Defining and Assessing Risk Analysis: The Key to Strategic Iteration in Real-World Problem Solving

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Abstract: Across domains from science to civics, experts plan to solve real-world problems iteratively. Despite the importance of strategic iteration, we lack precise understandings of effective iterative planning and novice challenges, making it difficult to assess formatively and therefore to teach. We conducted design-based research to understand iterative planning and design assessment tools in a full-time 6-week program where undergraduate teams worked on social impact design problems. We found that iterative planning requires a process of *risk analysis*: detecting risks in the problem space, prioritizing those risks, and setting goals to reduce them. Novices struggled with each step of risk analysis, so they did not plan iterations strategically. We designed assessment tools that surface students' thinking about risk analysis and support instructors to notice common challenges. We contribute detailed understandings of iterative planning and novice challenges as well as tools that can be adapted to assess real-world problem solving across domains.

Keywords: problem solving, design learning, iteration, planning, assessment, risk analysis

Across domains—from science inquiry, to engineering, to civics—learning scientists are committed to designing learning environments for teaching the highly complex, ill-structured problem solving that constitutes professional practice. This includes designing thoughtful assessments that provide instructors with critical insights on where students need help, but the challenges of assessing real-world problem solving are daunting. In this study, we developed tools (the *Design Canvas*, the *Iteration Plan*, and a *planning rubric*) for assessing students' planning in learning environments for real-world problem solving. We focus on planning because it is the core of successful problem solving. Planning is unlike other problem solving activities (e.g., gathering information, building and testing solutions, and analyzing data). Planning gives these activities a purpose; it is how problem solvers decide which activities to do and how to interpret the results. Without thoughtful planning, problem solvers will conduct other activities aimlessly and fail to create successful solutions.

Iterative planning to solve real-world problems

Most real-world problems cannot be solved in one try—they require iteration: the practice of testing and revising ideas to continually improve one's understanding of the problem and solution (Adams, Turns, & Atman, 2003; Wynn & Eckert, 2017). Scientists iterate on research questions to refine their contributions, engineers iterate on technical solutions to satisfy practical needs, and doctors iterate on diagnoses to prescribe more effective courses of treatment. *Iterative planning*—the process of strategically planning to iterate—is thus critical to teach when preparing students for practice in problem solving disciplines.

In iterative planning, professionals choose activities that enable them to continually improve both their understanding of the problem and their solution (Adams et al., 2003; Crismond & Adams, 2012). For example, a scientist might iteratively improve their argument in a research paper by planning to collect, analyze, and write up additional data. This approach to planning contrasts with teaching students to choose activities (like data collection, analysis, and writing) based on a predetermined project schedule. Unfortunately, novices struggle to iterate strategically (Ahmed, Wallace, & Blessing, 2003; Crismond & Adams, 2012).

Need for tools to assess iterative planning

If we want to teach iterative planning, we need formative assessments of iterative planning to help teachers decide where to focus instruction. To assess iterative planning *reliably*, assessors need to make consistent decisions about *what* information to seek when assessing performance, and *how* to assess it. Assessment tools could support consistent decision making when assessing iterative planning.

Previous work suggests assessing problem-solving by using performance rubrics and assessing argumentation. For example, it is common to assess the arguments students construct to justify their problem solving (Cho & Jonassen, 2002; Shin, Jonassen, & McGee, 2003). Highly-ill structured problems like design problems underlie professional practice in most disciplines (Jonassen, 2010). In these problems, assessing the solution itself is difficult because the criteria for evaluating design solutions are highly subjective, change with one's understanding of the problem, and are not fully known until the end of the design process (Jonassen & Hung, 2015). So, if we want to assess this type of problem solving, we cannot simply check whether students found the right solution. Rather, we need to assess how reasonable a proposed solution is, given one's current understanding of the problem. However, assessing the quality of students' arguments is an ambiguous task without clearly defined criteria for argument quality, which makes *reliable* assessment more difficult. To remedy this, Jonassen (2010) suggests using argumentation rubrics that define criteria for assessing students' problem solving performance.

