“String Theory”: Making Connections Between Theory, Design, and Task in Design-Based Research

Vanessa Svihla, Yan Chen, Aaron T. Cowan, Todd Hynson, Jordan O. James, Sara McGinnis, Abigail Ramirez Ortiz, Judith Tomasson, Margaret Tucker, Madalyn Wilson-Fetrow, Christy S. Albright, Jasmine Desiderio, Dayra Fallad-Mendoza, Kristen Ferris, Danielle Gilliam, Austin Megli, Michelle Roach, Clarissa Sorensen-Unruh, & Rebecca Williams
vsvihla@unm.edu, yanchen@unm.edu, acowan@unm.edu, thynson@salud.unm.edu, ndnplanner@gmail.com, saram@cableone.net, Lil_chick_1224@yahoo.com, tomasson@unm.edu, tuckerm@unm.edu, mefetrow144@unm.edu, calbright@unm.edu, jhenio@outlook.com, dfallad@unm.edu, ferrisk@unm.edu, dgilliam@unm.edu, amegli@unm.edu, maroach1@comcast.net, csoren1@gmail.com, RLWilliams1@salud.unm.edu
University of New Mexico

Abstract: Although popular, a challenge for those new to design-based research is the deliberate building, instantiation and testing of learning theory in a learning design. Building “humble” theory as a bricolage of constructs or grounding a more generalized theory into context is difficult and iterative work. We report on a polyvocal design-based research study in which the course instructors designed an activity to support students to build connections across theory, task, and design in two graduate courses (design-based research and advanced learning design). In both courses, students came to express more ownership over theory and saw theory not as inert, but as a tool they could wield and revise. This learning design thus supported students to take a design approach to theorywork.

Major issues & significance

As a hallmark methodology of the learning sciences, design-based research (DBR) is distinctive in its approach to learning theory (Sandoval, 2004). Learning to instantiate theory in a learning design is challenging, and this is evident to those who review DBR studies in which the connection between learning theory and learning design is tenuous or covert. For those who teach DBR, it can be challenging to help students make connections across theory, design, and data collection plans, all while also attempting to meet both worldly and scholarly needs. To support this difficult work, Sandoval (2014) proposed conjecture mapping, which allows researchers to planfully connect their high-level conjectures to their designed intervention and intended outcomes. This “argumentative grammar” makes explicit the elements—conjectures, tools, task structures, participant structures, discursive practices, observable interactions, participant artifacts, anticipated outcomes—and the relationships between elements. Iteratively refining conjecture maps can help document and support change in an intervention during the course of the project (Wilkerson, 2017).

Notably, only a fraction of papers citing Sandoval (2014) include conjecture mapping. Those who teach DBR may guess at the cause—while a promising tool for those already steeped in the discourse, conjecture mapping comes with a heavy terminological apparatus for newcomers, who spend more time trying to understand what the tool is asking of them than using it to support their theorywork. In this study, we report on a new technique—playfully named “string theory” by participants—that we designed to support newcomers make connections between the task, learning design, and learning theory explicit. Our purpose was to contrast two iterations of the same activity to understand its affordances for theorywork. We sought to investigate the following research question: How might making physical connections between task, learning design, and bricolage learning theory support graduate students to make sense of theorywork?

Theoretical approach

We situate our work as constructionist (Papert & Harel, 1991) in that we sought to co-create a playful, meaningful, relevant, and public-facing approach to theorywork, itself an activity that involves building connections in an ill-structured space. Constructionism is more than just expanded learning situations and learning by making; it encompasses the nature of knowing, situated as lasting meaning. To support such ambitious learning, we sought to instantiate and test a *bricolage* theory of learning: authenticity, paired with theorywork scaffolds, feedback, and revision should enhance graduate students’ sense of agency and ownership of, knowledge of, and ability to build their own humble theories of learning. We first situate theorywork as problem framing, then review research that influenced our theory.

Building theories is a process of framing

Viewed as design work—or as we have labeled it, *bricolage*—the process of building "humble theories" (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003) is ill-structured, meaning there are no canonical solutions (Jonassen, 2000) and situated (Dorst, 2003). This creative endeavor requires the designer to ask questions that lie outside of a problem-solving discourse and directly confront the creative unknown (Getzels, 1979). The way a designer frames the problem significantly impacts the solution, with designers who spend more time oriented to the problem typically producing more innovative designs (Getzels, 1979; Paton & Dorst, 2011; Restrepo & Christiaans, 2004). Framing may be impacted by many factors, some of which are also salient for theorywork, such as project goals, resources available, and the designer's prior knowledge and experience, as well as their preferences (Harfield, 2007). These also situate theorywork as an authentic practice.

