Perspectives on Learning from the Learning Sciences

Frank Fischer (corresponding author)
Ludwig-Maximilians-Universität München
Department of Psychology
Munich Center of the Learning Sciences
Leopoldstr. 13
D-80802 Munich
Germany
frank.fischer@psy.lmu.de
ORCID: 0000-0003-0253-659X

Daniel Sommerhoff (co-author)
Leibniz Institute for Science and Mathematics Education
Department for Mathematics Education
Olshausenstraße 62
D-24118 Kiel
Germany
sommerhoff@leibniz-ipn.de
ORCID: 0000-0002-0559-7120

Anna Keune (co-author)
Technische Universität München
TUM School of Social Sciences and Technology
Arcisstraße 21
D-80333 München
Germany
anna.keune@tum.de
ORCID: 0000-0002-1985-2313

Abstract

Since the 1980s, the learning sciences have been an emerging field of research that focuses on learning of individuals and groups in authentic social, material, and digital contexts from a multi-level perspective. The learning sciences have substantially advanced theoretical conceptions of learning and its support as well as methodological approaches, for example by introducing design-based research. The article provides an overview of the history, important theories and concepts

of learning and guidance, as well as methods of the learning sciences. The concluding part sketches potentially important areas for future research in the learning sciences.

Keywords

- Computer-Supported Collaborative Learning (CSCL)
- Constructivism
- Design-based Research (DBR)
- Inquiry Learning
- Learning Sciences History
- Problem-based Learning
- Learning-by-Design
- Scaffolding
- Situative Learning
- Socio-cultural perspective on Learning

1 A Brief History of the Learning Sciences

Interest in human learning and effective ways of supporting learning through teaching and other forms of instruction can be traced back for millennia. The *learning sciences* (LS) as an emerging academic field originated in the 1980s (Hoadley, 2018). The emergence of the LS was based on three groundbreaking shifts.

First, the idea of context and learning in situ moved to center stage. The shift toward context made it possible to consider the role of the social and physical world in and through which people learn as a basis for theorizing and understanding learning. Studying learning in context was a response to the cognitive paradigm of research on learning and instruction. As (socio-)constructivist and socio-cultural learning theories (e.g., Vygotsky & Cole, 1978) were increasingly adopted, the research focus shifted from studying the individual's cognition (cognitivism) in isolation to studying the learning of individuals and groups in their physical and social environments (e.g., Brown et al., 1989; Scardamalia & Bereiter, 1991). This development is mirrored in the influential 1993 special issue of the journal *Cognitive Science* which contained "a debate among proponents of two distinct approaches to the study of human cognition" (Norman, 1993, p. 1) and led to an increased interest in *situated action* or *situated cognition*, "emphasizing the role of the environment, the context, the social and cultural setting, and the situations in which actors [learners] find themselves" (p. 1). Viewing learning as driven by both internal and external factors led to a theoretical multiplicity, a tradition that the learning sciences continue to advance by staying open to new theoretical perspectives with utility for better understanding and supporting human learning.

Second, the understanding of learning as situated and influenced by socio-cultural and physical contexts required a new set of methodological approaches that can capture (ongoing) learning as understood from these new perspectives. Established prior paradigms from (educational) psychology such as aptitude-treatment interaction (Cronbach & Snow, 1977) was questioned, as these did not adequately mirror the way learning happens within complex school and out-of-school settings, missing important aspects of ongoing learning. As a consequence, research in school and out-of-school learning environments became a dominant paradigm, necessitating the development and use of qualitative, quantitative, and mixed-methods approaches for capturing and facilitating learning (e.g., design-based research). Notably, the learning sciences are characterized by a methodological multiplicity that continues to develop in light of recent technological developments (e.g., Rosé, 2018; Shapiro & Garner, 2021; Sommerhoff et al., 2018)

Third, the learning sciences are also associated with a shift toward interdisciplinary research fueled by the rise of computer science, research on artificial intelligence, computer learning (i.e., how do computers learn?), and computerized learning (i.e., how do humans learn using computers or other technologies?) (e.g., Bobrow & Collins, 1975; Sleeman & Brown, 1982; Wenger, 1987). Trailblazing scholars, including Roger Schank and Seymour Papert, anticipated that computers would radically transform human learning and research on learning, also considering computers as tools that could advance mental structures through the production of personal (learning) designs (e.g., Papert, 1980). In particular, the extension of the phenomenon of *learning* from humans to computers and the comparison and combination of both agents (i.e., people and computers) brought together researchers from a diverse range of fields, including education, psychology, and computer science. For example, major interdisciplinary research lines were the implementation of learning in programming languages (e.g., LISP, LOGO), research on artificial intelligence and learning (e.g., Anderson, Boyle & Reiser, 1985), and the development of computer-supported learning environments (e.g., Cognition and Technology Group at Vanderbilt, 1992). Corresponding interdisciplinary endeavors were, for example, nourished by first specific funding programs for the learning sciences, such as the "Cognitive Consequences of Programming" of the US National Institute of Education (Pea & Linn, 2020). The learning sciences have since participated in shaping a vision of computational innovations as mediating new and more advanced forms of learning (including computer-supported collaborative learning, see also Lee, 2017).

Together, these conceptual, methodological, and (inter-)disciplinary developments led to the formation of a community of researchers, which transcended the hitherto disciplinary boundaries and created the necessity for novel opportunities for meeting (e.g., conferences), publishing (e.g., journals), and funding (e.g., special programs). In 1989, the AERA special interest group "Education in Science and Technology" was founded and later also the sister special interest groups "Learning Sciences" and "Advanced Technologies for Learning" which became a central outlet for the developing learning sciences community. As a consequence of the significant growth of the learning sciences community in terms of impact and spread during the 1980s and 90s, higher education opportunities and separate scientific publication outlets in these areas of research became cogent for the further development of the field (Kolodner, 2004). The *Journal of the Learning Sciences* (JLS) was established in 1991 and the first doctoral program including the terms "Learning Sciences" in its title was launched at Northwestern University in 1992. The doctoral program evolved from the Institute for the Learning Sciences, which was founded at Northwestern in 1989. Parallel, the first International Conferences of the Learning Sciences (ICLS) and of Computer-Supported Collaborative Learning (CSCL) were held in the early 1990s (Kolodner, 2004; Sawyer, 2014). Since 1995, both conferences have repeated regularly in a biannual format. To bring these conferences and the Journal of the Learning Sciences (JLS) under one institutionalized umbrella, the *International Society of the Learning Sciences* was founded as a non-profit professional society in 2002. In particular, ISLS brought together partially different communities clustering around the learning sciences and CSCL (Hoadley, 2018). To address the partially different interests of the CSCL community, the *International Journal of Computer Supported Collaborative Learning* (ijCSCL) was established in 2006 (Stahl & Hesse, 2006).

Research and community building in the context of the learning sciences and CSCL also emerged internationally beyond the North American focal point (Pea & Linn, 2020). For example, the European Research Network *Kaleidoscope* was established in 2004 based on a funding program by the European Commission that centered on Technologies for the Information Society. The network focused on *technology enhanced learning* and brought together over 1,000 researchers from about 100 research units and approximately 20 countries, spanning the fields of computer and social sciences and education, with the goal to integrate different research communities in the context of technology-enhanced learning and to inform knowledge transfer between education, industry, and the wider society (Laurillard, et al., 2007). Within Kaleidoscope, special interest groups on CSCL and on Inquiry Learning became focal points for new scholarly communities with strong conceptual and methodological relationships to the learning sciences. Many of these European CSCL researchers later joined the CSCL community within ISLS. Also in 2004, the *Asia-Pacific Society for Computers in Education* (APSCE), which aims to promote the conduct and communication of scientific research related to all aspects of the use of computers in education, was formed, evolving from the Asia-Pacific Chapter (APC) of the *Association for the Advancement of Computers in Education* (AACE), which itself was established in 1994.

Based on these national and international developments and its theoretical, methodological, and disciplinary pluralism, the learning sciences as an academic field has developed into a multidisciplinary "tent" (Nathan, Rummel & Hay, 2016) that represents an international community and an emerging discipline. This is also reflected within the *Cambridge Handbook of the Learning Sciences* (Sawyer, 2005, 2014) and the *International Handbook of the Learning Sciences* (Fischer et al., 2018), the contents of which comprise conceptual, methodological, and epistemological foundations of the learning sciences as well as an overview of current research. The handbooks serve as introductions to learning sciences as a community and field of research for students and researchers. The handbooks capture the historical development of the learning sciences including proposals for future research trajectories for the academic field.

2 The (Self-)Concept of the Learning Sciences

Since its formation, the ISLS considers itself as a *community of practice* (Wenger, 1999) bringing together academics, professionals, and students who are seeking to advance the sciences and practices of learning. It investigates "fundamental inquiries on how people learn alone and in collaborative ways, as well as on how learning may be effectively facilitated by different social and organizational settings and new learning environment designs, particularly those incorporating information and communication technologies (ICT), as in computer-supported collaborative learning (CSCL)" (ISLS, 2009, p .1). It is a community that addresses authentic learning in contexts in which learning would naturally happen (Kolodner, 2004). The ISLS also has an educational mission, for example, to foster high quality learning sciences programs in higher education internationally. This educational aim led to the foundation of the *Network for Academic Programs in the Learning Sciences* (NAPLeS) at an ICLS conference in Sydney in 2012. NAPLeS' first activities were the establishment of a world-wide directory of affiliated learning sciences master's and PhD programs, a collection of syllabi for higher education introductory courses to the learning sciences, and a webinar series with a selection of learning scientists including pioneers who advanced groundbreaking insights that fundamentally shaped the learning sciences, including Carl Bereiter, Allan Collins, Jim Greeno, and Marlene Scardamalia. To date, NAPLeS has developed into an essential component of ISLS´s educational activities.

