided inquiry, introductory chemistry course while assessing student performance as compared and contrasted with previous non-inquiry introductory courses taught by the author. In general, inquiry teaching methods enhanced student performance, as course withdrawal and failure rates declined with its inclusion.

Hodges, L.C. (1999). Active Learning in Upper-Level Chemistry Courses: A Biochemistry Example. *Journal of Chemical Education*, 76(3), 376-377.

The article is a brief overview of one chemistry professor's use of a particular discussion techniques aimed at promoting student-centered, guided-inquiry into contemporary literature in Biochemistry. The article concludes with observations and conclusions concerning the employed methods efficacy, efficiency, and implementation with regard to the students' learning and the teacher's instructional practices.

Paulson, D.R. (1999). Active Learning and Cooperative Learning in the Organic Chemistry Lecture Class. *Journal of Chemical Education*, 76(8), 1136-1140.

A professor of organic chemistry evaluates the findings of a 15-year study that addressed the efficacy of the inclusion of active learning and cooperative learning instructional methods in lecture formatted organic chemistry courses. Of particular note is that the study encompasses his students only, and the same types of student assessments were used through the duration of the study (essay tests). It is found that percentages of students passing the course increased with the inclusion of student-centered teaching.

Gallet, C. (1998). Problem-Solving Teaching in the Chemistry Laboratory: Leaving the Cooks.… *Journal of Chemical Education*, 75(1), 72-77.

The author describes the inclusion of problem-solving teaching strategies within a chemistry laboratory curriculum at a Canadian, 2-year public institution. Aside from describing and discussion the suggested pedagogy, the author provides the reader with insight into the philosophical, cognitive, and pragmatic issues surrounding its origin, development and inclusion within the chemistry curriculum.

Herman, C. (1998). Inserting an Investigative Dimension into Laboratory Course. *Journal of Chemical Education*, 75(1), 70-72.

The article provides Chemical Educators with guidance concerning the insertion of investigative teaching/learning methods into laboratory chemistry course. Of particular interests are the topics of verification labs versus labs of inquiry, and topics that do and do not lend themselves easily to inquiry investigations.

c. Geosciences

Durbin, J.M. (2002). The benefits of combining computer technology and traditional teaching methods in large enrollment geoscience classes. *Journal of Geoscience Education*, 50(1), 56-63.

The article examines the effects of introducing computer technology into the instruction of an earth systems course. Both student achievement and affective concerns are examined.

Livingstone, D., & Lynch, K. (2002). Group project work and student-centered active learning: two different experiences. *Journal of Geography in Higher Education*, 26(2), 325-345.

The paper presents finding from a study exploring the outcomes of two instructors' experiences with cooperative learning projects as employed in their respective courses. Further, the paper provides an argument based upon those experiences for the careful design of future group-based work.

Brown, L.M., Kelso, P.R., & Rexford, C. B. (2001). Introductory geology for elementary education majors utilizing a constructivist approach. *Journal of Geoscience Education*, 49(5), 450-453

The article outlines constructivist pedagogy in context of elementary educators' preparation to teach.

Goodell, P.C. (2001). Learning activities for an undergraduate mineralogy/petrology course – "I AM / WE ARE." *Journal of Geoscience Education*, 49(4), 370-377.

The paper models interactive engagement and cooperative learning exercises employed in an undergraduate, introductory course in mineralogy and petrology. The activities discussed are linked in series, and employed to teach conceptual understanding of underlying chemical structure as pertaining to macroscopic properties of minerals and rocks.

Hodder, P.W. (2001). “EARTHQUAKE!” – A cooperative learning experience. *Journal of Geoscience Education*, 49(3), 280-285.

The article models a cooperative learning experience for students enrolled in an earth science laboratory course.

Reed, M., & Mitchell, B. (2001). Using information technologies for collaborative learning in geography: a case study from Canada. *Journal of Geography in Higher Education*, 25(3), 321-339.

The authors examine the use of technology to establish and promote an intercollegiate cooperative learning community for student within various courses at multiple universities. Evaluation techniques and other evaluative concerns are discussed.

Soja, C. M., & Huerta, D. (2001). Debating whether dinosaurs should be “cloned” from ancient dna to promote cooperative learning in an introductory evolution course. *Journal of Geoscience Education*, 49(2), 150-157.