Scaffolding access to authentic theorywork

Authenticity is a much used, but often poorly defined construct that may refer to a realistic context or task, alignment of instruction and assessment, realistic engagement in professional practices, or a focus on relevance (Shaffer & Resnick, 1999). To address this ambiguity, Strobel, Wang, Weber, and Dyehouse (2013) analyzed over 1000 papers that used the term authenticity related to learning. Based on their analysis, they proposed a definition for authentic problems as having a "primary purpose and source of existence [that] is not to teach or provide a learning situation; The primary purpose and source should be a need, a practice, a task, a quest and a thirst existing in a context outside of schooling and educational purposes" (Strobel et al., 2013, p. 151). Similarly, authentic learning has emphasized "***construction of knowledge***, through the use of ***disciplined inquiry***, to produce discourse, products, or performances that have ***value beyond school***" (Newmann, King, & Carmichael, 2007, p. 3). Yet, when students encounter such problems in a learning context, they may still view them as schoolish (Wernet, 2017), and at least in the context of mathematics, this can hinder learning (Palm, 2008). Furthermore, authentic problems, defined in this manner, can be problematic for learners. First, such problems are not designed to support learning. As has been long known, pure experience, without opportunities for reflection and sense making, is unlikely to spontaneously support learning (e.g., Kolb, 2014; Schwartz & Bransford, 1998). Second, the complexity and ill-structuredness common to such problems can make them inaccessible *because* of their authenticity. Thus, providing scaffolding can support students to learn from such authentic problems (Quintana, Shin, Norris, & Soloway, 2006). However, if the scaffolding is always present, students may fail to transfer what they have learned in the absence of scaffolding, highlighting the importance of gradually fading scaffolding. Yet, fewer studies have investigated fading, especially outside of K12 STEM learning (T.-C. Lin et al., 2012). In this study, we conjectured that fading cognitive scaffolds and modeling theorywork practices would support doctoral students to develop competence and confidence in building learning theory related to their dissertation topics.

Feedback and reflection make revision meaningful

Research has clarified characteristics of and approaches to effective and ineffective feedback (Kluger & DeNisi, 1996). First, feedback must be specific and actionable in order for students to make changes and learn based on it (Hattie & Timperley, 2007; Underwood & Tregidgo, 2010). It should also be formative and model corrections to common errors (Shute, 2008; Underwood & Tregidgo, 2010). Feedback in the form of peer review can be beneficial for the reviewer, helping them to tune into the task expectations (Baker, 2016). However, without revision, feedback, whether from instructor or peer, has little impact on learning and instead may be received just as a value judgement (Black & Wiliam, 1998; Wheeler & McDonald, 2000). Likewise, reflection on what and how students learned can cement this learning (DiSalvo, 2016; X. Lin, Hmelo, Kinzer, & Secules, 1999; Tawfik & Kolodner, 2016). In this study, we conjectured that both instructor and peer feedback, revision across forms of theorywork, and reflection on what had changed and what they learned would support enhanced understanding of the purpose of theorywork.

Enhancing learner agency builds ownership

Instructors can support learner agency by allowing students to make decisions that are organizational (e.g. related to classroom management and norms), procedural (e.g., presenting results as a poster versus presentation), or cognitive (e.g., making decisions about the ways to proceed in solving a problem) (Stefanou, Perencevich, DiCintio, & Turner, 2004). Although the most important form for supporting meaningful learning (Stefanou et al., 2004), cognitive agency is the least common, as allowing students this level of agency makes teaching harder to predict and therefore, harder to plan and control. It is also challenging for students, in part because they have less experience in such settings, meaning that students may experience frustration, though this may decrease over time as students pursue their own interests (Kajamaa & Kumpulainen, 2019). Likewise, practicing this kind of agency can build students' capacity to own and engage these skills in their independent work (Wertsch, Tulviste,

& Hagstrom, 1993). Our recent work has clarified the importance of students having agency to make decisions that are consequential to how they frame the problems they are working on (Svihla, Gomez, Watkins, & Peele-Eady, 2019), a form of agency we have labeled as *framing agency*. In this study, we conjectured that supporting students to develop framing agency related to theorywork would build their capacity to direct their own revisions and sense of ownership over theory.