The unification of the biannual ICLS and CSCL conferences into the “ISLS Annual Meetings”, the first of them held in Bochum, Germany in 2021, reflects the co-development of both learning sciences and CSCL and the growing coalescence of the learning sciences as an emerging discipline. However, even with this convergent development, the learning sciences remain a community that distinguishes itself through theoretical, methodological, and disciplinary pluralism. Within this pluralistic understanding of studying learning as it unfolds within a social and physical context, certain core concepts and methods exist within the learning sciences that are orbited by other adjacent concepts and methods (e.g., ISLS, 2009; Nathan et al., 2014; Sommerhoff et al., 2018). This makes the LS a dynamic society that aims to understand and foster human learning in authentic settings ranging from early childhood to adult education and informal learning over the life span.

3 Theories of Learning and Guidance in the Learning Sciences

3.1 Theorizing Learning

From the perspective(s) of the learning sciences, learning is predominantly considered from cognitive and socio-cultural perspectives on learning, with embodied and neuroscientific learning theories expanding. However, what can be attended to as learning and what it means to learn in different contexts can be described differently depending on the theoretical perspective. Thus, a multitude of nuanced learning theories have evolved over time, which expand the broad theoretical approaches for more specific learning situations, in particular also combining learning theories with educational perspectives on how to support learning in these situations.

The cognitive revolution (Miller, 2003), starting in the 1950s, led to a shift away from behavioral learning theories and was able to better account for many aspects of individual learning. However, subsequent research also highlighted multiple phenomena related to learning, for example individuals showing different performance in different contexts (e.g., Carraher, Carraher & Schliemann, 1985), which could not be accounted for adequately by these theories. Corresponding findings led to socio-cultural learning theories, which extended current cognitivist conceptions of learning. The research of the Soviet psychologist Lev Vygotsky had a major influence (also outside of Russia), based on the re-publication (and partial revision) of his work “Mind in Society” in the late 1970s (Vygotsky & Cole, 1978). This conception of learning takes the perspective that all learning is socially embedded, leading to the focus on learning (within) communities and, for example, knowledge building (Scardamalia & Bereiter, 1991; see section Computer-Supported Collaborative Learning below) within these communities. This conception was further developed within the learning sciences context with concepts such as i) “situated learning/cognition” (Lave & Wenger, 1991), positing that all knowledge is intrinsically linked to a specific social, cultural, and physical context, ii) “distributed cognition” (Hutchins, 1995), focusing on how cognition is distributed over an environment rather than taking place solely in the individuals’ minds, and, iii) “collective knowledge construction” (Cress & Kimmerle, 2018), which focuses on the joint creation of knowledge and content from relatively small groups to large communities, for example in wikis with hundreds of contributors.

For example, situated cognition draws on ideas from socio-cultural theories of learning and theorizes that learning is principally a social process (Brown et al., 1989) that emerges in interaction with others (Vygotsky & Cole, 1978). Within this theoretical approach, the notion of cognitive apprenticeship takes precedence, which refers to the enculturation of learners into the authentic, established, and valued practices of a community with the aim of becoming full members of that community (Lave & Wenger, 1991). Learning environments that are designed based on socio-cultural learning approaches support learners to interact with others toward engaging in ways of doing that are established and valued within the surrounding social context (e.g., Engle & Conant, 2002). This may mean identifying specific disciplinary practices and recognizing how learners use resources and approach content related to the discipline in ways that are recognizable and representative (Engle & Conant, 2002).

The shift from learning as something within an individual's mind toward considering learning as situated within a community of practice means inviting learning to be theorized, captured, and designed for at multiple levels within the larger socio-cultural and historical system of relevant practices. This alludes to another central theoretical background of learning from a learning sciences perspective: Activity theory. While its origins go back to the Soviet psychologists Sergei Rubinstein and Alexei Leont'ev, it was taken up by several Western scholars (e.g., Engestöm, 2000) and further developed, for example, through Danish's (2014) work that employed an activity theoretical lens for educational design and analysis to analyze complex socio-cultural systems and their interactions. While activity theory aims at describing a single individual, it positions this individual in a broader context, a socio-technical system, that includes the community as a whole and, as crucial aspects of this community, their specific cultural tools, their rules and the division of labor, all of which are necessary to describe the single individual within this context. Activity theorists often use the so-called activity triangle that can be applied as an analytical frame toward understanding an individual, a group, a community, or a system in context, their interactions, and possibly their changes over time. Besides this general necessity for context, activity theory also introduces a hierarchical structure of activity, which can be transferred to the notion of the multi-leveled nature of learning. Roschelle (1998) roughly characterizes these levels as "cultural, conscious, and automatic" (p. 243). While these three levels are often not considered explicitly enough, they inform why learning sciences research includes research approaches that range from the cultural level (e.g., using an ethnographic perspective) and the automatic level (e.g., using neuro-cognitive approaches). While less prominent in the learning sciences as a theoretical underpinning, a similar argument can be based on Newell's unified theories of cognition (1994), which positions learning on different time scales from milliseconds (biological processes) to seconds (cognitive and rational processes) to hours, days, weeks, and beyond (socio-cultural, organizational) (see also Nathan & Alibali, 2010).

Each of these concepts for learning highlights that learning is situated (e.g., Greeno, 2011) in the sense that it is situated within a community of individuals, situated in certain situations, and situated within certain objects or artifacts, which might be used as means for learning. This view of learning can be characterized as core to the learning sciences; however, there is also a broad periphery of less radically social conceptions of learning around this core, which are used within the learning sciences and lead to tensions and synergies (Danish & Gresalfi, 2018).

An example of a specific theoretical approach trying to combine cognitive and socio-cultural perspectives is learning with multiple representation (Ainsworth 1999, 2018). This approach gives a specific account on how multiple representations, such as texts, videos, or augmented/virtual reality impact learning and how they can (individually and in combination) be designed to support optimal learning. However, learning through multiple representations goes beyond purely cognitive theories of learning (e.g., Mayer, 2014; Sweller, Van Merriënboer & Paas, 1998) by building on semiotic and sociological perspectives to better address the role of the context in the analysis and the design of representations for learning.

The learning sciences is also increasingly focusing on embodied (Alibali & Nathan, 2012; Ma, 2016; Shapiro, 2019) and neuro-cognitive learning theories (Sousa, 2010; Varma et al., 2018). The former points to the importance of the human body for cognition and learning, in particular regarding the sensory, perceptual, and the motor/kinesthetic systems as well as how bodies and a combination of bodies are positioned together to facilitate relationships to domain-specific ideas and concepts. It is rooted in part in theories from developmental psychology emphasizing that knowledge and thought are not only reflected in specific actions, but that actions, for example specific motions and gestures, can also support learning (e.g., Goldin-Meadow, 2005). Finger-counting or drawing geometric objects in midair to illustrate one's cognition when solving mathematical problems are two examples of embodied cognitive approaches to learning (e.g., Alibali & Nathan, 2012). Corresponding theories underline that effective learning environments consider possibilities for learners to engage in (bodily) actions, for example by using specific analog or digital manipulatives that can support these actions (e.g., Abrahamson, 2009).

While theories of embodied cognition and their implications are already permeating learning sciences research, neuro-cognitive learning theories are only starting to change current conceptions of learning as examined in the learning sciences (e.g., Sousa, 2010). Cognitive neuroscience has already made impressive progress on explaining cognition of individual learners focusing on short timescales (partially at the level of fractions of seconds) in relatively controlled, laboratory settings (e.g., Eden et al., 2004; Postle, 2020). However, this is currently at odds with the learning sciences focus on learning *in situ* (Varma, McCandliss & Schwartz, 2008), which centralizes authentic, contextualized, social processes often related to timescales of days, weeks, and months.

3.2 Supporting Learning

3.2.1 The Design of Learning Environments in a Broad Range of Educational Contexts

Responding to the multilevel and multi-perspective view of learning, research that aims to support learning typically involves challenging situations that ask learners to grapple with tasks and problems “for which they do not have rote solutions or for which they cannot simply call upon a memorized factoid” (Fischer et al., 2018, p. 4). These challenging situations are typically embedded in information-rich environments that include interaction with other humans and technology.

Learning sciences research is addressing both the design of formal and informal learning environments. For example, formal learning environments have been investigated more systematically for primary and secondary mathematics and science education (e.g., Belland et al., 2017) and for argumentation and collaboration in different fields of higher education (Jeong, Hmelo-Silver & Jo, 2019). Informal learning environments have, for example, been studied in museums (Lyons, 2018) and in maker-centered learning spaces that can be situated within a range of educational institutions and that provide opportunities for people to engage with high- and low-technological tools and materials and can foster technological innovativeness (Peppler, Halverson & Kafai, 2016). Studying learning within out-of-school settings (rather than school settings) allows the advancement of knowledge about highly innovative designs for learning, as well as building inroads for later possible adaptation in school settings. Work on out-of-school settings also includes considering outdoor and indigenous knowledge spaces for broadening cultural relationships within STEM learning (e.g., Litts, Searle, Brayboy, & Kafai, 2021; Tzou et al., 2019).

In addition, learning sciences research considers the facilitation of learning and expertise across the lifespan. Although a majority of studies address K-12 learners, there is increasing interest in learning within early childhood (e.g., van Horne & Bell, 2017) and family settings (e.g., Roque, 2016). Research on expertise development has investigated environmental conditions and support for learners in a much broader age range, including learning at work and through professional development (Ludvigsen & Nerland, 2018; Reimann & Markauskaite, 2018).

3.2.2 Pedagogies

Learning scientists have systematically employed and explored pedagogies that acknowledge the multilevel nature of learning and address the design and use of challenging learning tasks (e.g., Eberle, 2018). They share the basic assumption that complex skills cannot be learned well solely through reading books, being exposed to teacher presentations, or solving massively simplified "toy" problems. Instead, situations are seen as more supportive of learning if they resemble real problem-solving situations in important dimensions of agency (Brown et al., 1989). Among these important dimensions are (a) agency in applying and transferring knowledge to new situations, cases, and problems; (b) agency in generating new knowledge (e.g., on natural and social phenomena), that is, to what extent learners take responsibility to find out about important mechanisms, effects, rules, or relations to explain natural or social phenomena; and (c) agency in coordinating with, explaining to, and negotiating with others the processes and outcomes of knowledge generation and knowledge application (argumentation and knowledge building).

