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Conjecture Maps as a Cognitive Tool for Connecting Engineering Education Research and Practice*

ALEJANDRA J. MAGANA
Department of Computer and Information Technology, School of Engineering Education, Purdue University, 401 N. Grant Street, West Lafayette, IN 47906, USA. E-mail: admagana@purdue.edu, ORCID: 0000-0001-6117-7502

The study proposes an approach for using conjecture mapping as a cognitive tool to overcome conceptual difficulties among novice discipline-based education researchers, including framing research questions, grounding studies in frameworks, and operationalizing constructs into measurements. The research question was: What are novice researchers' perceptions and experiences of conjecture mapping as an approach to guide their investigations? A Phenomenographic approach was used to analyze participants' perceptions and experiences of conjecture mapping. The participants consisted of eleven engineering and computing education researchers in the early stages of their graduate education. The participants learned about conjecture mapping and used it throughout the semester to propose learning and research designs. The participants reflected on their experiences. Five categories of description were identified, describing participants' perceptions of the affordances of conjecture mapping. Those categories of description were further organized into an outcome space describing more comprehensive ways of experiencing conjecture mapping, along with two dimensions of variation. This study contributes new knowledge that builds on the structure of conjecture mapping into specifics of a process of socialization and deployment with a population of novice researchers. The approach showed promise in overcoming some of the most pressing conceptual difficulties experienced by computer scientists and engineering novices in learning educational research methods.

Keywords: conjecture mapping; discipline-based education research; design-based research; phenomenography; qualitative methods

1. Introduction

The unique challenges of STEM education require discipline-specific educational research. 'Discipline-based education research (DBER) is an imperative area of scholarship that has the potential to improve undergraduate STEM education, as it investigates learning and teaching from a disciplinary perspective reflecting its knowledge and practices [1]. This can be accomplished by conducting basic and applied research, combining expert STEM disciplinary knowledge, knowledge about the challenges of teaching and learning in a discipline, and knowledge of the methods for conducting education research grounded in learning sciences [1]. Thus, DBER implementations are often performed by multidisciplinary collaborative teams [1]. However, challenges exist for the successful implementation of DBER. One relates to the conceptual difficulties experienced by faculty practitioners [e.g., 2] and novice discipline-based education researchers [e.g., 3], and another relates to collaboration challenges that originate from differences in theoretical and methodological approaches across disciplines in STEM and the social and learning sciences [4, 5]. Thus, guiding approaches and tools are needed to successfully accomplish the goals of DBER through interdisciplinary research, implementation of proper methodologies that connect research with practice, and training of career scientists. Like others [6], we argue that design-based research is a methodological approach with tools that can support the achievement of the goals of DBER. Specifically, in this study, we propose the use of conjecture mapping [7] as an approach to promote interdisciplinary research, the use of methodologies that connect research with practice, and how to facilitate the training of discipline-based education researchers. Our guiding research question is: *What are novice researchers' perceptions and experiences of conjecture mapping as an approach to guide their investigations?*

2. Background

Specific fields of engineering and computing have recognized the importance of rigorous education research [e.g., 8, 9]. However, as computing and engineering faculty or practitioners, including graduate students, become engineering education researchers, they may experience conceptual difficulties as they design education studies [2]. Some of these conceptual difficulties relate to framing their research questions, grounding their studies in frameworks, and operationalizing constructs into measurements. These conceptual difficulties are primarily attributed to the challenges associated with (a) identifying fundamental differences between *engineering* and *education* research and (b) approaching engineering education as practi-

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tioners or instructors rather than as education researchers. Even engineering education graduate students who often transition from engineering or computing disciplines to education research as they pursue their journeys in engineering education research still report the use of theoretical frameworks and qualitative and mixed-methods approaches as the most challenging conceptual difficulties [3]. However, research has also identified limited training in introducing disciplinary faculty to discipline-based education research [10]. Thus, engineering faculty, practitioners, or graduate students (herein novice researchers) need learning supports and cognitive tools to be equipped with strategies to overcome those conceptual difficulties, particularly with strategies that can explicitly connect engineering education research and practice.

To move the field forward, engineering and computing education researchers have suggested "looking inward to parent disciplines for theoretical and methodological direction, and looking outward to the world of practice for meaningful problems to guide its studies" [11]. One specific parent discipline is the field of learning sciences. Here, engineering and computing education researchers can borrow methods and approaches for conducting theoretical and empirical work [12, 13]. Learning scientists investigate learning, cognition, and development in varied contexts using multiple research methodologies combining laboratory-based and field-based studies. In addition to contributing to theory development, learning scientists also apply their findings to design novel learning environments. One of the most important methodological contributions from the learning sciences is design-based research [14].

Design-based research (DBR) was initially proposed by Brown [15] and Collins [16] as an approach to implementing design experiments that would bring together theoretical, methodological, and empirical considerations to the design and investigation of interventions in classroom settings. DBR bridges theory and practice by producing results that are embedded and inseparable from their educational contexts [14]. Thus, DBR provides researchers with a series of approaches that allow them to "engineer" and study selected forms of learning [17]. DBR has five main characteristics that make it suitable for addressing DBER-related problems. DBR is pragmatic, meaning that it contributes to both theory and educational practice [17, 18]. DBR is also grounded in theory or evidence-based pedagogies when generating designed interventions. DBR should be iterative in that the design is continuously refined [18]. DBR also integrates the use of multiple research methods [18]. Finally, DBR is contextual, meaning it is embedded in its designed context [6]. These characteristics make DBR ideal for helping STEM educators develop contexts, frameworks, tools, learning design principles, and pedagogical models with the intent to produce new theories, artifacts, and practices that can impact teaching, learning, and engagement in a naturalistic setting [14].

One important research tool emerging from research from the learning sciences is conjecture mapping [7]. This research tool is also gaining its place in supporting engineering education research [19–21]. Conjecture mapping is a tool used by learning scientists to systematically engage in design-based research [22]. This tool is particularly useful for making explicit connections between teaching practice and education research as it distinguishes conjectures about how a learning design should function based on theoretical conjectures and explains how it produces intended learning outcomes. The tool is also useful for promoting interdisciplinary collaboration between disciplinary STEM researchers and learning scientists [23]. However, even when Sandoval [7], in his seminal work, delineated the structure of a conjecture map and provided examples of their use, he did not provide a scaffolded approach for facilitating the learning of conjecture mapping. That is, although conjecture mapping provides a structure for aligning teaching practice and education research, learning how to use them effectively may have a steep learning curve, as understanding conjecture mapping may pose some difficulties. For instance, while working with individuals focused on technical research and practice, such as those from computer science disciplines, Chang identified that computer scientists found some elements of the structure of a conjecture map as difficult to grasp [24]. Thus, a contribution of this study focuses on the processes for introducing conjecture mapping to novice researchers through a scaffolded approach and the way novice researchers transitioning to engineering and computing education research experienced this learning process.

3. Theoretical Foundation

Variation Theory is the theoretical framework that guided the study's research design [25]. Variation Theory explains how individuals might come to see, understand, or experience a given phenomenon in a certain way [26]. Variation Theory's primary tenet is that individuals become aware of a phenomenon through experience of variations of such phenomenon. In a learning context, individuals need to be exposed to variation in order to experience a phenomenon to (a) become aware of critical aspects of a disciplinary concept, skill, or practice [27] and (b) discern different perspectives and improve learning [25]. Thus, learning interventions derived from variation theory must enable learners to notice the different aspects of a concept, skill, or practice and the relations between those aspects [27]. Design elements include (1) *awareness*, where aspects of the phenomenon are held in focal attention; (2) *discernment*, where critical features of a phenomenon are emphasized and distinguished from one another; and (3) *simultaneity*, where learners must be concurrently aware of multiple critical features of a concept. That is, individuals learn when they are exposed to experiences where aspects of the phenomenon and the relationships between them are discerned and simultaneously present in the individual's focal awareness [25].

In the context of this study, conjecture maps can be used as cognitive tools to promote awareness, discernment, and simultaneity by highlighting each of the different aspects of learning designs and research designs, as well as how they interact and inform each other. Cognitive tools are conceptual or technological artifacts that support or perform cognitive processes for learners to support learning [28]. Although cognitive tools have primarily been conceptualized in the context of computer-supported learning, other researchers [e.g., 29] have argued that anything can be characterized as a cognitive tool depending on its purpose. For instance, paper and pencil are used to take notes and thus support remembering, extending the capacity of working memory. Thus, the key characteristic of cognitive tools is that they are used to support learning processes. Learning processes refer to basic entities describing the activities a learner needs to do to increase their understanding of a certain domain.