Methodology

We used DBR to compare two iterations of "string theory." We characterize our approach to DBR in this study as polyvocal (Pithouse-Morgan et al., 2014) and participatory (DiSalvo, 2016). While DBR is typically collaborative, often involving teams of researchers and teachers (Cobb, Zhao, & Dean, 2009), we sought to engage the learners as informants. Given the focus of our study—graduate students engaged in their own theorywork in a constructionist setting—it seemed natural to include all participants as authors as a means to model theorywork in the authentic and public setting of publication. The participants included two instructors and graduate students enrolled in two courses—design-based research (n=7) and advanced learning design (n=10) in an interdisciplinary program in the southwestern United States. The courses met weekly for 16 weeks in a seminar room. Both courses included weekly readings and theory-building work, but for different purposes (Table 1).

Table 1: Overview of the two courses

	Design-Based Research course	Advanced Learning Design course
Focus of course	Methodology course. Explore origins standards, and practices; plan a DBR study and identify analytic methods that treat learning as process in context	Foundations course. Explore and develop a critical stance on designed learning environments and experiences, expand understanding of learning theory
Purposes of theorywork	Students develop contextualized or humble theory to instantiate and test in their learning designs with a goal of iterative testing.	Students develop ambitious designs for learning based on both grand theories of learning and humble theories of learning. They warrant these with theory
Key differences	Students completed conjecture mapping. Readings focused primarily on method/methodology	Students developed head-body-legs flipbooks of theory, designs, and research on affective/social/cultural aspects (head), learning (body), and assessment (legs). Readings focused on design and learning theories.

Students completed the "string theory" activity approximately halfway through the semester, after having practiced simpler activities. We specifically wanted students to both model and write about theory. Based on prior experience teaching modeling, we knew students might gravitate toward metaphoric models and onion diagrams, which helped them describe the kinds of constructs they were interested in but did not help them make progress in explaining how they thought learning occurred. We therefore required students to use systems modeling, articulating the directional relationships between constructs as direct (i.e., if construct 1 increases, construct 2 increases) or inverse (i.e., if construct 1 increases, construct 2 decreases). We explained that their theories had to be mechanistic, meaning the theory should explain how the constructs produced learning. We recognized that this would be challenging, and therefore developed a faded scaffolded approach (Figure 1).

In addition to providing peer feedback on sticky notes, we scaffolded them to make refinements using a modified KWL chart (Ogle, 1989): "What do you KNOW* about the relationships between your constructs? *Citations please!; What do you WONDER about the relationships between your constructs?; How will you LEARN** about relationships between constructs? **What search terms? Which journals? What kinds of publications?" Finally, each activity, including peer review, culminated with individual reflection about what they noticed, and plans for what they would do next based on that, followed by whole group discussion.

We first modeled the full string theory activity with a relatively simple and accessible, yet believable example, in which a collaborator of the first author wanted to teach her young son to do the laundry but had concerns about her white clothes ending up pink. She proposed an instructional design that included a predict-observe-explain activity to show her son that red fabric can bleed, then asking him to come up with a rule about sorting laundry and applying the rule, providing feedback about his choices. We collectively depicted the expert task of sorting laundry, the sequence of the instructional design, and the humble theory instantiated in the design.

We then modeled using yarn to make connections, for instance between the construct of feedback in the theory and the use of feedback in the design.

We provided students with three worksheets to create a process diagram depicting their proposed instructional design; a flowchart of steps comprising expert performance of the task; and their mechanistic systems model of their learning theory. We emphasized that they could complete these in any order and that they may find it helpful to not fully complete one before moving to the next. Once completed, students taped these to a white board, and used tape and yarn to connect elements across the three sheets that were related to each other, forming a network. As with other activities, we used sticky notes to provide peer feedback followed by reflection and discussion. In the following class, we debriefed the activity and reviewed course readings to begin collectively writing this paper. We used "string theory" to depict the experience (Figure 2).