In the following, we briefly introduce three types of pedagogies, (1) learning through problem-solving, (2) learning through inquiry, and (3) learning through design. In addition, we sketch the concept of (4) scaffolding as it probably is the most prominent form of instructional support in complex learning environments that result when the three pedagogies are applied.

(1) Learning through problem-solving: Environments for learning through problem-solving involve learners' engagement with complex problems with the goal of learning (Hmelo-Silver, Kapur & Hamstra, 2018). Problem-solving pedagogies typically focus more on learners' agency with respect to applying and transferring of canonical knowledge (agency dimension a) than on learners' initial discovery of that or new knowledge. Highly productive lines of research have addressed an individual's learning through solving problems. One central research area has addressed the issue of cognitive load that arises through complex problems for learners with little prior knowledge, for example while trying to solve mathematical problems. Goal-free instruction and worked-out examples have been suggested as scaffolding associated with a reduced amount of cognitive load in comparison to solving the problem by oneself (Sweller et al, 1998). Four Component Instructional Design (4C/ID) is an instructional approach that builds on cognitive load theory and that has been applied in many contexts, including higher education (e.g., Sommerhoff, Kollar & Ufer, 2021) and vocational education (e.g., van Merriënboer & Kirschner, 2018).

Another longstanding and influential line of research that is associated with learning through problem-solving has been the investigation of intelligent tutoring systems (ITS or cognitive tutors, Graesser, Hu & Sottilare, 2018b). With ITS, learners try to solve problems presented to them on a computer, while ITS use artificial intelligence to assess the process and the outcomes of a learner's attempts to solve a problem, to build a model of a learner's skills, and to offer feedback and scaffolding, for example, through more difficult or easier tasks, strategic hints, prompts, or examples. Beyond supporting individual learning through ITS, learning scientists began to explore the effects of collaborative learning within small group problem-solving that employ an ITS (Kumar

& Kim, 2014; Rummel, Walker & Aleven, 2016). Also, some approaches to game-based learning and simulations build on learning through problem-solving (Chernikova et al., 2020; Clark, Tanner-Smith & Killingsworth, 2016; Fields & Kafai, 2018).

There has been a long tradition of employing collaboration to enhance the effects of learning through problem-solving. The most prominent example is problem-based learning (PBL). In PBL scenarios, small groups of 5 to 12 learners collaborate around complex, domain-specific case problems (Dochy et al., 2003; Hmelo-Silver & Barrows, 2015). A main focus with respect to collaboration in this context is on pooling of resources: The group, supported by a tutor, identifies the knowledge needed to solve the case, for example to come up with an accurate diagnosis or a promising intervention for a patient case problem in medical education. The members of the group search for resources that offer access to the missing knowledge and share their findings in the group. In addition, further questions, including what makes tutors effective in PBL, have been addressed in research (Schmidt, Rotgans & Yew, 2011).

Recently, work within the learning sciences has started investigating the knowledge and skills necessary to engage in complex *collaborative* problem-solving (Graesser et al., 2018a) and has designed learning environments to facilitate them. For example, there have been approaches to use agent-based simulations where one or more human learners have interacted with collaboration partners that were simulated by a computer (e.g., Graesser & Mc Namara, 2010).

(2) Learning through inquiry: Inquiry learning requires learners increasingly to take responsibility to find out about important mechanisms, effects, rules, and relations to explain natural or social phenomena. In inquiry-based learning environments, learners are supposed to explore phenomena, use disciplinary and generic tools and methods (e.g., measurement devices, lab protocols, spreadsheets), and come up with sound descriptions and explanations of the observed phenomena (see Pedaste et al., 2015). Many computer-supported inquiry learning environments have been developed for and employed in middle school science classrooms (e.g., Linn, Clark & Slotta, 2003). Yet, increasingly, other domains (e.g., historical inquiry; Voet & de Wever, 2016) and other educational contexts (i.e., higher education; de Jong, Linn & Zacharia, 2013) have been explored in relation to inquiry-based pedagogies as well.

Building on research relating to the many problems that learners experience when engaging in knowledge generation through inquiry (e.g., de Jong & van Joolingen, 1998), several approaches to guided inquiry and discovery (in contrast to free discovery) have been developed and investigated (Donnelly, Linn & Ludvigsen, 2014). Typically, inquiry environments that learning scientists have developed include opportunities to interact with peers in small groups or whole classrooms in inquiry activities, such as formulating or evaluating hypotheses, generating evidence, or drawing conclusions and revising an explanation (Slotta, Quintana & Moher, 2018).

(3) Learning through designing: Pedagogies that build on learning through designing involve tasks in which learners engage in the process of utilizing disciplinary knowledge for generating ideas, devising a problem space, building prototypes, and evaluating and iteratively refining a product aimed at solving a challenging situation, often a provided problem. These pedagogies consider agency of the learners for engaging in inquiry activities by which they derive the disciplinary knowledge as well as the knowledge on the constraints and affordances of the problem, both of which are needed for designing, refining, and evaluating the product. Building on foundational work in the early 2000s (see Kafai, 2012; Kolodner et al., 2003), the field has substantially advanced by introducing more recent approaches to learning through designing digital games (Fields & Kafai, 2018), including augmented reality (Enyedy & Yoon, 2021), research on the

maker movement (Halverson & Peppler, 2018), research on design thinking in different educational contexts (Svihla & Reeve, 2016; Goldman & Kabayadondo, 2016), and considering alternative tools and materials for the study of equitable STEM education through design activities (e.g., Peppler & Glosson, 2013). Design pedagogies typically include a focus on interaction among peers where collaboration has quite different functions, including peer feedback on initial ideas, inter-group competitions with respect to the performance of the designed product, and collaborative knowledge building through joint experimentation and discussion (Kolodner et al., 2003; see Fields & Kafai, 2018). Design pedagogies typically initiate and support peer communities using either digital contexts such as internet platforms (e.g., Scratch; see Fields & Kafai, 2018) or material contexts, for example in the context of science learning (e.g., Clegg & Kolodner, 2014).

Theoretical foundations of learning through designing pedagogies are often constructionist, that is assuming that learning happens best when learners come to know the world while creating personally meaningful projects that can be publicly shared (Papert, 1980). A focus lies on the creation and manipulation of tools and materials. For example, in the process of design, materials that are being manipulated turn into "objects-to-think-with" (Papert, 1980, p.11) that make it possible for learners to become epistemologists who observe their own learning as well as personal and multiple ways of knowing (Papert & Harel, 1991). Studying particular material design situations thus allows research to expand on these theoretical ideas within constructionist approaches toward a richer understanding of ongoing learning within digital and physical learning through design situations.

(4) Scaffolding: Referring to the concept of the Zone of Proximal Development, the zone between what learners can do on their own compared to what they can do with the support of more experienced others (Reiser & Tabak, 2014; Vygotsky & Cole, 1978), pedagogies preferred by learning scientists are centered around complex situations that are typically somewhat too challenging for learners themselves. Initially, the learners cannot master these problem-solving, design, or inquiry tasks without additional support. Of the various forms of potential additional instructional support that exist (e.g., feedback, additional information, additional incentives), the learning sciences community has put particular focus on the idea of scaffolding (Wood, Bruner & Ross, 1976). Scaffolding refers to instructional support that enables learners to master tasks that are outside their reach without this support. Scaffolding is typically offered by more knowledgeable others or by (intelligent) computer systems. Wood et al (1976) identified main functions of scaffolding which include sparking situational interest (*recruitment*, p. 98), reducing the complexity and difficulty of tasks (*reduction in degrees of freedom*, p. 98), keeping learners focused on their goal (*direction maintenance,* p. 98), (4) highlighting crucial features of a task (*marking critical features*, p. 98), (5) motivating disappointed learners (*frustration control*, p. 98), and (6) providing solutions and models of a task (*demonstration*, p. 98). Building on Bruner's original work, several taxonomies of scaffolding functions emerged that differ mostly with respect to whether they address what is to be learned (e.g., scaffolding for joint sense-making or for building a hypothesis, e.g., Quintana et al., 2004) or whether they refer to how the learner is supported (e.g., prompting, hinting, channeling, Pea, 2004).

A joint assumption of scaffolding approaches is that the effectiveness of this kind of support depends on its contingency and timeliness. Scaffolding is considered to be temporary and needs to be removed (or faded) when the learner does not need it anymore because scaffolding can also be detrimental for learning (expertise reversal effect; Kalyuga, 2007). Thus, scaffolding requires a dynamic assessment of knowledge and skills, and consequential adaptive interventions–a complex interplay of guidance and self-regulation with respect to each and every individual learner (see Plass & Pawar, 2020). As this seems hardly possible in typical classrooms with only one or two teachers or tutors and 20 or more learners, technology and peers as sources of scaffolding increasingly became the focus of research (Tabak, 2004). Although theoretically straightforward, a recent meta-analysis found mixed evidence on the effects of instructionally adapting the scaffolding to the inferred needs of the learners (Belland et al., 2017).

There are several lines of research on scaffolding for individual learning (Belland et al., 2017). Scaffolding by using examples, so called example-based learning, is certainly one of the more systematically researched approaches to scaffolding (Renkl & Atkinson, 2003). In this approach, learners have the opportunity to follow someone else's steps in solving a difficult problem, typically without further explanation of why these steps were taken. Then, the learners typically have to self-explain the steps by using domain knowledge (e.g., principles of probability calculus). This type of scaffolding example has been used effectively in several domains. In particular, studying and self-explaining examples was more effective than engaging in problem-solving activities for learners with little prior knowledge (see van Gog & Rummel 2018).