As a cognitive tool itself, this study explores the use of conjecture maps to help novice researchers overcome their conceptual hurdles as they initiate their research training. Other cognitive tools are used in educational research, such as logic models for planning projects or program evaluation or visual models for visualizing procedures to perform mixed methods design. Specifically, a conjecture map specifies conjectures about how a learning design (e.g., an educational environment) should function based on theoretical conjectures (refer to Fig. 1).

A conjecture map also specifies how mediating processes produce intended learning outcomes. In its entirety, a conjecture map is composed of three elements and three conjectures connecting those elements. The three elements are the embodiment, mediating processes, and outcomes. The embodiment includes the elements of the learning environment in terms of tools, pedagogical practices, discursive practices, and task structures. The mediating processes describe the desired behaviors, salient performances, or products expected to result from the embodied elements. The outcomes are the result of the mediating processes, and these are the elements that are ultimately measure [7]. The three conjectures are a high-level conjecture, a design conjecture, and a theoretical conjecture. A high-level conjecture specifies a theoretical principle of how to promote some desired learning. A design conjecture articulates how embodied elements of the design generate mediating processes, and a theoretical conjecture articulates how those mediating processes will produce the desired outcomes [7].

An example of the use of a conjecture map for this study is presented in Fig. 2. As observed in Fig. 2, the conjecture map presents a high-level conjecture, the embodiment aligned with the learning design, the mediating processes we aim to promote

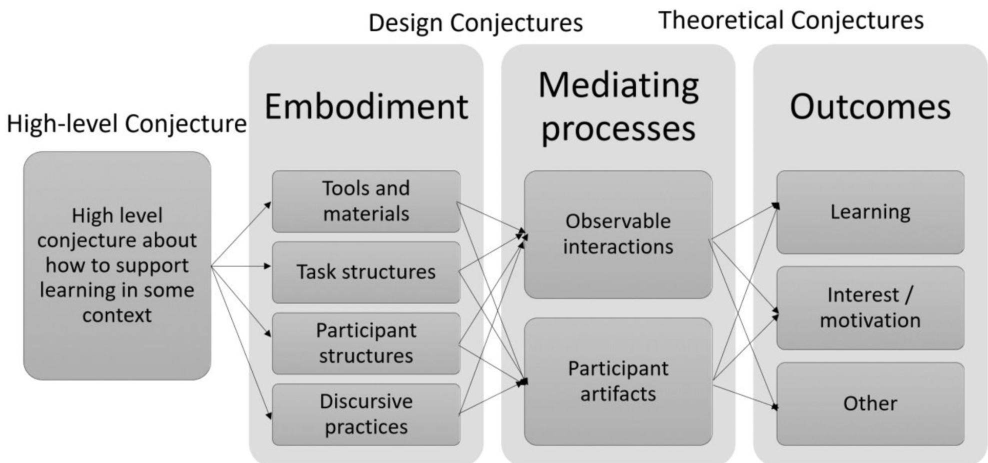

Fig. 1. Structure of a conjecture map as proposed by Sandoval [7].

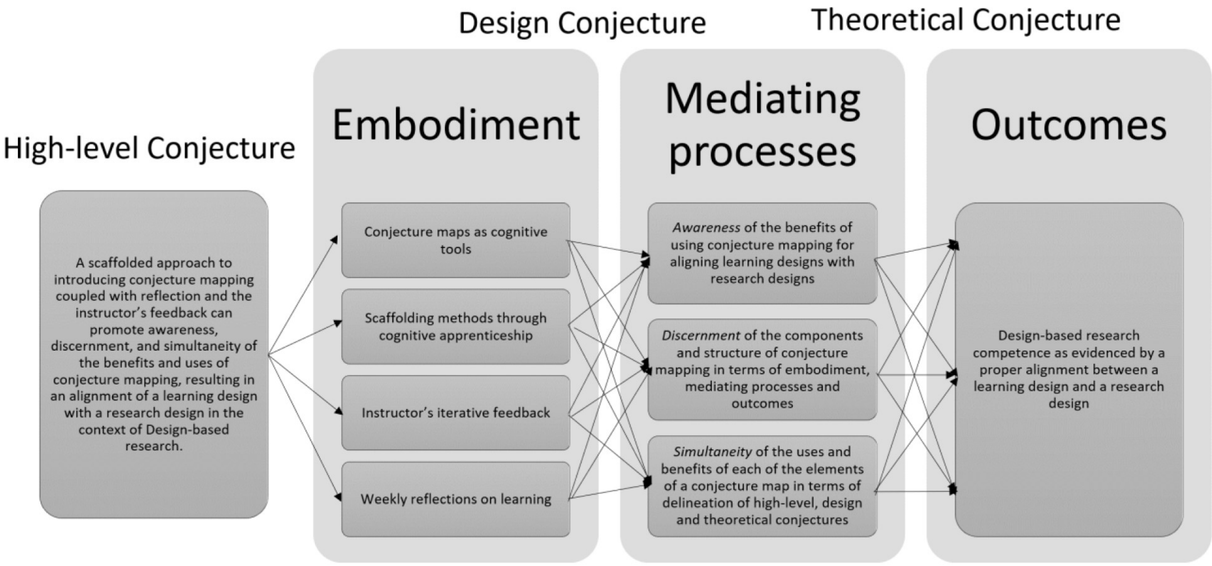

Fig. 2. An example of a conjecture map for the alignment of design and theoretical conjectures for this study.

grounded on principles of Variation Theory, and the outcomes aligned with the intended attitudes and outcomes.

According to the conjecture map in Fig. 2, the *high-level conjecture* hypothesizes that a scaffolded approach to introducing conjecture mapping coupled with reflection and the instructor's feedback can promote awareness, discernment, and simultaneity of the benefits and uses of conjecture mapping, resulting in increased competence in aligning a learning design with a research design. The *design conjecture* hypothesizes that a cognitive apprenticeship scaffolded approach for introducing conjecture mapping coupled with the instructor's feedback and weekly reflections on learning will promote the mediating processes of awareness, discernment, and simultaneity associated with conjecture mapping. Finally, the *theoretical conjecture* hypothesis that the mediating processes of awareness of the benefits of conjecture mapping, the discernment of the components of conjecture mapping, and the simultaneity of the uses of the high-level, design, and theoretical conjectures will result in DBR competence in aligning learning and research designs and positive attitudes and confidence in using conjecture mapping.

4. Implementation of Conjecture Mapping as a Cognitive Tool

Conjecture mapping is proposed as a cognitive and communication tool to guide novice researchers in the process of aligning their learning designs with their research designs. Specifically, we propose an instructional sequence (i.e., a series of steps) for facilitating the process of conjecture mapping grounded in methods of cognitive apprenticeship [30]. Cognitive apprenticeship is a pedagogical approach that focuses on cognitive skills by making the thought processes visible and explicit to the learners [31, 32]. Thus, cognitive apprenticeship is conceived as an approach to make these cognitive processes explicit so learners can observe, make meaning, and practice them [31]. An important component of a cognitive apprenticeship is the methods used to promote the development of expertise. These methods allow tacit knowledge to become explicit by giving learners opportunities to observe, engage in, and apply expert strategic knowledge in context [31]. Table 1 presents an adaptation of the cognitive apprenticeship methods for the introduction of conjecture mapping as a tool for aligning and grounding learning and research designs.