The paper presents the use of debate in an introductory course in paleontology and evolution to promote active learning, and provides data assessing student affective concerns regarding the unit in which the techniques were employed.

Yuretich, R.F., Khan, S.A., Leckie, R. M., & Clement, J.L. (2001). Active-learning methods to improve student performance and scientific interest in a large lecture introductory oceanography course. *Journal of Geoscience Education*, 49(2), 111-119.

The authors explore the effects of interactive and cooperative pedagogy upon student exam results and evaluations in an oceanography course designed for lower-level undergraduates. The strategies implemented are thoroughly discussed, and the results of a study adjudging their efficacy are offered.

Ritter, M. E., & Lemke, K. A. (2000). Addressing the ‘Seven principles for good practice in undergraduate education’ with internet-enhanced education. *Journal of Geography in Higher Education*, 24(1), 100-108.

The authors present principles for sound undergraduate instruction taken from personal experience and informed by the work of other science educators.

McKendrick, J.H., & Bowden, A. (1999). Something for everyone? An evaluation of the use of audio-visual resources in geographical learning in the UK. *Journal of Geography in Higher Education*, 23(1), 9-19.

The authors examine the use of audio-visual resources amongst a British college, geography faculty to elicit student participation in class.

Murck, B. (1999). Promoting and evaluating participation in high-enrollment undergraduate courses. *Journal of Geoscience Education*. 47(2), 131-134.

The paper describes one instructor's use of "One Minute Essays" to promote student attendance and active participation in a large enrollment earth science course. Beneficial logistical techniques for efficient implementation are discussed.

Windschitl, M. (1999). Using small-group discussions in science lectures: a study of two professors. *College Teaching*, 47(1), 23-27.

The author offers evaluations of interactive engagement techniques used in a biochemistry and meteorology course.

Reynold, S.J., & Peacock, S. M. (1998). Slide observations- promoting active learning, landscape appreciation, and critical thinking in introductory geology courses. *Journal of Geoscience Education*, 46(4), 421-426.

The paper presents an active learning approach for the teaching of landscape appreciation in a physical geography course within the context of a learning cycle. The extensive use of slide observations, their relevance to instructional goals, and implementation of the strategy are discussed.

Tucker, D.R., Tucker, M.R., & Rieck, W. A. (1998). A cooperative learning exercise using glacial gravels. *Journal of Geoscience Education*, 46(1), 41.

The authors present a model for cooperative learning exercises within an introductory earth science course to promote interaction and introduce students to the processes of the discipline.

Gibbs, G., Haigh, M., & Lucas, L. (1996). Class size, coursework assessment and student performance in geography: 1984-94. *Journal of Geography in Higher Education*, 20(2), 181-192.

The authors report on two studies that assessed the effect of class size upon student achievement. Correlative factors disconnecting an intuitive link between increase class size and decreased performance are examined as instructional practice is discussed with regard to results of the studies performed.

Charman, D.J., & Fullerton, H. (1995). Interactive lectures: a case study in a geographical concepts course. *Journal of Geography in Higher Education*, 19(1),
57-68.

The paper discusses the modification of an introductory course in geography to include interactive engagement strategies aimed at eliciting student participation. The results of a student questionnaire are examined.

Constantopoulous, T.L. (1994). A cooperative approach to teaching mineral identification. *Journal of Geoscience Education*, 42(3), 261-263.

Models a cooperative approach designed to teach mineral identification within a segment of an introductory geology lab.

D'Allura, J.A. (1991). Interactive education in an introductory environmental-geology course. *Journal of Geological Education*, (39)4, 279-83

This paper presents cooperative learning and interactive engagement strategies employed in a environmental geology course.

MacDonald, R. H. (1989). Small-Group Oral Presentations in Historical Geology. *Journal of Geological Education*, 37(1), 49-52.

The authors describe the use of geologic history as a source of content for student group presentations, providing a model for the organization of such activities. Student appreciation for the activities are discussed.

Gibbs, G., & Jenkins, A. (1984). Break up you lectures: or Christaller sliced up. *Journal of Geography in Higher Education*, 8(1), 27-39.

The authors present a lesson promoting student participation and interaction via interactive engagement strategies employed in the course of a single lecture.

Knight, D. B. (1979). Role playing, decision making and perception of place: the use of discussion croups for an introductory cultural geography course. *Journal of Geography in Higher Education*, 3(1), 38-44.