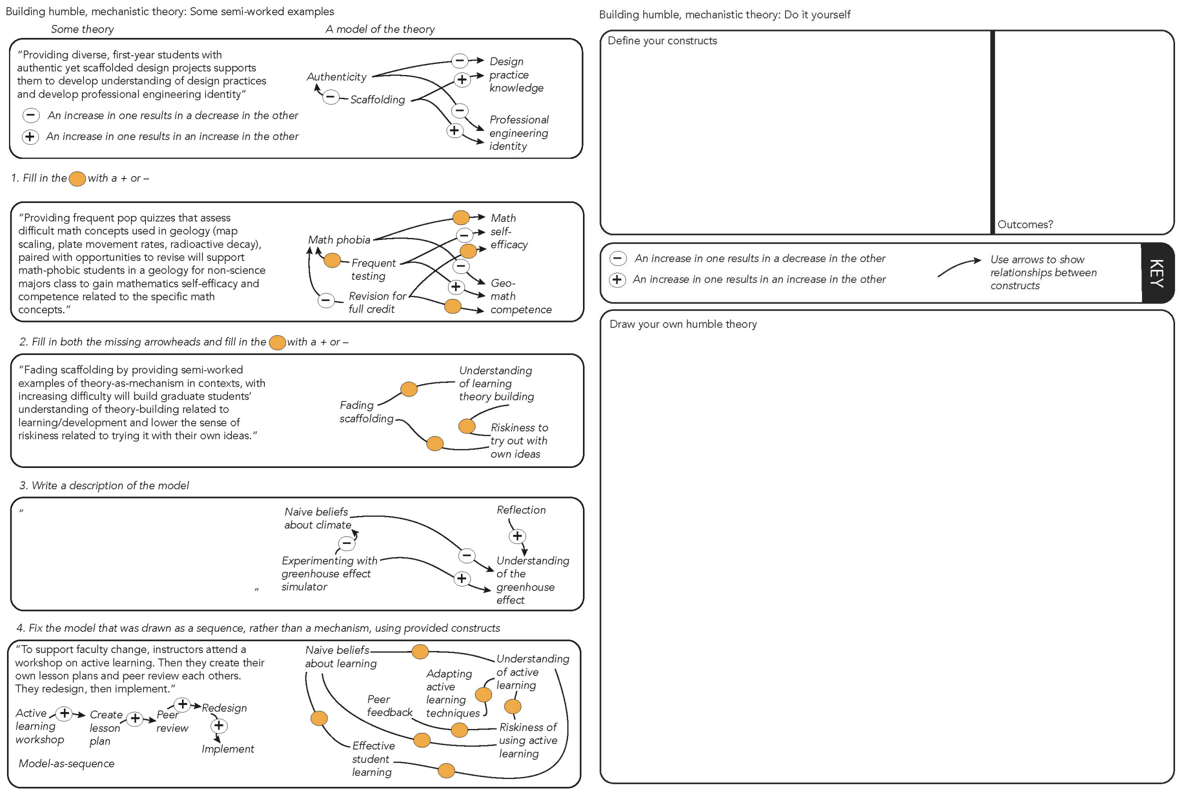

Figure 1. Faded scaffolds for developing understanding of systems modeling of mechanistic theory (left) included a series of semi-worked examples that increased in difficulty: Students choose between direct or inverse relationships on a subset, then all relationships; they explained a theory based on a model, then corrected a sequence flowchart to create a model. They applied this to their own theorywork, making their constructs and outcomes explicit.