According to Collins and Kapur (2014), the first three methods, modeling, coaching, and scaffolding, focus on acquiring knowledge and skills first by observation and then by guidance. The next two methods, articulation and reflection, focus on helping learners make observations, make connections to their context, and prepare them for further application. The final method, exploration, gives the learner autonomy to further apply the approach to other contexts. Of particular interest to our proposed approach is the method of scaffolding, which is defined as learning support that enables the learners to perform a task that would be outside of their independent activity [34]. In this context, scaffolding, as highlighted in Table 1, refers to supports provided to the learner that make the thinking processes visible. These supports can take the form of suggestions, cues, problem decom-

Table 1. A sequence of cognitive apprenticeship methods for using conjecture maps as cognitive tools for novice researchers

Method	Definition	Implementation
Modeling	Teacher performs a task so students can observe.	Modeling is adapted and facilitated by having learners read Sandoval [7], which explains the structure of conjecture maps along with examples of two implementations. Leaners are also asked to read Magana [33], which describes the role of frameworks in engineering education research.
Coaching	Teacher observes and facilitates while students perform a task.	Learners (a) identify a learning need and its relevance, (b) describe previous approaches to addressing the identified need aiming to also identify potential gaps, and (c), as a response to addressing those gaps, propose a learning innovation. Learners also create an initial version of a conjecture map and present it to the instructor and peers for feedback.
Scaffolding	Teacher provides supports to help students perform a task.	Scaffolding is provided in the form of heuristics that can help learners align (a) learning objectives with assessment methods along with the outcomes of a conjecture map, (b) pedagogical approaches guiding the implementation of the learning innovation as part of the embodiment, and (c) research questions with theoretical or conceptual frameworks as part of the mediating processes.
Articulation	Teacher encourages students to verbalize their knowledge and thinking.	Once an initial version of a conjecture map is conceived by the instructor and the learner, articulation is elicited by asking learners to explicitly write the high-level conjecture, the design conjecture, and the theoretical conjecture.
Reflection	Teacher enables students to compare their performance with others.	Reflection is facilitated by asking the learners to give presentations of their conjecture maps to other learners. Reflection is also facilitated through reflective practices guided by prompts.
Exploration	Teacher invites students to pose and solve their own problems.	Exploration is not considered part of this instructional sequence. However, learners use conjecture mapping to ground and align their future learning and research designs.

position, walk-throughs, contrasting cases, or worked-out examples, among others.

In our proposed cognitive apprenticeship approach to conjecture mapping, as shown in Fig. 3, four cues aimed at promoting awareness, discernment, and simultaneity can be provided to novice researchers to make explicit connections between elements of the *conjecture map* and elements of *learning and research designs*. As a result, these four cues scaffold the learner through the research design process as a whole. However, in our approach, in order to promote *awareness*, it is important that learners attempt an initial version of a conjecture map, coupled with some discussion with the instructor, before presenting the instructional sequence along with the scaffolding described in Fig. 3.

Fig. 3 shows specific aspects that are highlighted in the process of constructing or reconstructing a conjecture map facilitated in a particular order. Specifically, in *step 1*, as shown in Fig. 3, *discernment* is promoted by asking learners to align the

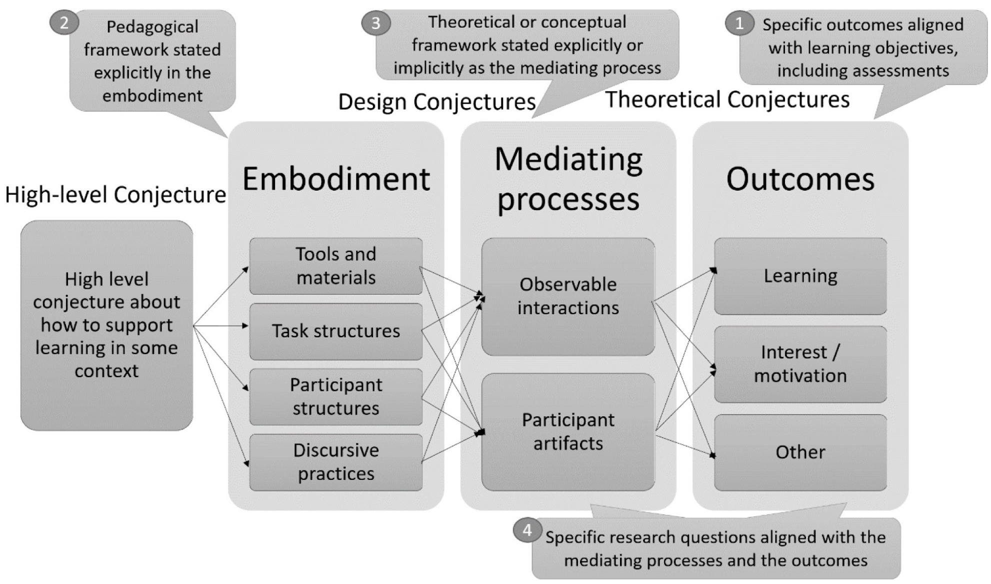

Fig. 3. Conjecture map with scaffolding 4-step cues aimed at making explicit connections between the elements of the map and the elements of research and learning designs.

learning objectives of the learning design to the specific outcomes of the conjecture map. Learners are also guided through the process of aligning learning objectives with corresponding assessment methods as prescribed by the backward design approach [35]. Backward design is an instructional approach that guides practitioners through the sequence of first identifying learning objectives and aligning those to corresponding assessment methods. The backward design approach also guides practitioners to define the pedagogical approach for guiding the delivery of the learning intervention as a final step of the learning design [35, 36]. Thus, as part of *step 2*, as shown in Fig. 3, learners are encouraged to explicitly state as part of the embodiment of the pedagogical approach that will guide the learners through the learning process or the teaching approach orchestrating the delivery of a learning intervention [33]. In this stage of the process, it is also recommended to make an explicit distinction of the role of frameworks in education research. For instance, Magana [33] proposed three families of frameworks according to their uses: (a) frameworks for defining, grounding, and explaining the focus of a study; (b) frameworks for palling and executing the methods of a study; and (c) frameworks for planning, delivering, and evaluating instruction. Pedagogical frameworks belong to the third family of frameworks.

Educational researchers and learning scientists have identified the mediating processes as the most challenging element to define in a conjecture map [24]. Thus, in *step 3* and as part of our approach, it is critical for learners to engage in *simultaneity* by making an explicit connection to a theoretical framework or a conceptual framework to guide the mediating processes of the learning intervention. Theoretical or conceptual frameworks are grounded or guided, implicitly or explicitly, in a learning theory [37]. Thus, these are useful starting points for predictions and generalization of the desired mediating processes [38], represented as observable behaviors or interactions, as well as in the form of student-generated artifacts. Finally, in *step 4*, learners are encouraged to state research questions aligned with both the outcomes of the learning design as well as the mediating processes as prescribed by a theoretical or conceptual framework. In this process, learners are encouraged to recycle the assessment methods for data collection purposes for the research, as well as identify new forms of data collection (e.g., recordings, think-aloud protocols, observations, learning analytics, etc.) to characterize or measure the mediating processes.

We recognize that there are two more elements that need to be considered as part of the process of conjecture mapping. One is the explicit definition of the high-level conjecture, the design conjecture, and the theoretical conjecture as part of *step 5*. In our proposed approach, the instructor iteratively works with novice researchers in refining these three statements in the process of articulation. The second element is the graphic connection with arrows between the subcomponents within the embodiment, mediating processes and outcomes. We considered that those explicit connections could be made later on as *step 6* in the process as the novice researchers become more proficient as they transition to the reflection and exploration stages.

5. Methods

This approach was implemented in the context of an introductory design-based research course for first-year graduate students who were considered novice computing or engineering education researchers. Since the study was grounded in Variation Theory and consequently focused on students' perceptions and experiences, phenomenography was used as the qualitative methodological approach to guide the analysis of the study. According to Marton [39], "phenomenography is the empirical study of the limited number of qualitatively different ways in which various phenomena in, and aspects of, the world around us are experienced, conceptualized, understood, perceived, and apprehended" (p. 4424). As such, it provided guidelines for describing variations in how individuals interpret an experience, an observable fact, a circumstance, or an event [40].