The authors examine the use of role-playing as a cooperative learning technique employed in a cultural geography course to promote continuity between topics and permit students an opportunity to address the process skills of the discipline.

d. Physics

Meltzer, D.E., & Manivann, K. (2002) Transforming the Lecture-Hall Environment: The Fully Interactive Physics Lecture. *American Journal of Physics*, 70(6) 639-654.

The authors review the current research related to how students learn in physics lecture classes. Then, given the reviewed research as a base, the authors describe a study which they performed testing the efficacy of interactive lectures as contrasted with non-interactive lectures. It is found students who had attended interactive lectures out-performed those who had not on standardized tests. The article concludes with the authors' reflections upon implementation, and a review of available resources for those who wish to attempt to make their lectures more interactive.

Burnstein, R.A., & Lederman, L.M. (2001). Using Wireless Keypads in Lecture Classes. *The Physics Teacher*, 39, 8-11.

The article notes potential for incorporation of wireless technologies into interactive lectures. Though the article does not present data, it does provide the reader with a snapshot of the technology and its uses within the classroom.

Greene, R.L. (2001). Illuminating Physics Via Web-based Self-study. *The Physics Teacher*, 39, 356-360.

The author notes Interactive Engagement (IE) strategies in CAL-base (Computer Assisted Learning) environments. Results of a study of the efficacy of CAL-based strategies is reported. Such strategies, it is found, aided student performance on standardized test measuring student understanding (TUGK, MBT, and FCI). A useful weblink is included in the bibliography for those who may wish to implement CAL-based strategies in their classes.

Crouch, C., & Mazur, E. (2001). Peer Instruction: Ten Years of Experience and Results. *American Journal of Physics*, 69(9), 970-977.

The article reports findings from a ten year study of peer instruction within algebra and calculus-based introductory courses in physics for non-majors of science at Harvard University. An increase in student conceptual reasoning and quantitative problem solving abilities was observed post-peer instruction implementation. Also, the authors describe the use of peer instruction and development as they occurred within their study; and, they offer suggestions for others wishing to implement peer instruction in their courses.

Poulis, J., Massen, C., Robens, E., & Gilbert, M. (1998). Physics Lecturing with Audience Paced Feedback. *American Journal of Physics*, 66(5), 439-441.

Describes and examines the use of a computer assisted learning (CAL)/ interactive engagement strategy in large lecture environments. It is shown that audience paced feedback (APF), fostered by the CAL-based provisions are a preferred method of instruction when used in conjunction with lecturing, Also, it is noted that pass rates increase when such strategies are implemented.

Thornton, R.K., & Sokoloff, D.R. (1998). Assessing Student Learning of Newton's Laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curriculum. *American Journal of Physics*, 66(4), 338-352.

The authors reviewed a study in which they implemented specific interactive learning strategies, then compared in-group and out-group performance on a standard measurement instrument for student understanding in physics. It is shown that the developed and implemented curriculum, which uses computers as a tool for achieving interactive instruction, and interactive lecture demonstrations can significantly enhance student conceptual understanding in physics.

Hake, R.R. (1998). Interactive-Engagement Versus Traditional Methods: A Six-thousand-student Survey of Mechanics Test Data for Introductory Physics Courses. *American Journal of Physics*, 66(1), 64-74.

Average effectiveness of courses promoting interactive engagement is discussed. In sum, interactive engagement treated populations show significant increases in normalized gain, a measure of average effectiveness, when compared to populations who were not engaged in interactive lectures.

IV. Informing Instructional Strategies

As stated in the introduction of this article, a desire to inform instructors of college science courses of potential resources guiding shifts in pedagogy from teacher-driven lectures towards student-centered learning is clearly manifest in the Science Education community. In considering such a shift in pedagogy an instructor unfamiliar with constructivist learning theory should explore inquiry-based teaching practices. Much of what has been written regarding inquiry in the last several decades has been written in light of constructivism[i]: and, a review of inquiry would serve as a review of what contemporary learning theory dictates instruction to look like in practice.

In addition, an instructor would benefit from broadly examining interactive engagement strategies, as all the various modes of engaging students in learning are instructional practices born of inquiry and constructivist origins. It would be a farce, however, to indicate to the reader the above practices are the only instructional practices informed by constructivism; therefore, other practices should be reviewed in an attempt to assess meaningful commonalities.