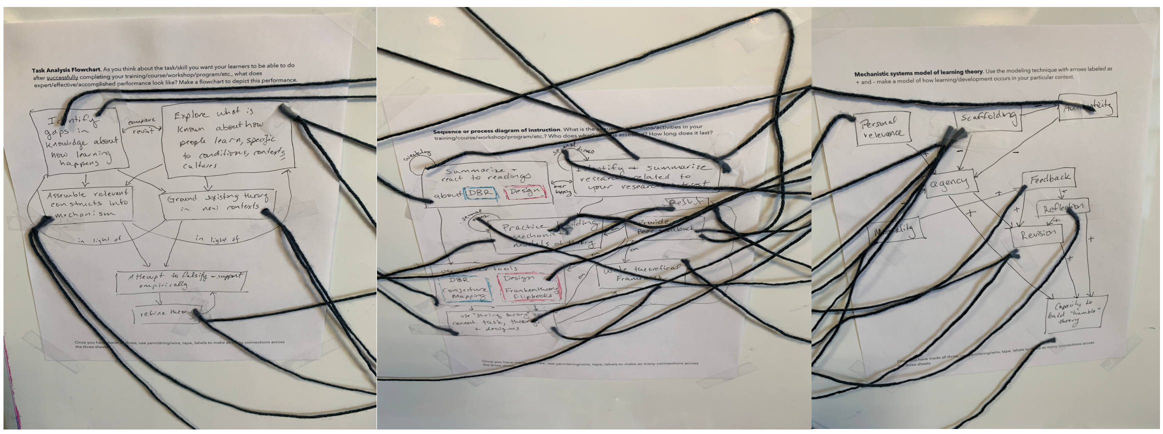

Figure 2. String theory applied to the string theory activity, and used to create the framework for this paper.

We collected artifacts of learning and participation and video and audio-recording of class meetings. We analyzed students' written reflections and in-class discussions collectively. We used our theory as an analytic lens, and this reinforced theory-as-tool stance. The instructors contrasted the two iterations through retrospective analysis to consider the role the activity played in supporting theorywork in the two different contexts of methods course and foundations course.

Results and discussion

We present results from two concurrent iterations, foregrounding students' reflections on the process in relation to the theory instantiated in the string theory activity.

Iteration 1: Design-based research course

Overall, we found that students in the methodology course appreciated seeing the big picture, making new connections, and refining their set of constructs. Specifically, students appreciated that "string theory allowed me the opportunity to take a step back from my work and look at the big picture." In discussing this idea, they noted that string theory helped them make connections between abstract and concrete planes (Figure 3), which in turn supported them to understand what it means to instantiate theory in a design for learning. "I saw connections that I hadn't even thought of before." Here, we see this as consistent with constructionism (Papert & Harel, 1991), as students used string to physically make representations of the connections they were building. Some noted that they used string theory to identify gaps in their theory as well as "orphaned constructs" that they liked, but had not actually placed into their designs, "I found the experience of connecting tasks, processes, and theories via strings was a helpful one for finding connections, where they existed, and identifying areas where connections ought to exist." The peer feedback reinforced this by identifying specific connections that had been seen by others or raising questions about existing connections.

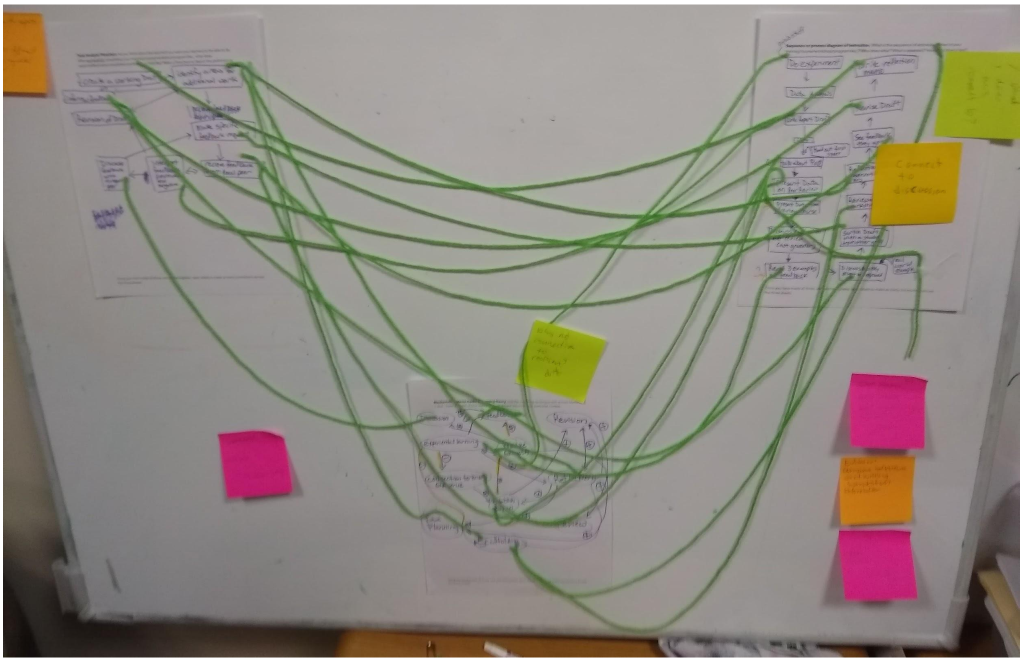

Figure 3. Example from the DBR course. Students made many connections across task, design, and theory.