Given that iterative planning is a key process within problem solving, we hypothesize that argumentation rubrics can also be used to assess performance in iterative planning. Like in solving design problems, there is no single correct solution in iterative planning. There are poorly-justified plans, and there are better-justified plans. If we can create rubrics that define poorly justified versus well justified plans, these rubrics might support reliable assessment of iterative planning performance. However, prior research does not provide specific guidance about tools and practices for constructing rubrics to assess iterative planning because iterative planning is currently an ill-defined task. And so we ask: *how do experts reason through iterative planning and where do novices struggle?* By answering this question, we can construct rubrics that effectively assess whether novices exhibit the desired performance.

Need for novice and expert models of iterative planning

Unfortunately, the literature tells us little about how experts (i.e., professionals) and novices (i.e., students) reason about iterative planning; that is, we lack expert and novice models of iterative planning that are detailed enough to create assessment rubrics. Experts solve design problems by *iterating*: refining their understanding of the problem and solution as new information emerges during problem solving (Adams et al., 2003; Adelson & Soloway, 1985; Atman et al., 2007; Guindon, 1990). However, we know little about how experts reason through the iterative planning process. Nor do we know what novices find difficult in that process. For example, a recent literature review on expert and novice design practices noted the importance of iteration (Crismond & Adams, 2012) but did not identify *how* experts carry out iterative planning. The same review established that novice designers undervalue and underutilize iteration, but did not identify *why* novices struggle to plan iteratively. We need to define how expert designers reason through iterative planning—and where in this reasoning process novices commonly struggle—to create assessments of iterative planning performance.

Research questions

The goal of this project was to develop reliable tools for assessing iterative planning performance, and corresponding expert and novice models which inform those tools. Specifically, we asked: (a) How do expert designers approach iterative planning? (b) What do novice designers typically struggle with when they attempt iterative planning? and (c) How can we assess design students' performance in iterative planning?

In this study we conducted 6 1-week iterations of data collection, analysis, and redesign to create tools for assessing student teams' planning in design projects. We developed expert and novice models of iterative planning to design a rubric tool to assess planning. We also developed two tools for externalizing students' plans: the Design Canvas (DC), the Iteration Plan (IP). The DC and the IP are complementary, poster-sized (40 in. x 60 in.) templates where students externalize the knowledge and reasoning they use to plan (for images see our companion study: Rees Lewis et al., 2018). This happens during collaborative planning in a design team, similar to professional design practice (Osterwalder & Pigneur, 2010). The rubric guides assessors to detect students' struggles by reviewing the DC and IP.

Methods

Context and participants

We conducted the research in a 6-week extra-curricular undergraduate summer program at a university design institute. In the program, each 4-5 person project team worked with a local community partner organization to design products and services to address a given real-world challenge for the duration of the program. Challenges included: improving airport accessibility for autistic travelers, reducing air-travel-related wheelchair breakages, improving accommodations for people with dementia, increasing first responder support for youth, and reducing teen depression. Teams worked approximately 36 hours a week to create an original solution based on their understanding of the problem. Each week, we prompted students to plan. First, students updated their DC so that it reflected their current knowledge of the problem space. Then, students constructed and represented a plan using the IP.

The study involved 21 undergraduates from 18-22 years old at a large private US university. Participants majored or double-majored in engineering (15), natural sciences (3), social sciences (3), art (3) and journalism (3), and included 4 first-, 12 second-, and 5 third-year students (57% female).