5.1 Context and Participants

The graduate course is titled Cyberlearning Research and Development, and it is offered for graduate students pursuing master's or doctoral degrees in computing or engineering education. The course explores and applies methodological and theoretical perspectives to the research, design, and evaluation of learning experiences and environments that integrate cyberlearning within a certain STEM discipline. To achieve the course objectives, the course was delivered as an in-person 2-hour weekly lecture, guided reading assignments coupled with in-class discussion, weekly asynchronous discussion forums where students reflected upon the reading assignments and how content learned from them would apply to their research, and a semester-long project where students used design-based research to propose a learning design grounded in a specific learning theory or pedagogical approach and a corresponding research design to measure the intended learning outcomes of their designs. The grading of the course consisted of two project submissions worth 50% of the overall grade. In the first submission, students developed their learning designs, and in the second submission, students developed their research designs. There were three individual in-class presentations worth 35% of the grade. In the first presentation, students provided an overview of the learning problem or need they decided to address. In the second presentation, students described the overall learning design aligning content, assessment, and pedagogy, and in the third presentation, students presented their research questions and described their research designs. The remaining 15% of the grading consisted of participating asynchronously in weekly discussion forums where students reflected on the reading assignments and how concepts learned would apply to their own projects. Students were graded based on the number of submissions of three postings in the online discussion forum, with three postings as the minimum requirement for getting full credit for the assignment of the week and not on the correctness or appropriateness of their answers.

In the Fall of 2022, the course had a population of first-year graduate students pursuing degrees in computing or engineering education (N = 12), with three female students and nine male students. All students were considered to have transitioned from engineering or computing practitioners (i.e., from industry or academia) to discipline-based education researchers; thus, all participants were considered as novice researchers. At the time of the study, three students were pursuing master's degrees in computer and information technology, two students were pursuing doctoral degrees in engineering education, two students were pursuing doctoral degrees in computer graphics with an emphasis on technology education, and five students were pursuing doctoral degrees in technology with an emphasis on computing and engineering education. Four students recently graduated with their bachelor's in computing, four students transitioned from industry positions to full-time graduate students, and three students were part-time students holding full-time jobs. Three students had teaching responsibilities as primary course instructors at the time or before taking the course, and one advanced graduate student audited the course (no data was submitted by this participant).

5.2 Procedures and Implementation

Our cognitive apprenticeship to conjecture mapping approach was implemented throughout the semester-long course. Specifically, as part of *modeling* in the first week of classes, students were assigned to individually read Sandoval's paper [7], Conjecture Mapping: An approach to systematic educational design research. Then, during the next class period in week 2, the manuscript was discussed as a whole class. During that discussion, students pointed out the difficulties of understanding the tool. The course instructor mentioned that throughout the semester, the students would learn about the specifics of the tool and the central role of the tool for the semester-long project.

In week 4 of the semester, for *coaching*, students created their first version of the conjecture map as part of the first assignment. For this, students had to first identify a learning need and its relevance, describe previous approaches to addressing the identified need, aiming to identify potential gaps, and then propose a cyberlearning innovation as a response to addressing those gaps. The initial proposal of the cyberlearning innovation had to be presented as a very early version of a conjecture map. During the next two weeks, students presented their initial ideas and received feedback from the course instructor and from peers.

In week 5 of the semester, students were tasked to individually read Magana's paper [33] titled: The role of frameworks in engineering education research. During the same week, students participated in an online discussion forum where they described how they would use frameworks for their learning designs and research. At this point, students received individual feedback as the instructor graded the discussion forum participation. Recall that the grade was based on the number of postings submitted by individual students and not the content of the postings. That same week, during the in-person class, the instructor and learners discussed which specific frameworks would guide their learning and research designs. At this point, the *scaffolding* approach shown in Fig. 1 was introduced. Then, in week 6, students submitted as an individual assignment a revised version of the conjecture map aligning the learning outcomes with the learning objectives of the learning design, the mediating processes aligned with a theoretical or conceptual framework, and the research questions aligned with the mediating processes and outcomes. This was used as the foundation for students to initiate the writing of their full research reports.

The following three weeks were devoted to individual class-time presentations of the revised conjecture maps. The students received feedback and questions from the instructor and peers, and the maps were then fine-tuned. At this point in week 9 of the semester, *articulation* took place by asking students to state the high-level conjecture, the design conjecture, and the theoretical conjecture, first as part of a discussion forum and then as part of a homework assignment. Students were provided with two examples to complete this task, and the instructor provided individual feedback. Finally, in week 10 of the semester, students were asked to submit a *reflection* regarding the role of conjecture mapping in their research. Students were asked to describe how their maps evolved throughout the semester and to describe their perceived affordances and hindrances of conjecture mapping. The rest of the semester was devoted to writing the research report, fine-tuning it through one-on-one consultations, and the iterative feedback process of revising and resubmitting, guided by a rubric and enabled through the learning management system.

5.3 Data Collection Method

The data collection method for the study consisted of the specific reflection students performed during week 10 of the semester. The reflections were submitted via the weekly online discussion forum. Students had one week to work on this assignment. During this same week, one-on-one consultations occurred during class so that students could discuss questions related to their learning or research designs with the course instructor. The following prompts guided the reflection:

Q1: What was the role of a conjecture map in your research/design, and how do you expect to use it in your research going forward?
Q2: Please provide a ''big picture'' description of your process for revising your conjecture map. Estimate how many times you revised your map. Briefly describe what the primary issue in the review process was. Describe the interactions (in person and online) with your professor in the revision process and the feedback taken from other students in the class while revising your map.
Q3: Please compare your first version of a conjecture map and your final class conjecture map. How did your frameworks impact the content of your conjecture map over time?
Q4: How has the conjecture map helped you communicate your ideas with ''experts in pedagogy'' (e.g., the course instructor)? How has the conjecture map helped you communicate your ideas with ''novices'' (e.g., other students in the class)?
Q5: What limitations of conjecture maps emerged in the process of designing your current project?
Q6: Regarding your peers' conjecture maps, how were those useful in your understanding?

The first reflection question, Q1, allowed the researchers to capture novice researchers' perceptions of conjecture mapping, while questions Q2 to Q6 allowed us to characterize their experiences in using conjecture mapping for the design of their projects.

5.4 Data Analysis Method

We followed Marton's [41] guidelines for conducting phenomenographic analysis. A phenomenographic analysis has two primary products: (a) categories of description describing similar experiences or perceptions reported by participants and (b) an outcome space describing a hierarchy of distinct but logically related categories of description [42]. The categories of description are identified by searching and identifying repeated patterns in a dataset. At this stage, the goal is to understand experiences, thoughts, or perceptions across participants [e.g., 43–45]. This can be achieved either by analyzing the data at the transcript level or by focusing on parts of the transcripts for a particular idea or event [46]. In this case, we selected a combined approach by (a) characterizing participants' perceptions of conjecture mapping, similar to an analysis at the transcript level to identify initial categories of description, and (b) focusing on particular ideas or events characterizing participants' experiences to uncover the outcome space.

We initiated our analysis by focusing on the novice researchers' perceptions of conjecture mapping. For this, we used the first reflection question, where they described the qualities or properties of conjecture mapping that define their possible uses, that is, their affordances. This first step involved reading each participant's response to the first question, generating initial codes deductively, and then grouping such codes into similar patterns that were then expressed into categories of description. The categories of description were examined to identify and group similarly expressed ways of experiencing the phenomenon. The analysis was repeated several times to determine whether the categories were descriptive enough and whether they were indicative of the data. In this way, the categories of description were identified. To validate the analysis, the researcher went through a ''reverse'' process of referencing selected quotes and actually testing the categories against the data. This process of continuous questioning and testing categories against the data allowed us to (a) establish the reliability of the analysis and (b) support the refinement of the categories [47].

The second product of phenomenographic analysis is the outcome space. Based on the categories of description, the outcome space is derived by identifying potential structural differences among participants' experiences and the distribution of participants across them [48, 49]. For this, the categories of description were then further organized and inspected in search of logical relationships and comparing those across participants. These comparisons were evaluated following Marton and Booth's [25] guidelines for assessing the quality of the descriptive categories generated in a phenomenographic study. For this, Excel was used to further analyze the data. A matrix was created with each of the participants exhibiting each category of description. This matrix provided the researcher with a means to visualize how the participants were distributed across all categories of description. After reorganizing the columns by grouping participants according to similar experiences (refer to Table 2), an outcome space was suggested by this organization. To further inspect this potential outcome space, responses from the other five reflection questions were used to identify further similarities, but more importantly, differences in participants' experiences. The relationships between the categories of description were then defined in terms of a structure of increasing complexity; thus, two additional components of the outcome space included a description of differences between and among categories of description and the structure of increasing complexity that characterized the hierarchy of the outcome space [25]. The final step in the analysis consisted of an iterative reading of the quotes between categories and within the same category to determine dimensions of variation [50]. To do this, similar experiences categorized under the same label of code were further inspected to determine nuances and how those nuances were represented across all categories. This final analysis was done to determine potential transition points from one category to the next.