Assessment and evaluation practices are informed by theories of learning and should be reviewed, as well. Assessment permits an instructor to confidently assert his or her students have successfully learned the material presented. Likewise, successful learning is quantified through evaluation, serving as an indication of student conceptual understanding as reviewed by others.

Subsection **a.**, below, presents information concerning inquiry-based instructional practices in a variety of forms. Subsections **b-d.** present additional studies and articles informing instructors new to interactive engagement strategies in large lectures. Last, subsection **e.** discusses a specific assessment tool that is already in use at Western Michigan University for students of Elementary Education: concept mapping. Other useful assessment strategies exist and should not be excluded; therefore, several may be reviewed in the references presented in subsection **e.**.

a. Considering Inquiry

Anderson, R.A. (2002). Reforming Science Teaching: What Research says about Inquiry. *Journal of Science Teacher Education*, 13(1), 1-12.

The author discusses research informing science educators about inquiry. The National Science Education Standards are discussed and definitions for the document's multiple use of the term "inquiry" are defined. In addition, research findings regarding the efficacy and use of inquiry teaching are discussed, as well as barriers and dilemmas confronted when implementing inquiry-based teaching/learning strategies.

Marbach-Ad, G., & Claassen, L.A. (2001). Improving Students' Questions in Inquiry Labs. *The American Biology Teacher*, 63(6), 410-419.

The authors informally describe a study in which they assessed a specific inquiry-based curriculum's ability to improve students' science question asking habits and abilities. Of the methods employed for teaching questioning techniques in science, it is found that explicit instruction most positively benefits students, though instruction through inquiry aides it.

Windschitl, M., & Buttemer, H. (2000). What Should the Inquiry Experience Be for the Learner? *The American Biology Teacher*, 62(5), 346-350.

Noting the promotion of inquiry-based teaching/learning strategies by the National Research Council and American Association for the Advancement of Science, the authors define what an inquiry experience should look like for a student. They then conclude their article with two examples from elementary and middle school life science classrooms.

Buxeda, R. J., & Moore, D.A. (2000). Using Learning-Styles Data to Design a Microbiology Course. *Journal of College Science Teaching*, 29(1), 159-164.

The authors informally discuss how the curriculum of a college microbiology class was designed when learning-styles of the students were accounted for within the class. Based on data obtained from the students, it was shown multiple types of learners were present in the class, and 2) lectures alone would not benefit all students.

Zoller, U. (1999). Scaling-up of Higher-order Cognitive Skills-oriented College Chemistry Teaching: an Action-oriented Research. *Journal of Research in Science Teaching*, 36(5), 583-596.

This article describes a study assessing the impact inquiry-based teaching methods have in a large lecture chemistry classroom upon the development of higher-order cognitive skills (HOCS) in students. Data supported the notion that inquiry-based strategies can have a positive impact upon student HOCS.

Spencer, J.N. (1999). New Directions in Teaching Chemistry: A Philosophical and Pedagogical Basis. *Journal of Chemical Education*, 76(4), 566-569.

The author notes the need for current reforms in how chemistry is taught at the college level. Then, he reviews the current research within the field of Chemical Education that may inform developers of change: cognitive studies and learning theory. Last, nation-wide efforts guiding current reforms in the teaching of chemistry are discussed.

Redish, E.F., & Steinberg, R.N. (1999). Teaching Physics: Figuring Out what Works *Physics Today*, 52(1), 24-30.

The authors explore three veins of contemporary research in Physics Education: 1) student understanding of physics, 2) student attitudes in physics classes and conceptions and their comprehension of physics, and 3) student responses to instruction in physics. In light of the issues raised in the discussion of these points of interest, the article closes with a discussion of implication for teaching.

Hansen, E.J. (1998). Creating Teachable Moments ... and Making Them Last. *Innovative Higher Education*, 23(1), 7-26.

The article discusses issues related to content concerns in inquiry classrooms. It is noted cognitive dissonance and critical self-reflection on the part of the learner is needed for meaningful, sustained knowledge to develop regarding specific curricular content.

Caprio, M.W., & Micikas, L.B. (1998). Getting There from Here. *Journal of College Science Teaching*, 26(1), 217-221.

The authors discuss the merits of arguments seen within Science Education literature favoring and not favoring the inclusion of student-centered strategies in large lectures.