Data collection and iterative analysis

We collected 1 photograph per week of each team's DC and IP, after the teams had planned. In total, we captured images of 30 plans across 5 teams. We also wrote field notes based on observations of team planning sessions. After each weekly planning session, we reviewed photographs and field notes to critique teams' planning. When we made a critique that was not already represented in the rubric tool, we added it to the rubric and wrote an analytic memo explaining why we would make a different planning decision. This process helped us to articulate the normally tacit knowledge we use to think about planning decisions. In many cases, assessing the quality of the plan required additional information, such as students' reasons for choosing a certain goal. When we found we needed additional information (beyond what we saw in the Design Canvas or Iteration Plan) to assess a plan, we revised the tools to prompt students to share that information. We also wrote an analytic memo explaining why we needed that additional information to judge the planning decision. Like with the memos we wrote to justify critiques, this enabled us to articulate elements of tacit knowledge that we use to think about planning decisions. For example, while the tools ultimately centered on a critical process of risk analysis (see Findings), the initial prototypes did not surface students' thinking about risk. By analyzing students' plans we recognized the centrality of risk in our own thinking, in part because it was impossible to evaluate students' planning without understanding how they thought about risk in the problem space. This led us to begin articulating our understanding of risk in an analytic memo, and to add additional boxes to the Design Canvas prompting students to explicitly identify risks.

What authorizes us to define expertise? First, we are experienced designers with over 50 collective years of design experience in industry and academic design-based research. Second, in a companion study of this learning environment (Rees Lewis et al., 2018), we tested instruction based on our understanding of iterative planning. Students who received this instruction engaged in key design practices (e.g., iteration, interviewing users, testing ideas with stakeholders) more than students from the previous year (when we did not emphasize iterative planning). This suggests that learning iterative planning (as we define it) helps students succeed in design.

Summative analyses

At the end of the program, we conducted summative analyses to test the final versions of our models and prototypes. One researcher used the final rubric to assess students' plans from each week. This allowed us to test the final novice model against data from each week of the program, and to aggregate our evidence for the final novice model. A second researcher used the final rubric to assess 5 of the plans we collected (17% of plans). This allowed us to calculate Cohen's kappa (.82) between researchers to test reliability of the assessment tools.

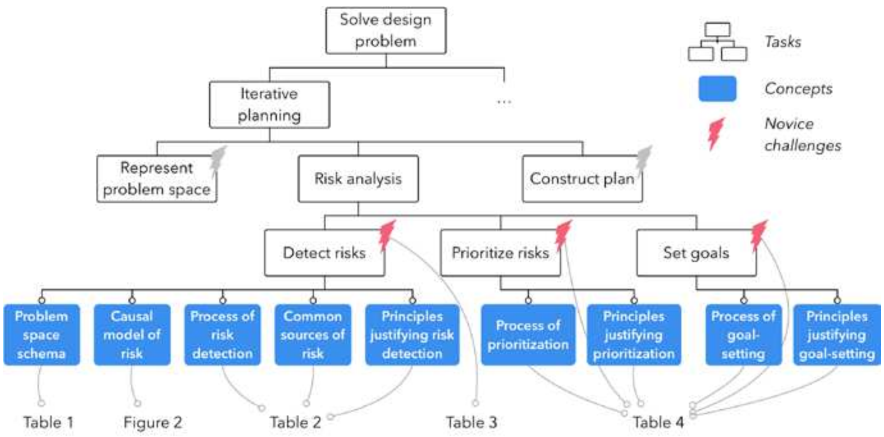

Figure 1. Task analysis of iterative planning. We found iterative planning requires risk analysis: detecting risks in the problem space, selecting high-priority risks to address, and setting near-term goals to reduce those risks. Novices struggled throughout iterative planning; this paper focuses on challenges with risk analysis.

Findings

We found that *risk analysis* is a central reasoning process in strategic iterative planning. In risk analysis, designers review their mental or external representation of the problem space to assess, prioritize, and set near-term goals to reduce risks in the problem space. We found that novice designers face challenges throughout the process of risk analysis. We found that the DC and IP successfully externalized students' reasoning about risk analysis such that we could tell where students struggled. Finally, we found we could assess students' risk analysis reliably using the assessment rubric.