3.2.3 Computer-Supported Collaborative Learning (CSCL) and its Approaches to Facilitating Learning

CSCL is concerned with groups that coordinate, co-regulate, and engage in argumentation and knowledge building in problem-solving, inquiry, and design tasks in technology-rich environments. In CSCL research, technology conceptualizations include providing complex and dynamic contexts for these activities and associated pedagogies, as well as enabling and structuring peer collaboration of small and large groups. The *International Handbook of Computer-Supported Collaborative Learning* (Cress et al., 2021) identified common ground of CSCL with other areas of the learning sciences but also differences with respect to phenomena, theories, and methods.

Collective knowledge construction within the learning sciences transcends a purely cognitivist perspective by building on key aspects of socio-cultural perspectives (e.g., Engeström, 2000; Vygotsky & Cole, 1978). Here, the group level as well as (group/cultural) artifacts, alongside individual learning are taken into consideration, with the aim to identify how to support both group and individual learning in the best way possible. Issues around *knowledge building* (see Scardamalia & Bereiter, 2021) have characterized CSCL research for many years. Conceptual and empirical research yielded design principles for learning environments in which learners in school create and share new knowledge for themselves, their class, or even the whole school through collaborative reasoning. The technology enabled the creation and linking of arguments, peer feedback on the arguments, and the revision of the arguments. The approach has been taken up in many places around the world and further investigated through implementations in schools (see Chan & van Aalst, 2018) and detailed network analyses (Oshima, Oshima & Matsuzawa, 2012). Some more recent theories of collective knowledge building (Cress & Kimmerle, 2018; Stahl, 2005) describe and explain how groups of people, from small groups working on one project, to organizations developing several new projects, to large communities producing online artifacts, co-create new knowledge, both regarding their individual knowledge but, in particular, knowledge at the group or community level. The focus of collective knowledge construction theories lies in recognizing a multi-level and multi-agent structure that consists of individual learning and acting, as well as group learning, interaction processes, and artifacts (e.g., Cress & Kimmerle, 2008).

Often, learners' engagement in collaborative knowledge building and argumentation have been analyzed from different theoretical perspectives, reflecting the different disciplinary roots and multiple epistemological backgrounds of the learning sciences. These perspectives include socio-cognitive approaches which are mainly interested in individual learning and focus on discussion and argumentation as potentially facilitating contexts of learning (e.g., Stegmann et al., 2011); dialogic education which considers dialogic argumentation as a major cultural tool to shape individual thinking (e.g., Philipson & Wegerif, 2016), as well as approaches to collaborative argumentation mainly interested in understanding and advancing the human capacity to jointly generate knowledge and resolve conflicts (e.g., Baker, Schwarz & Ludvigsen, 2021).

An important discovery of research on collaborative learning has been that collaborative argumentation and problem solving among learners is not productive in a broad range of contexts because learners often fail to work together (e.g., Barron, 2003; Weinberger, Stegmann & Fischer, 2010). Two lines of research examine forms of support that make productive collaboration more likely.

(1) *Awareness* research examines different forms of awareness support for self- and co-regulation in groups. For example, learners are provided with information about the prior knowledge of each collaboration partner or about the amount/quality of their own contributions compared to other learners in the group (cf. Bodemer, Janssen & Schnaubert., 2018). The effects of awareness support are mixed. It is likely that the extent to which this additional information can actually be used to improve collaborative problem-solving, inquiry, and design depends heavily on the self-regulation skills and learning preferences of the individuals and the group (Jeong et al, 2019). A promising new line of research uses dashboards to inform and support the teachers in their monitoring and scaffolding of computer-supported collaborative learners (Tissenbaum & Slotta, 2019; Van Leeuwen, 2015).

(2) *Scripting and orchestration* for groups: Research on CSCL has successfully broadened the concept of scaffolding individuals in groups and scaffolding groups as a whole (see Kim et al., 2020). Research on the design and the effects of collaboration scripts has emerged from an uptake and the extension of two complementary notions of the term script as a cognitive structure that enables understanding and acting (Schank, 1999) and as an instructional method to improve collaborative learning (O'Donnell et al., 1987). Through collaboration scripts, complex collaborative tasks are segmented into "scenes" and learners are supported by role specifications and, in some cases, engagement in individual subtasks such as formulating questions or arguments (see Fischer et al., 2013). Technology can be used for segmentation and coordination (e.g., Manathunga & Hernández-Leo, 2018) as well as to highlight a role, to provide just-in-time prompts and guidance, and to adapt the level of support (e.g., Amarasinghe, Hernández-Leo & Jonsson, 2019). Collaboration scripts were found to be particularly effective for learning collaboration skills (e.g., engaging in dialogic argumentation in a discussion) and, to a somewhat lesser extent, for domain learning, and segmentation into scenes proved to be the most effective approach to scaffolding (see Vogel et al., 2017). A negative effect of structuring collaboration on motivation has not received support from the existing evidence (see Radkowitsch, Vogel & Fischer, 2020). An extension of the scripting idea was presented with the concept of orchestration. The concept of orchestration addresses the distribution and coordination of technology-supported activities on individual, group, and collective level (Dillenbourg, Prieto & Olsen, 2018), with orchestration graphs (e.g., Prieto et al., 2018) being a "notation system" for planning, enacting and analyzing multi-level, computer-supported activity systems.

4 Methods in the Learning Sciences

The methodologies and methods used in the learning sciences have been analyzed from several perspectives (e.g., Sommerhoff et al., 2018; Yoon & Hmelo-Silver, 2017). According to these analyses, learning scientists have methodological roots in several disciplines, such as psychology, computer science, and science education. The different methods are often eclectically combined to address the analyses of complex processes in contexts like classrooms in schools and universities, laboratories, and informal learning contexts such as youth clubs, makerspaces (Keune & Peppler, 2019), and museums (Lyons, 2018).

The experimental paradigm has been expanded by an innovative combination with design methods coming from computer science. Design experiments (Brown, 1992) and later design research (see McKenney & Reeves, 2021) and design-based research (Anderson & Shattuck, 2012; Design-Based Research Collective, 2003; Sandoval & Bell, 2004) and design-based implementation research (Fishman & Penuel, 2018) have developed in response to the complexity of conditions that needed to be addressed when trying to investigate learning and teaching in authentic or real contexts. Design-based research is a cyclic methodology in which interventions are designed (and re-designed after testing their effects), mostly in collaboration with practitioners, to improve learning in real educational contexts with the equal goal to form and test theoretical advances toward understanding learning (see e.g., Cobb et al., 2003; DiSessa & Cobb, 2004). One approach to advance theory on learning, in and through design research, is conjecture mapping (Sandoval, 2014), which originates from a higher-level idea about how learning could be facilitated in a particular context and moves across design conjectures (e.g., the design and how it is used) to theoretical conjectures (e.g., the outcomes of learning and how they are observed with the design). Design-based Implementation Research (Fishman & Penuel, 2018) has developed as an extension to DBR to investigate and address the multiple questions arising from the implementation process of educational innovations in classrooms across longer periods of time and funding cycles.

In contrast to psychology and other disciplines investigating learning, units of analysis have been extended beyond the individual to include small groups or even classrooms, schools or large online communities (e.g., Stahl & Hakkarainen, 2021). These are addressed using a broad repertoire of methods, including cognitive, behavioral, and physiological measures, which either focus on individuals, interaction between individuals or their combination (see Sommerhoff et al., 2018). Besides DBR as the signature method of the learning sciences, diverse methods are employed. While case studies and classical experimentation are used frequently, methodological innovations are particularly widespread in the learning sciences. Qualitative and quantitative process analyses of “big data”, written and spoken language, of gestures, of artifacts, and of logfiles are used in these studies–and often so in combination in order to achieve a deep understanding of the mechanisms of learning and collaboration (Vogel & Weinberger, 2018) and the effects of technology for their support (Roschelle & Teasley, 1995; Koedinger & Aleven, 2007).

Think-aloud protocols and dialogue analyses (see Vogel & Weinberger, 2018), as well as (social) network analyses (e.g., Oshima et al., 2012; Shaffer, 2017) are among the methods frequently used to analyze reasoning and learning in authentic settings. Logfile analyses have been used to more specifically target the interaction of learners with and within technology-enhanced learning environments. Increasingly, physiological measures like eye-tracking or heart rate variability are used to assess attentional processes and mental load in the learning process. Beyond these physiological measures, the learning sciences has been rather slow in making use of new methods from the neurosciences (see Varma et al., 2018).

Core and periphery. DBR is systematically taught in around 25% of learning sciences programs (Sommerhoff et al., 2018) and is the method of choice in an even smaller fraction of conference and journal contributions in the CSCL community within the learning sciences (Hmelo-Silver & Jeong, 2021). However, the programs that teach DBR systematically seem to form a core of programs in the learning sciences community that are conceptually and methodologically more coherent, and relatively similar. Sommerhoff et al. (2018) suggest in their conclusions that this set of programs may be considered as the nucleus of an emerging discipline of the learning sciences. This nucleus is surrounded by orbiting programs that have strong roots in other disciplines. These programs in the periphery drive methodological innovation and shape the field of the learning sciences. Recent methodological developments with strong influence on the learning sciences include learning analytics (Lang, Siemens, Wise, & Gasevic, 2017), eye-tracking (Jarodzka, Skuballa & Gruber, 2021), and multi-modal learning process analyses (Malmberg et al., 2019).

5 An Outlook on Advancing Research on Learning in the Learning Sciences

The learning sciences have produced and worked on a successful research program on individual and collaborative learning in authentic contexts in formal and informal settings over the past 40 years. This program includes new conceptual frameworks (e.g., collective knowledge construction, knowledge building, scaffolding) and new methods that were adopted from contributing disciplines and further developed to advance knowledge on learning (e.g., design-based research). Looking ahead, we highlight five fields of potential importance for the future of the learning sciences that can help to fill existing research gaps and to generate new insights to address pressing educational and societal issues. They span from (1) replicating prior findings, to (2) novel means of assessment and (3) conceptual and methodological innovation in future research, to (4) fundamental aspects related to educational equity within understanding learning and (5) personalized learning as a key focus of interest and goal within the LS.