5.5 Researcher's Positionality and Trustworthiness Considerations

The researcher's positionality is that of a computing and engineering education researcher with over fifteen years of experience as a researcher in the field, over twelve years of experience teaching research methods courses at the graduate level, and over twelve years of experience mentoring and advising graduate students on design-based research projects. Since the researcher was the course's primary instructor, these identities are relevant to the study because the instructor recognizes their potential influence on students' participation and responses provided to the reflection questions. Therefore, ethical and trustworthiness considerations must have been set in place to protect students' confidentiality and privacy, as well as to integrate strategies to ensure the trustworthiness of the study.

During the design of the study, two knowledgeable learning scientists experienced in conjecture mapping were involved in the design and revision of the reflection questions. This process ensured that the questions were relevant and clear. Once the questions were created and iteratively revised, we proceeded to request approval from the University's Institutional Review Board. The study was approved under protocol # IRB-2022-1410 as exempt, as the research took place within the normal educational activities of the course. Students were informed about using their responses for a study aimed at identifying better ways to teach and learn about conjecture mapping, and they all agreed to have their responses included in the analysis. Two more actions were performed to protect students' privacy and confidentiality. Once the semester ended and grades were submitted, the course instructor (i.e., the researcher) prepared the data for analysis by downloading and deidentifying it. Also, the analysis was started a year later by the researcher so that the researcher would have time to decouple from her instructor's role and approach the analysis more objectively.

Specifically, to perform a phenomenographic study, the data analysis must be grounded in the participants' lived experiences [51]. Given the researcher's positionality, the instructor is also aware of their own potential biases and recognizes that those may shape the research. Thus, trustworthiness strategies were implemented so that the analysis revealed the participants' experiences and not the researcher's expectations. Bracketing is the primary strategy recommended in phenomenography to achieve an understanding of the participants' experiences [52]. Bracketing involves setting aside a researcher's own assumptions in order to register the participants' own points of view [51]. Ashworth and Lucas provided a framework for guiding the bracketing of key presuppositions that could hazard the aim of engaging with the experience of the participant. Presuppositions that were bracketed for this study were (a) introducing prior research findings, (b) assuming any theoretical structures or particular interpretations of the categories of descriptions, (c) introducing the researcher's personal knowledge and beliefs, and (d) avoiding the researcher's need to uncover the cause of the experience rather than characterizing the experience themselves.

6. Results

The findings of the study characterize students' perceptions and experiences for integrating conjecture mapping as a tool to guide their design-based research projects. The findings are organized into two subsections describing the two primary outcomes of a phenomenographic study: the categories of description and the outcome space.

6.1 Categories of Description

This section presents the five categories of description derived from the experiences of the eleven novice researchers who described the potential uses of conjecture mapping for designing their design-based research projects. The order of the categories was determined by the number of participants experiencing that category. That is, the category with fewer participants experiencing it is presented first, with the ones with an increased number of observations are presented consecutively.

A. To Realize my Research Accomplishments and Increase My and Others' Confidence

Two participants, herein P1 and P2, perceived this category of description. Participants from this category described instances where the conjecture maps either produced by themselves or others resulted in increased confidence. For example, P2 commented, "The more I learned about my peers' projects, the more I grasped the meaning of the conjecture maps. It also seemed that many of my peers got more confident as their projects became clear, and hence, they could communicate better." This same idea was expressed by P1, who mentioned, "This procedure increased my confidence in the project I was working on. After the conjecture map has been finalized, I will review it frequently to ensure that I am continuing with my project correctly."

B. To Specify the Design and Theoretical Conjectures

Three participants, P2, P3, and P4, perceived this category of description. The participants described how creating the conjecture map may help them align embodiment with mediating processes and mediating processes to outcomes. For instance, P4 mentioned,

> "The design conjecture links embodiment or design elements to mediating processes that provide the researcher with support in selecting methodologies, sources of data collection, analysis of results, and interpretation frameworks. The theoretical conjecture links mediating processes to anticipated outcomes from which learning objectives and research questions are derived."

Participants in this category also described how conjecture maps could allow them to break down or expand the conjectures into practical design and research outcomes. For example, P3 indicated, "Expanding the conjecture map shows how the overall conjecture derives into the practical design's concrete elements to the processes which portray them (both theoretical and design) and finally, to the theoretical outcomes which the research should result in."

C. To Guide and Align the Research Designs

Five participants, P4, P5, P6, P7, and P8, perceived this category of description. Participants in this category of description mentioned that the process of conjecture mapping could help them clarify the role of theory in the process. Specifically, conjecture mapping could allow them to align the pedagogical framework and the research framework with the design elements. For example, P8 mentioned,

> "[Conjecture mapping] is a good tool for clarifying which theories/frameworks you are using during different parts of the study. I will continue to use conjecture maps in design-based research studies because they extract the most relevant elements of a 'messy' natural educational environment. A conjecture map will serve as a guide for the process of my research study so that I can ensure that the desired outcomes have a clear path to success.

Furthermore, an additional benefit identified was that once the conjecture map was formed, the participants could identify research questions aligned with the design and theoretical conjectures. An example of a claim in this regard was provided by P7,

> "In my current DBR, I am expecting to employ the conjecture map to define the research-related aspects, such as pedagogical or theoretical framework, which support my design. Also, one of the main attributes of the conjecture map is the guidance to structure the research questions aligned with the chosen conjectures."

Finally, the map could be used as a tool to reflect changes in the design based on assumptions informed by the selected frameworks.

D. To Assist in Planning and Implementing a Research Project

Six participants, P6, P7, P8, P9, P10 and P11, perceived this category of description. This group of participants identified the benefits of the conjecture map for planning or guiding the implementation of a project. The conjecture map was also identified by some participants as helpful to define the scope of the study and, at the same time, stay focused. In addition, the map could guide them in the process of clarification of their research project and help them make sure the project was complete. For instance, P8 mentioned,

> "The most important part of the interactions I had with the professor and classmates was helping refine my research study by making things more specific and "narrower" to measure better results. In general, I would start out very broad and unspecific, but through constant feedback, I was able to specify my scope better and operationalize my study's objectives better."

E. To Organize My Thinking and Receive Feedback

Eight participants, P1, P2, P6, P7, P8, P9, P10 and P11, perceived this category of description. This category of description encompassed students' perceptions of the use of conjecture mapping for visualizing the elements of a project that were then used for communication and feedback. Students mentioned that conjecture mapping could be used as a tool to brainstorm, organize, and refine ideas and, at the same time, clarify the direction of a project. For example, P10 commented,

> "I feel the conjecture map helped me organize and finalize my thoughts before starting with the more elaborative steps of the research. Once a research topic is finalized, making the conjecture map can provide a baseline of information to expand on. For example, after a conjecture is created, we have the foundation for learning outcomes, research questions, pedagogical framework, and theoretical framework. We can also derive specific study activities from mediating processes and expand on them. I feel the time spent on developing this map would eventually save me a lot of time in the later stages of research."

6.2 Outcome Space

The five categories of description generated in this study represent the outcome space that identifies similarities and differences in perceptions of conjecture mapping among novice researchers. As we further inspected the differences between categories to identify if a hierarchy existed, we started to notice that the categories less experienced by the participants were more encompassing or, in a way, superior to the categories most experienced by the participants. The potential hierarchy became more evident as we identified the dimensions of variation, as explained in Subsection 6.3. Thus, the categories that define the outcome space are organized in a hierarchical fashion in Table 2, where Category A is more encompassing than Category B, and Category B is more encompassing than Category C, and Category C is more encompassing than Category D, and finally, Category D is more encompassing than Category E.

As observed in Table 2, there is some overlap between categories regarding the novice researchers' perceptions of conjecture mapping. For example, P1 and P2 overlapped in Categories A and E, identifying the benefits of conjecture mapping in helping them increase their confidence and their uses as tools to organize their thinking and receive feedback. It can also be observed that P6, P7, and P8 also overlapped on their perceptions of conjecture mapping in Categories C, D, and E, finding conjecture mapping as a guide to improve their research designs, assisting them in the planning and implementation of their research projects, and also as tools to organize their thinking and receive feedback. The highest overlap in perceptions among participants was between Categories D and E, having P6, P7, P8, P9, P10, and P11, finding conjecture mapping as useful for assisting them in the planning and implementing a research project and, at the same time, helping them organize their thinking and receive feedback in the process. Interestingly, only one participant, P4, overlapped in Categories B and C, finding conjecture mapping as a useful tool to specify the design and theoretical conjectures and consequently as a guide to improve their research designs.