During peer review, students gave specific and actionable feedback, because the basic action at issue was whether to add, move, or remove a string. One student stated that, "giving feedback was easier for me because I could place the sticky note right where the issue existed." Such feedback is also straightforward for students to evaluate and apply or reject because of its specificity and usability (Underwood & Tregidgo, 2010).

Students came to see theory as a tool, and specifically, one they used agentively (Stefanou et al., 2004; Wertsch et al., 1993) and displayed framing agency as they reshaped their theories. For instance, one student reflected that string theory "showed me that the design I was working on could contribute to leading me to the path of reaching my goal, but there were key pieces that I was still missing." The string theory activity helped students make connections between their personal goals and theory, suggesting the activity was authentic for students given this sense of value beyond classwork (Newmann et al., 2007).

Consistent with research on reflection (DiSalvo, 2016; X. Lin et al., 1999), the reflective discussion helped to cement students' learning about how theories can be constructed, revised, and used. Once students received feedback, reflected upon the new information, and explained their own thinking, they expressed greater confidence in their theoretical models.

In this course, we also specifically contrasted conjecture mapping with the string theory activity. Students described conjecture mapping as "rigid, prescribed," not getting the big picture, "less natural" and linear. The small boxes on conjecture maps signaled that they needed to "think smaller," which seemed to restrict them to procedural agency (Stefanou et al., 2004). Several students noted that they spent time trying to figure out if they were doing it correctly, and had few insights about their theories, designs, and methods. This is not to say that conjecture mapping is not an effective tool for experienced researchers to map the progress of their conjectures, but rather to highlight that students did not find it helpful for supporting their theorywork. This speaks to definitions of authenticity that highlight a primary purpose outside learning settings (Strobel et al., 2013); making such authentic practices also authentic for learners can be challenging, because even with additional scaffolding that provides access to the terms, students may still fail to see the relevance or value to the tool. We observed that conjecture mapping reinforced their sense that theorywork might be out of their reach. In contrast, string theory helped them develop a sense of ownership over theory. Part of their developing sense of ownership came from viewing string theory—because of the simplicity of materials—as an agile process, meaning they characterized it as iterative and improvable, and one over which they retained framing agency (Svihla et al., 2019).

Iteration 2: Advanced learning design course

In reflecting on the string theory activity, students in the foundations courses explained that it helped them "get my mind around" the purpose of theorywork. One student explained that they finally shifted from trying to create a generalizable "big change the world" theory to one that could still "make a huge difference" and this resonated with other students. They explained that it helped them "hone in" and consider how the theory would function for a specific group of learners. Some said they identified gaps and others noted it helped them identify orphaned constructs. They argued that the string itself helped them get more specific in making theory that could "do something."

In this course, several students described the process as challenging, "I did struggle a little with mapping the task analysis to the design and learning constructs." Primarily, these comments related to the utility of the task analysis. As a common instructional design tool, we placed less emphasis on task analysis for this class but realized we should have. Some students described what an expert's experience would be if they were a student in the instructional design, or they envisioned a particular expert who would perform the task in a less than ideal way, rather than expert performance of the desired task. This led to a high level of overlap between descriptions of the instructional design and the task analysis. We also wonder if students completed the initial worksheets, or at least the task analysis in a pro forma manner (Wernet, 2017). Comments suggest some did not see value or purpose in this aspect, "I understand and perform task analyses all the time, but I may not quite understand the intent of this part yet in the context of the string theory." This in turn suggests that the activity was somewhat less meaningful for and authentic to these students and may explain why the task was less well connected to the instructional design and theory, compared to the DBR course students (Figures 3 & 4).