(1) *Replicating research findings*. In its early years, research in the learning sciences was often descriptive with the aim to discover mechanisms and conditions rather than their validation through additional research. While the discoveries within the learning sciences contributed to novel perspectives on educational phenomena, topics such as replication and open science have hardly been addressed in the learning sciences. For example, there are only a few meta-analyses on learning sciences and CSCL research (e.g., Belland et al., 2017, Jeong et al., 2019) which leaves important programmatic papers (e.g., Wise & Schwarz, 2017) speculating on the state of research. The learning sciences have produced a wealth of new evidence through empirical studies. To advance the field, a more systematic examination of the robustness, replicability, and transferability of the discoveries is needed. It is currently still subject to discussion within the field whether and by which methods such investigations of robustness and transferability should be undertaken. It is conceivable that an expansion of research in the learning sciences that aims to confirm and evaluate findings across contexts is a prerequisite for systematic impact in related fields and practice (e.g., teacher education).

(2) *Emphasis on assessment*. There is highly important work in the learning sciences that considers novel approaches to assessment that are aligned with educational perspectives central to

the learning sciences (Hickey & Harris, 2021). Yet, it has not been a central focus of the learning sciences to develop new forms of assessment that are aligned with domain-specific and cross-domain knowledge and skills facilitated through problem-solving, inquiry, and design pedagogies. Better aligned assessment is needed to evaluate the effects of these pedagogies for different uses, including their formative use in classroom assessment to help students to learn, their summative use to determine individual achievement, and their use to evaluate specific interventions, programs, or institutions (Pellegrino, 2018). Given the strong focus on disciplinary knowledge and engagement (Herrenkohl & Polman, 2018) in the learning sciences, models of domain-specific competence development (Ufer & Neumann, 2018) and learning progressions (Alonzo, 2018) seem to provide good starting points for these new kinds of assessment. Technology can play a new important role in assessment, beyond making the data collection more efficient. For example, in formative assessment, technology can be used to analyze log file data quickly to help teachers to give adaptive and process-related feedback to individuals and groups, and to adjust the level of scaffolding (e.g., van Leeuwen, 2015; Zhai et al., 2020). Ultimately, better means of assessment will be necessary for the learning sciences (i) to validate that the way learning is observed and supported within the learning sciences corresponds to their theoretical conceptions and (ii) to provide a basis for the further creation and confirmation of highly valid research findings.

(3) *Appreciation of conceptual and methodological innovations from other disciplines*. Learning scientists differ on whether they believe they are a discipline with a common methodological core (Sommerhoff et al., 2018), an interdisciplinary group working on common projects requiring shared conceptual framework models (Wise & Schwarz, 2017), or a multidisciplinary community of researchers who mutually inspire each other through insights into their respective disciplinary research. It is likely that all three views apply, but to different groups of learning scientists (Sommerhoff et al., 2018) and that innovations from several related disciplines, which are being taken up and used, are an important driver of progress in the learning sciences. A clear example of this is the rapid development in the areas of data science in general, and educational data mining and learning analytics specifically (e.g., Romero & Ventura, 2020; Rosé, 2018; Teasley, 2019). Among others, similar innovations could be found, for example, in psychology with recent attempts to link the nomothetic (striving for general regularities) and the idiographic (explaining the individual case) research paradigms (e.g., Cook, Kilgus & Burns, 2018; Molenaar & Campbell, 2009). Taking up existing opportunities and generating new opportunities to monitor better the "innovations next door", and to use them for LS research on authentic contexts of learning and collaboration, will be of high importance for the LS.

(4) *Educational Equity.* Many learning scientists have grappled with questions of educational equity in recent years with the aim of understanding how forms of marginalization and representation relate to understanding learning and learning opportunities (e.g., Politics of Learning Writing Collective, 2017; Bang & Vossoughi, 2016; Esmonde & Booker, 2017; Uttamchandani, Bhimdiwala & Hmelo-Silver, 2020). Within the work of educational equity, design has been considered as a foundational approach toward transforming social and community realities that, along the traditional aim of educational design research, contribute to theoretical approaches regarding equitable learning opportunities (Gutiérrez & Jurow, 2016). Among other things, researchers in this area ask to what extent learning materials, curricula, and pedagogies interact with learner characteristics associated with race, ethnicity, and gender. These interaction effects can systematically create and perpetuate disadvantage and the erasure of general learning effects. Moreover,

knowledge about these interaction effects can also be used to support learning in specific conditions with specific measures. Empirical work related to educational equity within the learning sciences increasingly focuses on STEM and computer science learning, where diversified representation, restorative approaches, and justice-centered orientation promise more social sustainability also through the transformation of these domains (e.g., Barton, Tan & Greenberg, 2017; Vossoughi et al., 2013). Work in this area has focused on, for example, indigenous knowledges (e.g., Tzou et al., 2019; Kafai et al., 2014) as well as racial and ethnic representation (e.g., Tofel-Grehl & Searle, 2017; afrofuturism, Holbert, Dando & Correa, 2020). Moreover, also LGBTQ+ issues (e.g., Uttamchandani et al., 2020) and gender equity (e.g., Buchholz et al., 2014; Keune, Peppler & Wohlwend, 2019) have been increasingly addressed. A crosscutting focus of this work has been transforming domain areas, inviting diverse cultural practices, and identifying relevance of cultural and community practices. For example, work with indigenous families has focused on opening up STEM practices to contribute to the socio-historical and community practices of non-dominant and marginalized people in these fields through intergenerational design and storytelling (e.g., Tzou et al., 2019). While these issues have, to date, predominantly been identified within North American contexts, they have been increasingly taken as exemplary for raising pressing questions about educational equity in other countries and for addressing them with empirical research (e.g., Bang, 2019). The broader international interest in educational equity within the learning sciences has been substantiated with the formation of the ISLS Equity and Justice committee that is charged to identify and address “issues related to diverse representation, the systemic marginalization or erasure of particular voices, and justice-oriented scholarship” (ISLS, https://www.isls.org/members/committees/).

(5) *Personalized learning*. Using technology to adapt the content to be learned and the instructional support to each individual learner’s current needs, both on micro and macro time scales, and to do this in meaningful social contexts is a vision in current approaches to personalized learning (see Plass & Pawar, 2020). Research projects are currently underway across the world that focus on the role of artificial intelligence in education more generally and in facilitating learning processes more specifically. The learning sciences have had a head start with decades of research on ITS, scaffolding, and CSCL in general. Strong theorizing about learning mechanisms and processes in individual and collaborative learning has made studies in the learning sciences amenable to data scientists, even beyond the often-employed well-structured domains. The algorithms used, and rapidly evolving, in learning analytics are often far superior in predicting learning outcomes based on multiple learning process measures than the mostly pure linear regression analyses that have been common in practice within the LS and related educational research until now. Moreover, these approaches resonate, both with calls for educational equity and individual assessment that allow to capture processes and products as well as knowledge and skills. While there is initial evidence for positive effects of systematically employing these AI-based approaches in theory-based adaptive scaffolding environments, there are still challenges waiting to be tackled by interdisciplinary teams of experts from the learning sciences and learning analytics (Rosé, 2018).

6 References

Abrahamson, D. (2009). Embodied design: Constructing means for constructing meaning. *Educational Studies in Mathematics* **70(1)**, 27-47.

Ainsworth, S. (1999). The functions of multiple representations. *Computers & Education* **33(2-3)**, 131-152.

Ainsworth, S. (2018). Multiple representations and multimedia learning. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 96-105. New York: Routledge.

Alibali, M. W. and Nathan, M. J., 2012. Embodiment in mathematics teaching and learning: Evidence from learners' and teachers' gestures. *Journal of the Learning Sciences* **21(2)**, 247-286.

Alonzo, A. C. (2018). An argument for formative assessment with science learning progressions. *Applied Measurement in Education* **31(2)**, 104-112.

Amarasinghe, I., Hernández-Leo, D. and Jonsson, A. (2019). Data-informed design parameters for adaptive collaborative scripting in across-spaces learning situations. *User Modeling and User-Adapted Interaction* **29(4)**, 869-892.

Anderson, J. R., Boyle, C. F. and Reiser, B. J. (1985). Intelligent tutoring systems. *Science* **228(4698)**, 456-462.

Anderson, T. and Shattuck, J. (2012). Design-based research: A decade of progress in education research?. *Educational Researcher* **41(1)**, 16-25.

Baker, M. J., Schwarz, B. B. and Ludvigsen, S. R. (2021). Educational dialogues and computer supported collaborative learning: critical analysis and research perspectives. *International Journal of Computer-Supported Collaborative Learning* **16**, 583–604.

Bang, M. (2019). *Storywork across the landscapes of home and school: Towards indigenous futures in Thailand* (doctoral dissertation). Seattle: University of Washington, http://hdl.handle.net/1773/45175.

Bang, M. and Vossoughi, S. (2016). Participatory design research and educational justice: Studying learning and relations within social change making. *Cognition and Instruction* **34(3)**, 73-193.

Barron, B. (2003). When smart groups fail. *Journal of the Learning Sciences* **12(3)**, 307-359.

Barton, A. C., Tan, E. and Greenberg, D. (2017). The makerspace movement: Sites of possibilities for equitable opportunities to engage underrepresented youth in STEM. *Teachers College Record* **119(6)**, 1-44.

Belland, B.R., Walker, A.E., Kim, N.J. and Lefler, M. (2017). Synthesizing results from empirical research on computer-based scaffolding in STEM education: A meta-analysis. *Review of Educational Research* **87(2)**, 309-344.