To further test the preliminary hierarchical structure presented in Table 2, we inspected novice researchers' (i.e., participants') experiences with conjecture mapping to identify similarities and, more importantly, differences. In doing so,

Participants' experiences from *Category A: To realize my research accomplishments and increase my confidence*, deferred from those in *Category B: To specify the design and theoretical conjectures* in the challenges they experienced. While all participants had difficulties identifying the mediating processes, participants in Category A also had difficulties identifying the outcomes of the study. Also, while both participants in Category A identified that seeing peers' maps helped them comprehend better the structure of a conjecture map, participants in Category B mainly relied on the feedback received by the instructor and peers during the in-class presentations. Such feedback helped them refine their maps. An important distinction between students in Category A and students in Category B was that they identified the pedagogical framework as the primary source for revising the embodiments of the conjecture map, while participants in Category B mentioned that the theoretical framework helped them refine the outcomes of the study.

Moving on with identifying distinctions between *Category B: To specify the design and theoretical conjectures*, from *Category C: To guide and align the*

Table 2. Categories of description experienced by the participants suggesting a hierarchical structure

Categories	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
A	x	x									
B		x	x	x							
C				x	x	x	x	x			
D						x	x	x	x	x	x
E	x	x				x	x	x	x	x	x

research designs, it was observed that no other major challenges were identified in Category C (except for the identification of mediating processes experienced by all participants). Also, participants in Category C, in addition to feedback from the instructor and peers as the primary strategy for improving their designs, also identified as useful meeting with the professor during office hours. Participants in Category C also identified disadvantages of conjecture mapping, one of them being a lack of space to elaborate the details of the map, such as to specify measurements or assessments. Participants from Category C overlapped with those experiences from participants in Category A in finding useful the use of the pedagogical framework in revising the embodiments of the conjecture map. In addition, participants from Category C overlapped with the experiences of participants from Category B by noticing how the theoretical framework helped them refine the outcomes of the study.

Regarding challenges observed between *Category C: To guide and align the research designs*, and *Category D: To assist in planning and implementing a research project*, we identified that no additional challenges were observed in Category D as compared to Category C, thus sharing the only challenge of the difficulty of identifying the mediating processes. However, participants in Category D identified more strategies that helped them learn conjecture mapping and the feedback from the instructor and peers during class time presentations. Students from this group identified seeing their peers' maps as a way to better understand the structure of a conjecture map. Peers' maps also helped them comprehend better the role of frameworks and even gave them ideas of elements to incorporate into their own projects. For one participant in Category D, their peers' maps helped them learn about advances in education research. For another participant in Category D, what helped them was to see other peers presenting their maps "backward" by starting with the outcomes, then moving on to mediating processes, to finally conclude with the embodiment. Considering the limitations of conjecture mapping observed by participants in Category D, this group, in addition to the limitations identified by participants in Category C, identified as a disadvantage steep learning curve to understand conjecture mapping. Specifically, participants mentioned that since the tool was not intuitive, they had to first learn the features of the tool to then focus on how it could be used for DBR. Specific aspects from conjecture mapping that were useful in guiding their design were sparse among participants in Category D. Two participants mentioned that the pedagogical framework helped them refine their embodiments, and one mentioned that the outcomes and mediating processes guided them in the selection of the pedagogical and theoretical frameworks.

Finally, comparing *Category D: To assist in planning and implementing a research project* with *Category E: To organize my thinking and receive feedback*, it was observed that all participants in Category E mentioned having challenges in identifying the mediating processes. However, half of the participants from this group also had difficulties identifying the outcomes. Focused on the features of conjecture mapping that were particularly useful for the participants, no new strategies were identified in this group. Participants in this group, similar to participants in other categories, identified as a very useful strategy to refine their maps, receiving feedback from their instructor and peers during the in-class presentations. They also found it useful to see their peers' maps to help them better comprehend the structure of a conjecture map and to meet with the professor during office hours. By seeing others' maps, they were also able to learn about advances in education research and research design. Regarding disadvantages noticed in conjecture mapping, participants in Category E also noticed the limited space to elaborate on details and the tool not being intuitive, resulting in a steep learning curve. Finally, regarding the uses of the conjecture map in helping participants refine their designs, four participants noted that the pedagogical framework helped them refine their embodiments, two participants mentioned that the theoretical framework helped them refine the outcomes, and two other different participants mentioned that the theoretical framework impacted the refinement of the mediating processes.

By further inspecting the categories of description based on novice researchers' perceptions and experiences, it can be noted that a hierarchical structure may hold for categories A through D, each of them encompassing a more complex experience, described in terms of challenges experienced, strategies that helped them move forward with their designs, overall disadvantages noted while using conjecture mapping, and the revisions made on their projects as a result of working on their conjecture maps. However, a clear distinction between Category D and E was difficult to identify. The only difference observed was in how defining the outcomes was difficult to do at first for some participants, but then it seemed that the theoretical framework had a critical role in helping them refine the mediating processes and the outcomes. This was due, in part, to the overlap between six participants out of the eleven in total in both categories of description.

Table 3. Overview of the dimensions of variation across categories

Category	Use of frameworks and theory to inform the study designs	Use of learning strategies to help refine one's thinking
A	The pedagogical framework helped refine the embodiments, and the theoretical framework helped refine the outcomes.	Seeing other peers' maps helped me comprehend the structure of the conjecture map and reflect on revisions of one's own conjecture map.
B	The theoretical framework helped refine the outcomes.	Feedback from the instructor and peers during in-class presentations helped revise one's own conjecture map.
C	The pedagogical framework helped refine the embodiment.	The explanation provided by the professor, along with the visual cues, helped me understand the structure of a conjecture map.
D	The outcomes and mediating processes guided the selection of the pedagogical and theoretical frameworks.	Meeting with the professor during office hours helped structure an initial conjecture map.
E	The theoretical framework impacted the refinement of the mediating processes.	Seeing other peers' maps provided an overview of advances in education research.

6.3 Dimensions of Variation

Two dimensions of variation were identified in the final stage of the analysis through an iterative analysis of the reflection data. These two dimensions of variation were experienced by all participants, but in different ways according to the categories. One dimension of variation was the way students used frameworks and theories to inform their designs of the study. The other dimension focused on the learning strategies the students found useful in promoting their understanding. Table 3 presents an overview of the dimensions of variation across all categories.

The dimension of the *use of frameworks and theory to inform the study design* ranges from incorrect or incomplete awareness of the role of frameworks in informing the learning and research designs to an understanding of how frameworks can help refine and align the elements of a learning design and a research design. Specifically, while students in Category E inaccurately identified the role of the theoretical framework to refine the mediating process, students in Category B accurately identified that the role of the theoretical framework helped them refine the outcomes of their study. However, students in Category B did not place an emphasis on the role of a pedagogical framework to help refine the embodiment as students in Category C did, and vice versa. In contrast, participants in Category D identified the role of both the theoretical and pedagogical frameworks but viewed those as derived from their designs, as opposed to using those to inform or refine their designs as in Category A. Thus, students in Category D appear to have used the frameworks as an add-on rather than as a way to guide their designs. Students in Category A accurately used the pedagogical framework to inform the embodiment and, thus, the learning design and accurately used the theoretical framework to define the mediating processes and other aspects of their research designs.

The dimension of the *use of learning strategies to help refine one's thinking* focuses on how students benefitted from the scaffolding and socialization processes provided by the course instructor. While students in Category E benefited from the socialization processes by being aware of their peers' projects in a general way, students in Category A reflected upon others' maps to better understand others' research alignment but also to refine their own thinking processes and consequently revise their conjecture maps. The Categories in between A and E primarily benefited from feedback provided by the instructor either through the lecture where the instructor introduced the structure of a conjecture map (Category C) or by meeting one-on-one during office hours (Category D). In addition to the instructor's feedback, students experiencing Category B benefited from feedback received from their peers during in-class presentations.