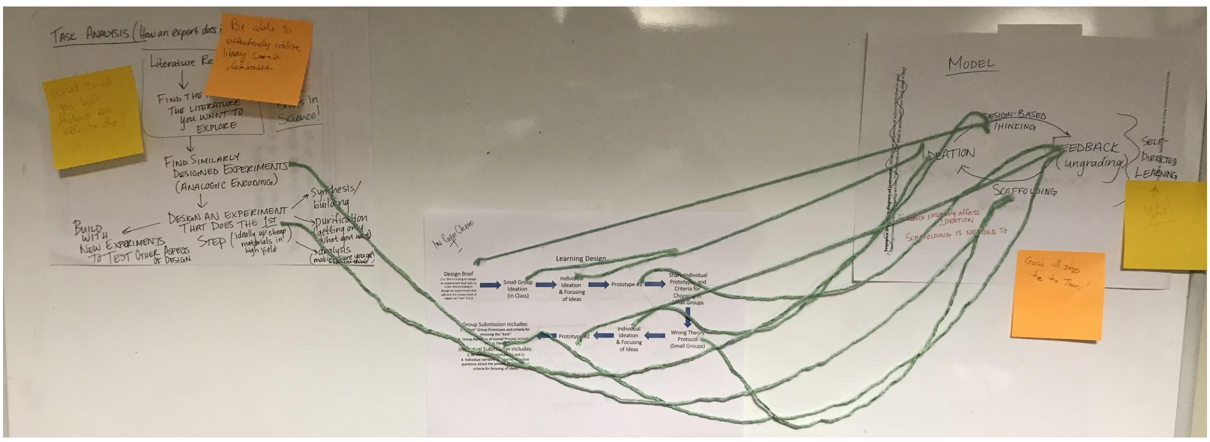

Figure 4. Example from the foundations course. Students made fewer connections overall, especially to the task.

String theory helped students make sense of theorywork, "I had been confused about theory building for some time prior to this assignment. It allowed me to make connections throughout my three different components of the bricolage theory model - task analysis, learning experience, and theory - and find holes or incompatible constructs in the theory I was building. It also helped me focus my theory on constructs that actually made sense to the learning design and the expert task analysis." Perhaps because the focus of this course was on connecting theory to learning designs and envisioning more ambitious designs, students appreciated string theory as a tool for warranting their designs, "Overall, I thought this was a very helpful approach to designing instruction and gives a way to outline the learning constructs that back up the design - something I think could be very useful when explaining or justifying designs to customers/stakeholders." And another student explained, "I felt it really helped to make sure that the design had evidence-based backing and that all of the relevant or most important learning constructs were represented in the design. This required some back and forth from design to learning theory." This "back and forth" suggests the string theory activity supported students to display framing agency—making decisions both about their theories and how to proceed in their theorywork (Svihla et al., 2019).

Conclusions and retrospective analysis

The string theory activity promoted deeper understanding of theorywork. Across the two iterations, students cited that the string theory activity helped them focus their theories if they had too many constructs and identify gaps and orphaned constructs. This constructionist experience helped students make public their ideas and build new connections, both physically and mentally (Papert & Harel, 1991). It invited them to additionally place their prototype humble theories in harm's way, an integral part of DBR (Cobb et al., 2003), albeit one that typically occurs later in the process. In the DBR course, students additionally argued for the importance of the physical medium, which signaled revisability. We believe this aligns to the course context, which emphasized the importance of iteration in DBR. In contrast, the foundations course students suggested—and in some cases, acted on—making the activity digital. Our results suggest that while conjecture mapping may be an effective tool for experienced researchers, it may stand in the way of theorywork for newcomers. String theory provided a means for newcomers to develop increased sense of ownership over theorywork, while also developing a more nuanced understanding of contextualized or humble theory as useful and useable. This shifted students from treating theory as inert, static and inaccessible to viewing it as a dynamic tool. While we generally found support for our conjectures, our results should be replicated through additional iterations and in new settings. Additionally, future iterations could investigate using the string theory activity *iteratively* in the same course to further support and document this process and student learning.

References

Baker, K. M. (2016). Peer review as a strategy for improving students' writing process. *Active Learning in Higher Education, 17*(3), 179-192.

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education, 5*(1), 7-74.

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

Cobb, P., Zhao, Q., & Dean, C. (2009). Conducting design experiments to support teachers' learning: A reflection From the field. *Journal of the Learning Sciences, 18*(2), 165-199.

DiSalvo, B. (2016). Participatory design through a learning science lens. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems.*

Dorst, K. (2003). The problem of design problems. *Design Thinking Research Symposium, Sydney, 17*(19.11).

Getzels, J. W. (1979). Problem finding: A theoretical note. *Cognitive Science, 3*(2), 167-172.

Harfield, S. (2007). On design `problematization': Theorising differences in designed outcomes. *Design Studies, 28*(2), 159-173.

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research, 77*(1), 81.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63-85.