Bobrow, D. G. and Collins, A. (1975). *Representation and understanding: Studies in cognitive science*. New York: Academic Press.

Bodemer, D., Janssen, J. and Schnaubert, L. (2018). Group awareness tools for computer-supported collaborative learning. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 351-358. New York: Routledge.

Brown, A.L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences* **2(2),** 141-178.

Brown, J. S., Collins, A. and Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher* **18(1)**, 32-42.

Buchholz, B., Shively, K., Peppler, K. and Wohlwend, K. (2014). Hands on, hands off: Gendered access in crafting and electronics practices. *Mind, Culture, and Activity* **21(4)**, 278-297.

Carraher, T. N., Carraher, D. W. and Schliemann, A. D. (1985). Mathematics in the streets and in schools. *British Journal of Developmental Psychology* **3(1)**, 21-29.

Chan, C. K. and van Aalst, J. (2018). Knowledge building: Theory, design, and analysis. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 295-307. New York: Routledge.

Chernikova, O., Heitzmann, N., Stadler, M., Holzberger, D., Seidel, T. and Fischer, F. (2020). Simulation-based learning in higher education: A meta-analysis. *Review of Educational Research* **90(4)**, 499-541.

Clark, D. B., Tanner-Smith, E. E. and Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research* **86(1)**, 79-122.

Clegg, T. and Kolodner, J. (2014). Scientizing and cooking: Helping middle-school learners develop scientific dispositions. *Science Education* **98(1)**, 36-63.

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R. and Schauble, L. (2003). Design experiments in educational research. *Educational Researcher* **32(1)**, 9-13.

Cognition and Technology Group at Vanderbilt (1992). The Jasper series as an example of anchored instruction: Theory, program description, and assessment data. *Educational Psychologist* **27(3)**, 291-315.

Cook, C. R., Kilgus, S. P. and Burns, M. K., (2018). Advancing the science and practice of precision education to enhance student outcomes. *Journal of School Psychology* ***66***, 4-10.

Cress, U. and Kimmerle, J. (2008). A systemic and cognitive view on collaborative knowledge building with wikis. *International Journal of Computer-Supported Collaborative Learning* **3(2)**, 105-122.

Cress, U. and Kimmerle, J. (2018). Collective knowledge construction. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 137-146. New York: Routledge.

Cress, U., Oshima, J., Rosé, C. and Wise, A. F. (2021). Foundations, processes, technologies, and methods: An overview of CSCL through its handbook. In Cress, U., Wise, A., Rosé, C., & Oshima, J. (Eds.) *International handbook of computer-supported collaborative learning*, pp 3-22. Cham: Springer.

Cress, U., Wise, A., Rosé, C., & Oshima, J. (eds.) (2021). *International handbook of computer-supported collaborative learning*. Cham: Springer.

Cronbach, L. J. and Snow, R. E. (1977). *Aptitudes and instructional methods: A handbook for research on interactions*. Irvington: Ardent Media US.

Danish, J. A. (2014). Applying an activity theory lens to designing instruction for learning about the structure, behavior, and function of a honeybee system. *Journal of the Learning Sciences* **23(2)**, 100-148.

Danish, J. A. and Gresalfi, M. (2018). Cognitive and sociocultural perspective on learning: Tensions and synergy in the learning sciences. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 34-43. New York: Routledge.

De Jong, T., Linn, M. C. and Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science* **340(6130)**, 305-308.

De Jong, T. and Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research* **68(2)**, 79-201.

Design-Based Research Collective (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher* **32(1)**, 5-8.

Dillenbourg, P., Prieto, L. P. and Olsen, J. K. (2018). Classroom orchestration. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 180-190. New York: Routledge.

DiSessa, A. A. and Cobb, P. (2004). Ontological innovation and the role of theory in design experiments. *Journal of the Learning Sciences* **13(1)**, 77-103.

Dochy, F., Segers, M., Van den Bossche, P. and Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and instruction* **13(5)**, 533-568.

Donnelly, D. F., Linn, M. C. and Ludvigsen, S. (2014). Impacts and characteristics of computer-based science inquiry learning environments for precollege students. *Review of Educational Research* **84(4)**, 572-608.

Eberle, J. (2018). Apprenticeship learning. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 44-53. New York: Routledge.

Eden, G. F., Jones, K. M., Cappell, K., Gareau, L., Wood, F. B., Zeffiro, T. A., Dietz, N. A., Agnew, J. A. and Flowers, D. L. (2004). Neural changes following remediation in adult developmental dyslexia. *Neuron* **44(3)**, 411-422.

Enyedy, N. and Yoon, S. (2021). Immersive environments: Learning in augmented+ virtual reality. In Cress, U., Wise, A., Rosé, C., & Oshima, J. (Eds.) *International handbook of computer-supported collaborative learning*, pp 389-405. Cham: Springer.

Engle, R. A. and Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction* **20(4)**, 399-483.

Engeström, Y. (2000). Activity theory and the social construction of knowledge: A story of four umpires. *Organization* **7(2)**, 301-310.

Esmonde, I. and Booker, A. N. (2016). *Power and privilege in the learning sciences*. New York: Routledge.

Evans, M. A., Packer, M. J. and Sawyer, R. K. (eds.) (2016). *Reflections on the learning sciences*. Cambridge, UK: Cambridge University Press.

Fields, D. A. and Kafai, Y. B. (2018). Games in the learning sciences: Reviewing evidence from playing and making games for learning. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 276-284. New York: Routledge.

Fishman, B. and Penuel, W. (2018). Design-based implementation research. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 393-400. New York: Routledge.

Fischer, F., Hmelo-Silver, C.E., Goldman, S.R. and Reimann, P. (eds.) (2018). *International handbook of the learning sciences*. New York: Routledge.

Fischer, F., Goldman, S. R., Hmelo-Silver, C. E., & Reimann, P. (2018). Introduction: Evolution of research in the learning sciences. Fischer, F., Hmelo-Silver, C.E., Goldman, S.R. and Reimann, P. (eds.) (2018). I*nternational handbook of the learning sciences*. pp 1-8. New York: Routledge.

Fischer, F., Kollar, I., Stegmann, K. and Wecker, C. (2013). Toward a script theory of guidance in computer-supported collaborative learning. *Educational Psychologist* **48(1)**, 56-66.

Goldin-Meadow, S. (2005). *Hearing gesture: How our hands help us think*. Cambridge, MA: Harvard University Press.

Goldman, S. V. and Kabayadondo, Z. (eds.) (2016). *Taking design thinking to school*. New York: Routledge.

Graesser, A.C., Fiore, S. M., Greiff, S., Andrews-Todd, J., Foltz, P. W. and Hesse, F. W. (2018a). Advancing the science of collaborative problem solving. *Psychological Science in the Public Interest* **19(2)**, 59-92.

Graesser, A. C., Hu, X., & Sottilare, R. (2018b). Intelligent tutoring systems. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 246-255. New York: Routledge.

Graesser, A. and McNamara, D. (2010). Self-regulated learning in learning environments with pedagogical agents that interact in natural language. *Educational Psychologist* **45(4)**, 234-244.

Greeno, J. G. (2011). A situative perspective on cognition and learning in interaction. In Koschmann, T. (ed.) *Theories of learning and studies of instructional practice* (pp 41-71). New York: Springer.

Gutiérrez, K. D. and Jurow, A. S. (2016). Social design experiments: Toward equity by design. *Journal of the Learning Sciences* **25(4)**, 565-598.

Halverson, E. and Peppler, K. (2018). The maker movement and learning. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 285-294. New York: Routledge.

Herrenkohl, L. R. and Polman, J. L. (2018). Learning within and beyond the disciplines. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 106-115. New York: Routledge.

Hmelo-Silver, C. E. and Barrows, H. S. (2015). Problem-based learning: Goals for learning and strategies for facilitating. In Walker, A., Leary, H., Hmelo-Silver, C. E (eds.). *Essential readings in problem-based learning: Exploring and extending the legacy of Howard S. Barrows*. pp 69-84. West Lafayette: Purdue University Press.

Hmelo-Silver, C.E. and Jeong, H. (2021). Benefits and challenges of interdisciplinarity in CSCL research: A view from the literature. *Frontiers in Psychology* **11**.

Hmelo-Silver, C. E., Kapur, M. and Hamstra, M. (2018). Learning through problem solving. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 210-220. New York: Routledge.

Hmelo-Silver, C. E. and Jeong, H. (2021). An overview of CSCL methods. In Cress, U., Wise, A., Rosé, C., & Oshima, J. (Eds.) *International handbook of computer-supported collaborative learning*. pp 65-83. Cham: Springer.

Hickey, D. and Harris, T. (2021). Reimagining online grading, assessment, and testing using situated cognition. *Distance Education* **42(2)**, 290-309.

Hoadley, C. (2018). A short history of the learning sciences. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 11-23. New York: Routledge.

Holbert, N., Dando, M. and Correa, I. (2020). Afrofuturism as critical constructionist design: building futures from the past and present. *Learning, Media and Technology* **45(4)**, 328-344.

Hutchins, E. (1995). How a cockpit remembers its speeds. *Cognitive Science* **19***,* 265-288.

International Society of the Learning Sciences (2009). The international society of the learning sciences. Retrieved from https://www.isls.org/wp-content/uploads/2020/06/ISLS_Vision_2009.pdf

Jarodzka, H., Skuballa, I. and Gruber, H. (2021). Eye-tracking in educational practice: Investigating visual perception underlying teaching and learning in the classroom. *Educational Psychology Review* **33(1)**, 1–10.

Jeong, H., Hmelo-Silver, C. E. and Jo, K. (2019). Ten years of computer-supported collaborative learning: A meta-analysis of CSCL in STEM education during 2005–2014. *Educational research review* ***28***, 100284.

Kafai, Y. B. (2012). *Minds in play: Computer game design as a context for children's learning*. New York: Routledge.