7. Discussion and Implications

Findings from this study describe the different ways novice researchers perceived and experienced conjecture mapping for the purpose of designing DBR projects. The categories of description identified in the study present the different affordances the novice researchers *perceived* for the uses of conjecture mapping, while the outcome space also elaborates on the different ways novice researchers experienced conjecture mapping, along with the dimensions of variation describing transition points from one category to another. Th distinctions encompassed by the categories of description are important because, according to Gibson [53], affordances describe the functional properties of tools that define how such tools could be potentially used. Furthermore, recent studies in the area of neuroscience have further operationalized the affordances of tools at two levels [54]. Affordances at the *physical* level focus on what is objectively observable (i.e., perceptions), and affordances at the neurocognitive level focus on what is subjectively lived (i.e., experiences).

The categories of description describe five different functionalities of conjecture mapping perceived by novice researchers, one more encompassing than the other, thus describing the outcome space. While further inspecting the outcome space, we also identified how novice researchers actually experienced the process of conjecture mapping. Unsurprisingly, and as documented by previous research, all participants identified the process of characterizing the mediating processes as the most difficult step in creating a conjecture map [23]. In this regard, it is important to also mention that while some students mentioned that the pedagogical framework strongly influenced their mediating processes, others mentioned that the theoretical framework had the same impact on their maps. This could potentially be a source of confusion because, as explained in Section 4, what should have impacted the mediating processes should have been a theoretical or a conceptual framework and not precisely a pedagogical framework. However, it could be the case that the theoretical and the pedagogical framework had a dual role, such as in the case of self-regulated learning for some of the projects. Thus, as identified through the dimensions of variation, to overcome this particular challenge, it is important to have an understanding of (a) the role of learning theories and how constructs associated with a particular learning theory can inform the mediating processes and (b) engage in socialization processes to learn vicariously from others' maps, and get feedback from peers and experienced researchers so the alignment between frameworks and elements of conjecture maps result in usable cognitive tools. That is, the pedagogical and theoretical frameworks used for their studies, along with the socialization processes of presenting, discussing, and getting feedback from the course instructor and their peers, may help novice researchers define a working conjecture map.

Two additional observations can be made in the way the novice researchers experienced conjecture mapping. One is the "direction" of navigating the conjecture map while designing a research study. For some novice researchers, the theoretical and pedagogical frameworks guided the embodiments, mediating processes, and outcomes of their conjecture maps. For others, the embodiments, mediating processes, and outcomes guided the selection of their theoretical and pedagogical frameworks. These observations suggest that the integration of theory and evidence-based practices in the context of conjecture mapping can be achieved in both directions. Another observation focused on the way novice researchers "read" others' conjecture maps or how participants "explained" their conjecture maps to others. While some novice researchers started explaining their conjecture maps from the high-level conjecture, many of them actually started their explanations with the outcomes. Some students even mentioned that reading the map "backward" actually helped them better understand others' maps. Lastly, two participants mentioned their confusion with the arrows connecting elements of the embodiment with elements of the mediating processes and arrows connecting the elements of mediating processes with elements of the outcomes. These connections were explicitly addressed in the proposed scaffolding approach but were not explicitly taught in the context of the specific course (due to lack of time). These observa-

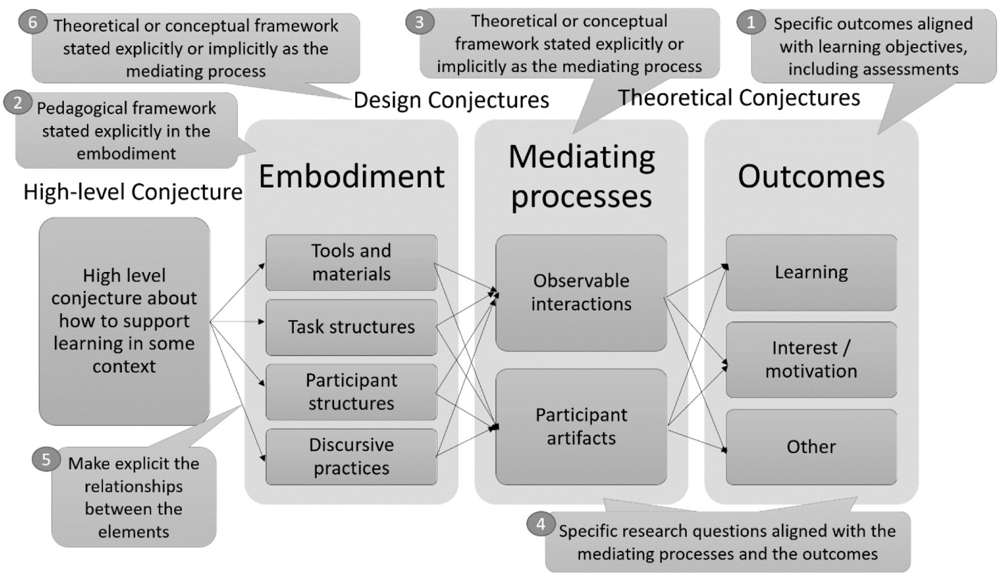

Fig. 4. Conjecture map with scaffolding 6-step cues aimed at making explicit connections between the elements of the map and the elements of research and learning designs (Revised version derived from Fig. 3).

tions are the source for future considerations for improving our scaffolding approach proposed in Fig. 3 into a more refined process as proposed in Fig. 4.

Our initial scaffolding process, defined in Table 1 and expanded in Fig. 3, is provided in the form of heuristics that can help learners align (a) learning objectives with assessment methods along with the outcomes of a conjecture map, (b) pedagogical approaches guiding the implementation of the learning innovation as part of the embodiment, and (c) research questions with theoretical or conceptual frameworks as part of the mediating processes. As shown in Fig. 4, our scaffolding process is proposed to be revised to now include (d) making explicit connections between the elements of each of the components of the conjecture map and (e) making the design and the theoretical conjectures clear and making sure that those align with the research questions proposed in the study. However, more research is needed to identify if the proposed revisions addressed the challenges the novice researchers experienced. Furthermore, more research, in general, is needed to identify the specific affordances of the arrows by novice as well as experienced researchers. In his seminal study, Sandoval [7], mentioned that "Each arrow in a conjecture map specifies a relation open to empirical refinement;" (p.27) however, no further details were provided into how to define them or use them.

7.1 Implications

The implications of this study relate to the use of conjecture mapping for training the next generation of Discipline-Based Education Researchers at an early stage in their developmental path as researchers. While the potential of conjecture mapping can help novice researchers start early with their research projects, as was the case for many of the participants in this study who were in their first year of graduate school, it is also important to emphasize the steep learning curve many novice researchers experienced. They mentioned that to benefit from the tool, they had to first learn the structure of the conjecture map and understand its components so then they could benefit from it as they applied it to their research projects. For this reason, it is critical that (a) the course instructor, mentor, or research advisor provides iterative guidance in the process, (b) novice researchers have opportunities to present their maps to their peers, receive feedback, and do the same for other researchers, and (c) use the conjecture maps as communication and thinking tools that can be iteratively revised and improved as the novice researchers understand better the role of theory, or as they test their designs in working classrooms and findings inform better designs [e.g., 20]. These are important socialization processes that are also aligned with the principles of cognitive apprenticeship [31]. Also, according to Variation Theory, the mediating processes of awareness, discernment, and simultaneity appear to be effective in resulting not only in competence in the alignment of research designs and learning designs but also in using the conjecture maps as cognitive tools that allowed the students to plan their studies and give them confidence on their progress.