Kajamaa, A., & Kumpulainen, K. (2019). Agency in the making: analyzing students' transformative agency in a school-based makerspace. *Mind, Culture, and Activity, 26*(3), 266-281.

Kluger, A. N., & DeNisi, A. (1996). Effects of feedback intervention on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin, 119*(2), 254.

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*: FT press.

Lin, T.-C., Hsu, Y.-S., Lin, S.-S., Changlai, M.-L., Yang, K.-Y., & Lai, T.-L. (2012). A review of empirical evidence on scaffolding for science education. *International Journal of Science and Mathematics Education, 10*(2), 437-455.

Lin, X., Hmelo, C. E., Kinzer, C., & Secules, T. (1999). Designing technology to support reflection. *Educational Technology Research and Development, 47*(3), 43-62.

Newmann, F. M., King, M. B., & Carmichael, D. L. (2007). *Authentic instruction and assessment*. Des Moines, IA: Iowa Department of Education.

Ogle, D. M. (1989). The know, want to know, learn strategy. *Children's comprehension of text: Research into practice*, 205-223.

Palm, T. (2008). Impact of authenticity on sense making in word problem solving. *Educational Studies in Mathematics, 67*(1), 37-58.

Papert, S., & Harel, I. (1991). Situating constructionism *Constructionism* (pp. 1-11). New York, NY: Ablex Publishing Corporation.

Paton, B., & Dorst, K. (2011). Briefing and reframing: A situated practice. *Design Studies, 32*(6), 573-587.

Pithouse-Morgan, K., Naicker, I., Chikoko, V., Pillay, D., Morojele, P., & Hlao, T. (2014). Entering an ambiguous space: Evoking polyvocality in educational research through collective poetic inquiry. *Perspectives in Education, 32*(4), 149-170.

Quintana, C., Shin, N., Norris, C. A., & Soloway, E. (2006). Learner-centered design. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 119-134). New York: Cambridge University Press.

Restrepo, J., & Christiaans, H. (2004). Problem structuring and information access in design. *Journal of Design Research, 4*(2), 218–236.

Sandoval, W. (2004). Developing learning theory by refining conjectures embodied in educational designs. *Educational Psychologist, 39*(4), 213-223.

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

Schwartz, D. L., & Bransford, J. D. (1998). A time for telling. *Cognition and Instruction, 16*(4), 475-522.

Shaffer, D. W., & Resnick, M. (1999). "Thick" authenticity: New media and authentic learning. *Journal of Interactive Learning Research, 10*(2), 195-215.

Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research, 78*(1), 153.

Stefanou, C. R., Perencevich, K. C., DiCintio, M., & Turner, J. C. (2004). Supporting autonomy in the classroom: Ways teachers encourage student decision making and ownership. *Educational Psychologist, 39*(2), 97-110.

Strobel, J., Wang, J., Weber, N. R., & Dyehouse, M. (2013). The role of authenticity in design-based learning environments: The case of engineering education. *Computers & Education, 64*, 143-152.

Svihla, V., Gomez, J. R., Watkins, M. A., & Peele-Eady, T. B. (2019). Characterizing framing agency in design team discourse *Proceedings of the ASEE 126th Annual Conference and Exhibition*: ASEE.

Tawfik, A. A., & Kolodner, J. L. (2016). Systematizing scaffolding for problem-based learning: A view from case-based reasoning. *Interdisciplinary Journal of Problem-based Learning, 10*(1), 6.

Underwood, J. S., & Tregidgo, A. P. (2010). Improving student writing through effective feedback: Best practices and recommendations. *Journal of Teaching Writing, 22*(2), 73-98.

Wernet, J. L. (2017). Classroom interactions around problem contexts and task authenticity in middle school mathematics. *Mathematical Thinking and Learning, 19*(2), 69-94.

Wertsch, J. V., Tulviste, P., & Hagstrom, F. (1993). A sociocultural approach to agency. *Contexts for learning: Sociocultural dynamics in children's development*, 336–356.

Wheeler, E., & McDonald, R. L. (2000). Writing in engineering courses. *Journal of Engineering Education, 89*(4), 481-486.

Wilkerson, M. H. (2017). Teachers, students, and after-school professionals as designers of digital tools for learning. *Participatory design for learning: Perspectives from practice and research*, 125.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. EEC 1751369. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.