Kafai, Y., Searle, K., Martinez, C. and Brayboy, B. (2014). Ethnocomputing with electronic textiles: Culturally responsive open design to broaden participation in computing in American Indian youth and communities. In Nagel, K. and Dougherty, J. D. (eds.) *Proceedings of the 45th ACM technical symposium on Computer science education.* pp 241–246. Atlanta, GA: ACM.

Kalyuga, S. (2007). Expertise reversal effect and its implications for learner-tailored instruction. *Educational psychology review* **19(4),** 509–539.

Keune, A. and Peppler, K. (2019). Materials-to-develop-with: The making of a makerspace. *British Journal of Educational Technology* **50(1),** 280–293.

Keune, A., Peppler, K. and Wohlwend, K. (2019). Recognition in makerspaces: Supporting opportunities for women to "make" a STEM career. *Computers in Human Behavior* **99**, 368–380.

Kim, N. J., Belland, B. R., Lefler M., Andreasen, L., Walker, A. & Axelrod, D. (2020). Computer-based scaffolding targeting individual versus groups in problem-centered instruction for STEM education: Meta-analysis. *Educational Psychology Review* **32,** 415–461.

Koedinger, K.R. and Aleven, V. (2007). Exploring the assistance dilemma in experiments with cognitive tutors. *Educational Psychology Review* **19(3)**, 239–264.

Kolodner, J.L., (2004). The learning sciences: Past, present, future. *Educational Technology* **44(3),** 34–40.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse B., Gray, J., Holbrook, J., Puntambekar, S. & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by design (tm) into practice. *Journal of the Learning Sciences* **12**, 495–547.

Kumar, R. and Kim, J. (2014). Special issue on intelligent support for learning in groups. *International Journal of Artificial Intelligence in Education* **24(1),** 1–7.

Lang, C., Siemens, G., Wise, A. and Gasevic, D. (eds.) (2017). *Handbook of learning analytics*. New York, NY: Society for Learning Analytics and Research (SOLAR).

Laurillard, D., Alexopoulou, E., James, B., Bottino, R. M., Bouhineau, D., Chioccariello, A., Correia, S., Davey, P., Derry, J., Dettori, G. and Dirckinck-Holmfeld, L. (2007). The Kaleidoscope scientific vision for research in technology enhanced learning. TELEARN Open Archive. Retrieved from https://telearn.archives-ouvertes.fr/hal-00190011

Lave, J. and Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, MA: Cambridge University Press.

Lee, V. (2017). A short history of the learning sciences. *Foundations of Learning and Instructional Design Technology*. In West, R. E. (ed.) Foundations of learning and instructional design technology - historical roots and current trends. ch. 4. EdTech Books. Retreived from https://edtechbooks.org/lidtfoundations/history_of_learning_sciences.

Linn, M.C., Clark, D. and Slotta, J.D. (2003). WISE design for knowledge integration. *Science education* **87(4),** 517–538.

Litts, B. K., Searle, K. A., Brayboy, B. M. and Kafai, Y. B. (2021). Computing for all?: Examining critical biases in computational tools for learning. *British Journal of Educational Technology* **52(2)**, 842–857.

Ludvigsen, S. and Nerland, M. (2018). Learning at Work. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R., & Reimann, P. (eds.) *International handbook of the learning sciences*. pp 147–156. New York, NY: Routledge.

Lyons, L. (2018). Supporting informal STEM learning with technological exhibits: An ecosystemic approach. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R., & Reimann, P. (eds.) *International handbook of the learning sciences*. pp 234–245. New York, NY: Routledge.

Ma, J. Y. (2016). Designing disruptions for productive hybridity: The case of walking scale geometry. *Journal of the Learning Sciences* **25(3)**, 335-371.

Malmberg, J., Järvelä, S., Holappa, J., Haataja, E., Huang, X. and Siipo, A. (2019). Going beyond what is visible: What multichannel data can reveal about interaction in the context of collaborative learning?. *Computers in Human Behavior* **96**, 235–245.

Manathunga, K. and Hernández-Leo, D. (2018). Authoring and enactment of mobile pyramid-based collaborative learning activities. *British Journal of Educational Technology* **49(2)**, 262–275.

Mayer, R. E. (2014). Cognitive Theory of Multimedia Learning. Mayer, R. E (ed.) The Cambridge handbook of multimedia learning. 2nd ed, pp 43–71. Cambridge, UK: Cambridge University Press.

McKenney, S. and Reeves, T. C. (2021). Educational design research: Portraying, conducting, and enhancing productive scholarship. *Medical Education* **55(1)**, 82–92.

Miller, G. A. (2003). The cognitive revolution: A historical perspective. *Trends in cognitive sciences* **7(3)**, 141–144.

Molenaar, P. C. and Campbell, C. G. (2009). The new person-specific paradigm in psychology. *Current directions in psychological science* **18(2)**, 112–117.

Nathan, M. J. and Alibali, M. (2010). Learning sciences. *Wiley Interdisciplinary Reviews: Cognitive Science* **1(3)**, 329-345.

Nathan, M. J., Rummel, N. and Hay, K. E. (2016). Growing the learning sciences: Brand or big tent. Evans, M. A., Packer, M. J. and Sawyer, R. K. (eds.). *Reflections on the learning sciences*. pp 191-209. Cambridge, UK: Cambridge University Press.

Newell, A. (1994). *Unified theories of cognition*. Cambridge, MA: Harvard University Press.

Norman, D. A. (1993). Cognition in the head and in the world: An introduction to the special issue on situated action. *Cognitive science* **17(1)**, 1-6.

O'Donnell, A. M., Dansereau, D. F., Hall, R. H. & Rocklin, T. R. (1987). Cognitive, social/affective, and metacognitive outcomes of scripted cooperative learning. *Journal of Educational Psychology* **79(4)**, 431–437.

Oshima, J., Oshima, R. and Matsuzawa, Y. (2012). Knowledge Building Discourse Explorer: a social network analysis application for knowledge building discourse. *Educational technology research and development* **60(5)**,903-921.

Papert, S. A. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic books.

Papert, S. & Harel, I. (1991). Situating constructionism. *Constructionism* **36***,* 1-11.

Pea, R. D. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *Journal of the Learning Sciences*, 13(3), 423-451.

Pea, R. D. and Linn, M. C. (2020). Personal Perspectives on the Emergence of the Learning Sciences: 1970s–2005. *Frontiers in Education* **5**, 130.

Pedaste, M., Mäeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A., Kamp, E. T., Manoli, C. C., Zacharia, Z. C. and Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational research review* **14**, 47-61.

Pellegrino, J. W. (2018). Assessment of and for learning. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 10-421. New York: Routledge.

Penuel, W. R., Bell, P., Bevan, B., Buffington, P. and Falk, J. (2016). Enhancing use of learning sciences research in planning for and supporting educational change: Leveraging and building social networks. *Journal of Educational Change* **17(2)**, 251-278.

Peppler, K. and Glosson, D. (2013). Stitching circuits: Learning about circuitry through e-textile materials. *Journal of Science Education and Technology* **22(5)**, 751-763.

Peppler, K., Halverson, E. and Kafai, Y.B. (eds.) (2016). *Makeology: Makerspaces as learning environments* (Vol. 1). New York: Routledge.

Phillipson, N., & Wegerif, R. (2016). *Dialogic education: Mastering core concepts through thinking together*. New York: Routledge.

Plass, J. L. and Pawar, S. (2020). Toward a taxonomy of adaptivity for learning. *Journal of Research on Technology in Education* **52(3)**, 275-300.

Politics of Learning Writing Collective (2017). The learning sciences in a new era of US nationalism. *Cognition and Instruction* **35(2)**, 91-102.

Postle, B. R. (2020). *Essentials of cognitive neuroscience*. Hoboken, NJ: John Wiley & Sons.

Prieto, L. P., Sharma, K., Kidzinski, Ł., Rodríguez-Triana, M. J. and Dillenbourg, P. (2018). Multimodal teaching analytics: Automated extraction of orchestration graphs from wearable sensor data. *Journal of Computer Assisted Learning* **34(2)**, 193-203.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., Kyza, E., Edelson, D. and Soloway, E. (2018). A scaffolding design framework for software to support science inquiry. *Journal of the Learning Sciences* **13(3)**, 337-386.

Radkowitsch, A., Vogel, F., & Fischer, F. (2020). Good for learning, bad for motivation? A meta-analysis on the effects of computer-supported collaboration scripts. *International Journal of Computer-Supported Collaborative Learning* **15(1)**, 5-47.

Reimann, P. & Markauskaite, L. 2018. Expertise. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 54-63. New York: Routledge.

Reiser, B. J. and Tabak, I., 2014. Scaffolding. In Sawyer, R. K. (ed.) *The Cambridge handbook of the learning sciences.* 2nd ed, pp 44-62. Cambridge UK: Cambridge University Press.

Renkl, A. and Atkinson, R.K. (2003). Structuring the transition from example study to problem solving in cognitive skill acquisition: A cognitive load perspective. *Educational Psychologist*, **38(1)**, 15-22.

Romero, C. and Ventura, S. (2020). Educational data mining and learning analytics: An updated survey. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery* **10(3)**, e1355.

Roque, R. (2016). Family creative learning. In Peppler, K., Halverson, E., & Kafai, Y. B. (Eds.). *Makeology: Makerspaces as learning environments (Vol. 1)*. pp 47-63. New York: Routledge.

Roschelle, J. (1998). Activity theory: A foundation for designing learning technology?. *Journal of the Learning Sciences* **7(2)**, 241-255.

Roschelle, J. and Teasley, S.D. (1995). The construction of shared knowledge in collaborative problem solving. In O'Malley, C. (ed.) *Computer supported collaborative learning*. pp 69-97. Heidelberg: Springer.

Rosé, C. P. (2018). Learning analytics in the learning sciences. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 511-519. New York: Routledge.