Based on the findings from this study, a revised version of the conjecture map for the study is presented in Fig. 5. As shown in Fig. 5, the embodi-

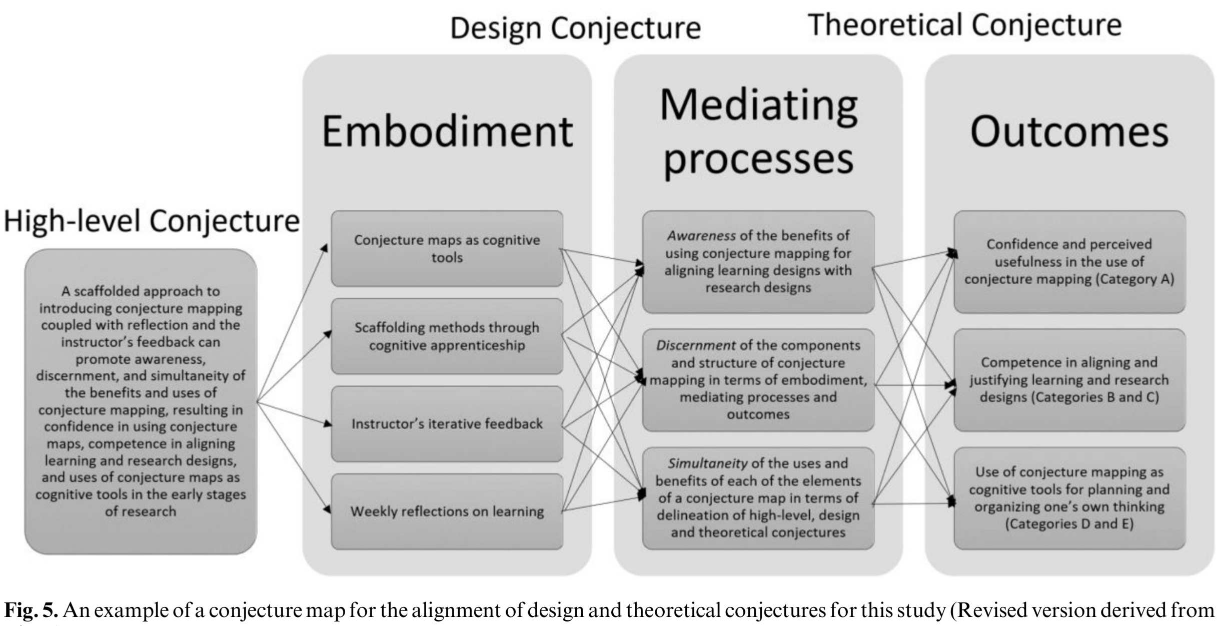

Fig. 5. An example of a conjecture map for the alignment of design and theoretical conjectures for this study (Revised version derived from Fig. 2).

ment and mediating processes did not change. However, through the phenomenographic approach, we were able to identify two additional outcomes derived from the scaffolded approach for introducing conjecture mapping. The outcomes are (a) confidence and perceived usefulness in the use of conjecture mapping, aligned with Category A; (b) competence in aligning and justifying learning and research designs, aligned with Categories B and C; and (c) Use of conjecture mapping as cognitive tools for planning and organizing one's own thinking, aligned with Categories D and E.

Our findings also have implications in terms of the three conjectures of the study. The *high-level conjecture* hypothesizes that a scaffolded approach, grounded in cognitive apprenticeship methods, to introducing conjecture mapping coupled with reflection and the instructor's feedback can promote awareness, discernment, and simultaneity of the benefits and uses of conjecture mapping, resulting in confidence in using conjecture maps, competence in aligning learning and research designs, and uses of conjecture maps as cognitive tools in the early stages of research. The *design conjecture* remained the same, hypothesizing that a cognitive apprenticeship scaffolded approach for introducing conjecture mapping coupled with instructor's feedback and weekly reflections on learning will promote the mediating processes associated with Variation Theory of awareness, discernment, and simultaneity in the context of conjecture mapping. Finally, the *theoretical conjecture* now hypothesizes that the mediating processes of awareness of the benefits of conjecture mapping, the discernment of the components of conjecture mapping, and the simultaneity of the uses of the high-level, design, and theoretical conjectures will result in confidence and perceived usefulness in the use of conjecture mapping, competence in aligning and justifying learning and research designs, and use of conjecture mapping as cognitive tools for planning and organizing one's own thinking.

The scaffolded process presented in this study also has implications for addressing two of the primary experienced conceptual difficulties for novice researchers [2], as those are also commonly experienced by DBER graduate students [3]. One of them relates to the grounding of their studies in frameworks. Our proposed scaffolded approach of conjecture mapping provides a means to make the frameworks explicit and, in a way, explain how those frameworks can be used or inform the learning and research designs. In this regard, the outcome of the phenomenographic study could also be used by novice researchers to ascertain where they are in terms of the completeness of understanding what conjecture maps can be used for (their affordances) and aspects of using them they may need to be aware of (the types of challenges they might face, the strategies they may need, etc.). Similarly, the dimensions of variation can be used by novice researchers to better understand how to move from categories associated with less understanding of conjecture mapping (i.e., Category E) to categories closer to proper understanding and use of conjecture mapping (i.e., Category A).

Our proposed approach also makes explicit the alignment between the research questions, the designs, and the selected frameworks. However, the operationalization of constructs into measurements is also an important conceptual difficulty experienced by novice learners. The novice researchers in this study precisely identified this as a limitation of conjecture mapping. Thus, future work could consider expanding the components of conjecture maps to also include guidelines for the operationalization of constructs and the alignment with the intended outcomes.

Implications of the study also relate to the use of conjecture mapping to support faculty development efforts that aim to (a) improve teaching practice and (b) provide a foundation for the scholarship of teaching and learning [55]. This project also has implications for community-based efforts and communities of practice aimed at providing mentoring, peer reflection, and peer reviews to improve engineering education research [e.g., 56, 57]. Furthermore, our findings also have implications for the use of design-based research and conjecture mapping as an approach that merges and aligns the reform paradigm with the research paradigm identified by Borrego et al. [58] over a decade ago. The reform paradigm emphasizes curricular change and the integration of evidence-based practices, and the research paradigm emphasizes systematic investigations, rigorous methods, and convincing evidence. Implementing design-based research can address both concerns by achieving the creation of theoretical insights with practical implementation in the classroom [59-61]. As such, conjecture mapping can jointly address the reform paradigm and the research paradigm. Our contribution from this study may provide a way to increase the level of adoption of conjecture mapping for this dual purpose.

7.2 Limitations

This study has the inherent limitations of a qualitative study in terms of the generalization of its findings. Also, the study did not address the characterization of the mediating processes documenting how students developed competence conjecture mapping. This was an intentional decision as all students developed usable conjecture maps at the end of the semester, in part because of the scaffolding and feedback provided by the instructor and the peers. Thus, we took a phenomeonographic approach where the focus of the study was placed on the perceptions and experiences of the students to identify benefits, challenges, and strategies to make the use of conjecture mapping more understandable and usable for them. The use of phenomenography as a methodological approach also posed limitations, as the focus of the research was on perceptions and experiences. Furthermore, based on the findings, it can be noted that the instructor had a critical role in facilitating the learning process. Therefore, future research is needed to identify (a) if the revised version of the process of socialization presented in Fig. 2 addressed or diminished some of the challenges and limitations experienced by the novice researchers and (b) if this approach can be effectively deployed by individual novice researchers with reduced or minimal support from the expert in education research.

8. Conclusion

This study contributes with new knowledge that builds on the *structure* of conjecture mapping into specifics of a *process* to be used as a scaffolded instructional sequence. Our approach followed principles of cognitive apprenticeship to scaffold the process for novice researchers involving aspects of socialization and deployment of conjecture mapping within interdisciplinary teams of education researchers (i.e., the instructor), and practitioners (i.e., the novice researchers). The findings of the study identified the affordances of this process by describing the different ways in which novice researchers perceived conjecture mapping and experienced it in the process of design-based research. The ultimate goal of this research program is to facilitate interdisciplinary research in STEM learning by providing education researchers and faculty practitioners with thinking tools that can help them define, align, and communicate their design and research decisions.

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Alejandra J. Magana is the W.C. Furnas Professor in Enterprise Excellence in the Department of Computer and Information Technology and Professor in the School of Engineering Education at Purdue University. Dr. Magana holds a BE in Information Systems and an MS in Technology, both from Tec de Monterrey, and an MS in Educational Technology and a PhD in Engineering Education, both from Purdue University. Her research program investigates how model-based cognition in Science, Technology, Engineering, and Mathematics (STEM) can be better supported by means of expert tools and disciplinary practices such as data science computation, modeling, and simulation. In 2015, Dr. Magana received the National Science Foundation's Faculty Early Career Development (CAREER) Award for investigating modeling and simulation practices in undergraduate engineering education. In 2016, she was conferred the status of Purdue Faculty Scholar for being on an accelerated path toward academic distinction, and in 2022, she was inducted into the Purdue University Teaching Academy, recognizing her excellence in teaching.