Stohr-Hunt, P.M. (1996). An Analysis of Frequency of Hands-on Experience and Science Achievement. *Journal of Research in Science Teaching*, 33(1), 101-109.

The article provides a brief review of the history of "hands-on" curriculum dated to the Sputnik era. Then, it examines data obtained from 1988's NELS study. It is determined that eighth grade students who experience hands-on activities every day in class or once a week score better on standardized tests. The article concludes with the author examining implications for teaching.

Redish, E.F. (1994). Implications of Cognitive Studies for Teaching Physics. *American Journal of Physics*, 62(9), 796-803.

The author reviews co-current literature (up to 1994) within the field of cognitive studies that may have an impact upon the teaching of science. Four major principles are offered, and their corresponding corollaries are discussed with relevant implication for the teaching of science.

b. Considering Interactive Engagement

Gravett, S., & Petersen, N. (2002). Structuring Dialogue with Students via Learning Tasks. *Innovative Higher Education*, 26(4), 281-291.

The author describes a discussion technique employed in multiple college-level classrooms, and discusses the techniques efficacy (ability to aide student engagement with the material covered). In addition to noting how the technique may be employed, the author discusses results of an informal survey in which students favorably support the techniques' inclusion in the classes studied.

Marbach-Ad, G., Seal, O., & Sokolove, P. (2001). Student Attitudes and Recommendations on Active Learning. *Journal of College Science Teaching*, 30(7), 434-438.

The authors report the findings of an undergraduate introductory biology student's survey and interviews of fellow students' attitudes and recommendations for their shared course that used both traditional instruction (lectures) and student-centered instruction (cooperative learning, interactive engagement discussions, etc.). In general, students favored student-centered instructional strategies.

Wyckoff, S. (2001) Changing the Culture of Undergraduate Science Teaching. *Journal of College Science Teaching*, 30(5), 306-312.

The author provide data taken from her teaching which supports the notion that lecturing is of little value to students when it comes to performance on tests. With that understanding in mind, data comparing and contrasting two groups of students is discussed. It is shown students who participate in classes that employ interactive engagement strategies show greater consistent gains in conceptual understanding as measured by pre and post-tests than those who are taught by traditional lecture. The author concludes with a discussion of the merits of interactive engagement and how to plan its implementation in a large lecture course.

Caccavo, F.J. (2001). Teaching Introductory Microbiology with Active Learning. *The American Biology Teacher*, 63(3), 172-174.

The author provides insights into the development of an introductory microbiology course for non-science majors.

Sutherland, T.E., & Bonwell, C.C. (Eds.). (1996). Using Active Learning in College Classes: A Range of Options for Faculty. In Menges, R.J. (Ed.) *New Directions for Teaching and Learning*, n. 67. San Francisco: Jossey-Bass.

A collection of articles that describes what active learning is, how it can be used in college classes, why it should be used, and the types of instructional strategies that can be considered active learning methods of instruction.

Meltzer, D.E., & Manivannan, K. (1996). Promoting Interactivity in Physics Lecture Classes. *The Physics Teacher*, 34, 72-76.

The authors reviews/discuss readily applicable methods for reorganizning Physics lectures to include interactive, student-centered learning strategies: 1) flashcards, and 2)peer-centered instruction through group problem solving. The flashcard is more thoroughly discussed, and a favorable overview of results for a study pertaining to the methods used in lecture is discussed.

c. Considering Cooperative/ Peer Learning

Cooper, S. Marie A (2002). Classroom Choices for Enabling Peer Learning. *Theory Into Practice*, 41(1), 53-60.

The article guides teachers in the implementation of peer learning within their classrooms. The role of the teacher and learner are addressed as a thorough summary of research regarding peer learning are reviewed and

discussed. The bibliography and appended additional resource sections contain many useful references.

Fagen, A.P., Crouch, C.H., & Mazur, E. (2002). Peer Instruction: Results from a Range of Classrooms. *The Physics Teacher*, 40, 206-209.

The article offers a discussion of survey results regarding instructional use of peer techniques. Though results are favorable, the focus of the article is to inform readers of peer instruction as a viable pedagogical approach within a class, rather than to state evidence supporting its worth. The article offers tips for those wishing to implement peer instruction.

Johnson, D.W., & Johnson, R.T.(1999). Making Cooperative Learning Work. *Theory Into Practice*, 38(2), 67-73.