Rummel, N., Walker, E. and Aleven, V. (2016). Different futures of adaptive collaborative learning support. *International Journal of Artificial Intelligence in Education* **26(2)**, 784-795.

Sandoval, W.A. and Bell, P. (2004). Design-based research methods for studying learning in context: Introduction. *Educational Psychologist* **39(4)**, 199-201.

Sandoval, W. (2014). Conjecture mapping: An approach to systematic educational design research. *Journal of the Learning Sciences* **23(1)**, 18-36.

Sawyer, R. K. (ed.) (2005). *The Cambridge handbook of the learning sciences*. Cambridge, UK: Cambridge University Press.

Sawyer, R. K. (ed.) (2014). *The Cambridge handbook of the learning sciences*. *2nd ed.* Cambridge, UK: Cambridge University Press.

Scardamalia, M. and Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *Journal of the Learning Sciences* **1(1)**, 37-68.

Scardamalia, M. and Bereiter, C. (2021). Knowledge building: Advancing the state of community knowledge. In Cress, U., Wise, A., Rosé, C. and Oshima, J. (eds.) *International handbook of computer-supported collaborative learning*. pp 261-279. Cham: Springer.

Schank, R. C. (1999). *Dynamic memory revisited*. Cambridge, UK: Cambridge University Press.

Schmidt, H. G., Rotgans, J. I. and Yew, E. H. (2011). The process of problem-based learning: what works and why. *Medical Education* **45(8)**, 792-806.

Shaffer, D.W., 2017. *Quantitative ethnography*. Morrisville, NC: Lulu.com.

Shapiro, L. (2019). *Embodied Cognition*. New York: Routledge.

Shapiro, B. R. and Garner, B. (2021, advance online publication). Classroom interaction geography: visualizing space & time in classroom interaction. *Journal of Research on Technology in Education*, 1-15.

Sleeman, D., & Brown, J. S. (eds.). (1982). *Intelligent tutoring systems*. New York: Academic Press.

Slotta, J. D., Quintana, R. M. and Moher, T., 2018. Collective inquiry in communities of learners. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 308-317. New York: Routledge.

Sommerhoff, D., Szameitat, A., Vogel, F., Chernikova, O., Loderer, K. and Fischer, F. (2018). What do we teach when we teach the learning sciences? A document analysis of 75 graduate programs. *Journal of the Learning Sciences* **27(2)**, 319-351.

Sommerhoff, D., Kollar, I. and Ufer, S. (2021). Supporting mathematical argumentation and proof skills: Comparing the effectiveness of a sequential and a concurrent instructional approach to support resource-based cognitive skills. *Frontiers in Psychology* **11**, 3664.

Sousa, D. A. (ed.) (2010). *Mind, brain, & education: Neuroscience implications for the classroom*. Bloomington: Solution Tree Press.

Stahl, G. (2005). Group cognition in computer-assisted collaborative learning. *Journal of Computer Assisted Learning* **21(2)**, 79-90.

Stahl, G. and Hakkarainen, K., (2021). Theories of CSCL. In Cress, U., Wise, A., Rosé, C., and Oshima, J. (eds.) *International handbook of computer-supported collaborative learning*. pp 23-43. Cham: Springer.

Stahl, G. and Hesse, F. (2006). ijCSCL - a journal for research in CSCL. *International Journal of Computer-Supported Collaborative Learning* **1(1)**, 3-7.

Stegmann, K., Wecker, C., Weinberger, A., & Fischer, F. (2012). Collaborative argumentation and cognitive elaboration in a computer-supported collaborative learning environment. *Instructional Science* **40(2)**, 297-323.

Svihla, V. and Reeve, R. (eds.) (2016). *Design as scholarship: Case studies from the learning sciences*. New York: Routledge.

Sweller, J., Van Merrienboer, J. J. and Paas, F. G. (1998). Cognitive architecture and instructional design. *Educational Psychology Review* **10(3)**, 251-296.

Tabak, I. (2004). Synergy: A complement to emerging patterns of distributed scaffolding. *Journal of the Learning Sciences* **13(3)**, 305-335.

Teasley, S. D. (2019). Learning analytics: where information science and the learning sciences meet. *Information and Learning Sciences* **120 (1/2)**, 59-73.

Tissenbaum, M. and Slotta, J. (2019). Supporting classroom orchestration with real-time feedback: A role for teacher dashboards and real-time agents. *International Journal of Computer-Supported Collaborative Learning* **14(3)**, 325-351.

Tofel-Grehl, C. and Searle, K. (2017). Critical reflections on teacher conceptions of race as related to the effectiveness of science learning. *Journal of Multicultural Affairs* **2(1)**, 4.

Tzou, C., Meixi, Suárez, E., Bell, P., LaBonte, D., Starks, E. and Bang, M. (2019). Storywork in STEM-art: Making, materiality and robotics within everyday acts of Indigenous presence and resurgence. *Cognition and Instruction* **37(3)**, 306-326.

Ufer, S., & Neumann, K. (2018). Measuring competencies. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 433-443. New York: Routledge.

Uttamchandani, S., Bhimdiwala, A. and Hmelo-Silver, C. E., 2020. Finding a place for equity in CSCL: Ambitious learning practices as a lever for sustained educational change. *International Journal of Computer-Supported Collaborative Learning* **15(3)**, 373-382.

van Gog, T., & Rummel, N. (2018). Example-based learning. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 201-209. New York: Routledge.

van Horne, K. and Bell, P. (2017). Youth disciplinary identification during participation in contemporary project-based science investigations in school. *Journal of the Learning Sciences* **26(3)**, 437-476.

van Leeuwen, A. (2015). Learning analytics to support teachers during synchronous CSCL: Balancing between overview and overload. *Journal of Learning Analytics* **2(2)**, 138-162.

van Merriënboer, J. J. and Kirschner, P. A. (2018). 4C/ID in the context of instructional design and the learning sciences. *In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) International handbook of the learning sciences. pp* 169-179*. New York: Routledge.*

Varma, S., Im, S.-H., Schmied, A., Michel, K., & Varma, K. (2018). Cognitive neuroscience foundations for the learning sciences. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 64-74. New York: Routledge.

Varma, S., McCandliss, B.D. and Schwartz, D.L. (2008). Scientific and pragmatic challenges for bridging education and neuroscience. *Educational Researcher* **37(3)**, 140-152.

Voet, M. and De Wever, B. (2016). History teachers' conceptions of inquiry-based learning, beliefs about the nature of history, and their relation to the classroom context. *Teaching and Teacher Education* **55**, 57-67.

Vogel, F. and Weinberger, A. (2018). Quantifying qualities of collaborative learning processes. In Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) *International handbook of the learning sciences*. pp 500-510. New York: Routledge.

Vogel, F., Wecker, C., Kollar, I. and Fischer, F. (2017). Socio-cognitive scaffolding with computer-supported collaboration scripts: A meta-analysis. *Educational Psychology Review* **29(3)**, 477-511.

Vossoughi, S., Escudé, M., Kong, F. and Hooper, P. (2013). Tinkering, learning & equity in the after-school setting. In *Proceedings of the Annual FabLearn conference. Palo Alto, CA: Stanford University*.

Vygotsky, L. S. and Cole, M. (1978). *Mind in society: Development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Weinberger, A., Stegmann, K. and Fischer, F. (2010). Learning to argue online: Scripted groups surpass individuals (unscripted groups do not). *Computers in Human Behavior* **26(4)**, 506-515.

Wenger, E. (1987). *Artificial intelligence and tutoring systems: Computational and cognitive approaches to the communication of knowledge*. San Francisco, CA: Morgan Kaufmann.

Wenger, E. (1999). *Communities of practice: Learning, meaning, and identity*. Cambridge UK: Cambridge University Press.

Wise, A. F. and Schwarz, B. B. (2017). Visions of CSCL: Eight provocations for the future of the field. *International Journal of Computer-Supported Collaborative Learning* **12(4)**, 423-467.

Wood, D., Bruner, J.S. and Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology & Psychiatry* **17(2)**, 89-100.

Yoon, S.A. and Hmelo-Silver, C.E. (2017). What do learning scientists do? A survey of the ISLS membership. *Journal of the Learning Sciences* **26(2)**, 167-183.

Zhai, X., Yin, Y., Pellegrino, J.W., Haudek, K.C. and Shi, L. (2020). Applying machine learning in science assessment: a systematic review. *Studies in Science Education* **56(1)**, 111-151.

Further Readings

Cress, U., Wise, A., Rosé, C., & Oshima, J. (Eds.). (2021). *International handbook of computer-supported collaborative learning*. Cham: Springer.

Evans, M. A., Packer, M. J. and Sawyer, R. K. (eds.) (2016). *Reflections on the learning sciences*. Cambridge UK: Cambridge University Press.

Fischer, F., Hmelo-Silver, C. E., Goldman, S. R. and Reimann, P. (eds.) (2018). *International handbook of the learning sciences*. New York, NY: Routledge.

Sawyer, R. K. (ed.). (2014). *The Cambridge handbook of the learning sciences. 2nd ed*. Cambridge UK: Cambridge University Press.

Sommerhoff, D., Szameitat, A., Vogel, F., Chernikova, O., Loderer, K. and Fischer, F. (2018). What do we teach when we teach the learning sciences? A document analysis of 75 graduate programs. *Journal of the Learning Sciences* **27(2)**, 319-351.

Yoon, S. A. and Hmelo-Silver, C. E. (2017). What do learning scientists do? A survey of the ISLS membership. *Journal of the Learning Sciences* **26(2)**, 167-183.

Relevant Websites

Homepage of ISLS - https://www.isls.org/

ISLS Committees - https://www.isls.org/members/committees/

Network of Academic Programs in the Learning Sciences (NAPLeS) - https://www.isls.org/naples/

Journal of the Learning Sciences - https://www.tandfonline.com/toc/hlns20/current

International Journal of Computer Supported Collaborative Learning - https://www.springer.com/journal/11412pxn