The article presents an overview of research regarding cooperative learning. The authors review their research findings as they define and qualify cooperative learning, discuss elements of instruction aiding its uses, and describe benefits it brings to the members of a class when appropriately used.

Klionsky, D.J. (1998). A Cooperative Learning Approach to Teaching Introductory Biology. *Journal of College Science Teaching*, 27, 334-338.

The article describes an inquiry-based teaching strategy implemented by one professor attempting to evaluate the merits of a cooperative learning strategy used in a microbiology course. Though the study is not rigorous, it is found the inclusion of the strategy aided student performance on quizzes and tests.

Felder, R.M., Felder, G.N., & Dietz, E.J. (1998). A Longitudinal Study of Engineering Student Performance and Retention. V. Comparisons with Traditionally-taught Students. *Journal of Engineering Education*, 87(4), 469-480.

This paper is the fifth part in a series of articles originating from a longitudinal study that tracked a cohort of students through a chemical engineering preparatory program. This paper compares the treated cohort to a control, traditionally taught, cohort.

d. Other Instructional Practices

Smith, G.R. (2001). Guided Literature Exploration. *Journal of College Science Teaching*, 30(7), 465-469.

The author, a biology professor, discusses his departments' reform efforts within departmental courses (inclusion of interactive engagement strategies consistent with inquiry teaching/learning methods); and, he provides evidence that guided primary literature exploration aided his students to meet the goals addressed by the departments reform efforts.

Herried, C.F. (1997) What is Case? *Journal of College Science Teaching*, 27(2), 92-94.

The author reviews the use of case study teaching methods in Law and Medical School while attempting to elicit a sound reasoning for its inclusion in the teaching of science.

Glasson, G.E., & Mckenzie, W.L. (1998) Investigative Learning in Undergraduate Freshman Biology Laboratories. *Journal of College Science Teaching*, 27, 189-193.

The article examines and shares a professor's struggle to come to terms with low rates of student understanding post-instruction, and the reflections that led to the implementation of inquiry-based teaching strategies in his lecture and TAs' recitations. The article does not explicate data supporting qualitative claims made by the authors.

e. Assessment Strategies

Mintzes, J.L., Wandersee, J.H., & Novak, J.D. (2001). Assessing Understanding in Biology. *Journal of Biological Education* (2001), 35(3), 118-124.

The article discusses assessment strategies that may be employed within science courses to encourage and promote the development of student understanding. The strategies discussed include: concept mapping, V diagrams, image-based testing, clinical interviews, SemNet (a software package that aides students in assessing their knowledge structure of key science topics), the use of portfolios, written products, and student task performance measuring and conceptual diagnostic testing.

Trowbridge, J.E., & Wandersee, J.A. (1994). Identifying Critical Junctures in Learning in a College Course on Evolution. *Journal of Research in Science Teaching*, 31(5), 459-473.

The article reports the findings of a study designed to assess the impact of the inclusion of concept mapping as a tool for student understanding and knowledge construction in a college course in evolution. It is found that the use of concept maps may aide instructors in determining when students are approaching or have past key junctures in the learning of key concepts; moreover, students that engaged in concept mapping tend to spend more time actively studying. Also discussed are implementation concerns within large classes and implications for Biology Education.

Al-Kunifed, A., & Wandersee, J.A. (1990). One-Hundred References Related to Concept Mapping. *Journal of Research in Science Teaching*, 27(10), 1069-1075.
The article presents a list of one-hundred references of articles, books, and other resources pertaining to concept mapping.

Acknowledgements:

The authors would like to express sincere thanks to those who have aided in the development of this bibliography: Dr. William W. Cobern, Dr. Marcia K. Fetters, Dr. Julie Henderleiter, Dr. Robert H. Poel, Dr. Joseph P. Stoltman, Ms. Candis Collick, and Dr. John R. Canon for his recommendations for this document's publication.

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2. Kuhn, T.S. (1996). *The structure of scientific revolutions.* Chicago: University of Chicago Press.

3. Matthews, M.R. (1994). *Science Teaching: The Role of History and Philosophy of Science.* New York: Routledge.

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[i] Inquiry predates constructivism as a term and idea by nearly a century in educational literature regarding science instruction; nevertheless, constructivism has embraced inquiry methods of teaching in recent years, and as a theory about learning it informs inquiry-based instructional practices.