Strategic iterative planning requires *Risk Analysis*

As we observed teams and assessed their Design Canvases and Iteration Plans, we reflected upon their planning decisions. When we identified a decision that we would make differently, we wrote an analytic memo to (a) catalogue our critique of the team's planning decision and (b) articulate our reasoning about why we would make a different decision. In doing so, we found that our implicit expert model of iterative planning centered on the process of *risk analysis*, in which designers detect risks in the problem space, prioritize these risks, and set near-term goals to reduce high-priority risks (Figure 1). We found that iterative planning also involves representing the problem space and constructing the full plan (Figure 1), but we focused on risk analysis in this study. We found risk analysis relies on several key concepts that novices must develop, including: a problem space schema (Table 1); a causal model for detecting *risk* (Figure 2); knowledge of the process of risk analysis (Table 2: *Experts ask themselves*; Table 4: *What experts do*); knowledge of principles justifying the process of risk analysis (Tables 2 and 4: *Why it matters*); and knowledge of common sources of risk (Table 2: *Common sources of risk*). The corresponding novice model identifies several aspects of risk analysis that students found to be particularly challenging (Table 3; Table 4).

Table 1: A problem space schema that the experts used to analyze iterative planning in social impact design

Problem Aspects	**Description**
Community Partner (CP)	A person at a partner organization with expertise in the problem area (e.g., a relevant non-profit). The CP connects problem solvers with resources (e.g., information, access to users). The CP may also implement designers' solution, if they find it helpful.
User Access Plan	How designers plan to access users (see User row) to learn about their needs.
Demoing Plan	How designers plan to get regular feedback from the CP.
Desired Impact	The social impact that designers want to have.
User	A persona who will use the proposed solution. Users have *needs,* which have 3 components: a "job" (a task users must complete), a "pain" (a challenge they face in that task), and a "gain" (the benefit they will attain if they can complete the task). By satisfying user needs, problem solvers can entice users to adopt the proposed solution (and thereby promote the Desired Impact).
Root Causes	An analysis of the underlying, fixable causes that explain why the user need, CP need, and desired impact are not yet satisfied.
Value Proposition (VP)	A proposed solution and an argument for how the proposed solution will overcome the root causes to satisfy the user need, CP need, and desired impact.
Existing Solutions	Designers need to account for existing solutions and argue why theirs is better.
Implementation Strategy	Explains who will implement the proposed solution and how. Commonly, this involves handing off the solution to the CP, who integrates it into their existing operations.
Impact	Evidence that designers have achieved the desired impact.

The central concept in risk analysis is *risk*—the probability that the design project fails to make impact (i.e., change the status quo in a desired way). Designers' concept of risk derives from an implicit causal model of the factors affecting whether a design project makes impact (Figure 2). Teams increase the probability of making impact by working on the causal factors that affect impact (Figure 2). For example, for the project to make impact, the team must ensure that users adopt the designed solution, which means designing something that users value, which requires understanding user needs (see the problem space schema in Table 1 for explanations of user, community partner, and other terms). Likewise, a second causal chain focuses on understanding the needs of the community partner (CP), who also affects whether the designed solution is adopted. Furthermore, assuming the solution is adopted by users and CPs, the solution also must work as intended to achieve its desired impact. Each causal chain presents a possible risk to the impact of the project, so design teams iteratively plan activities that help them understand and address risks of user need, partner need, and solution efficacy.

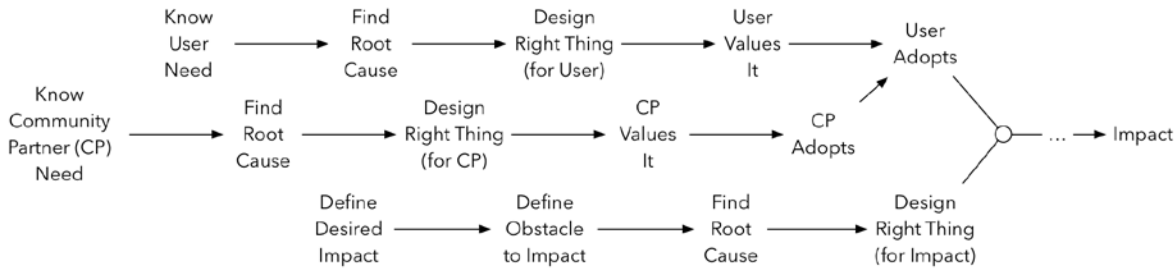

Figure 2. Experts (us) used this implicit causal model to detect *risk* in the problem during iterative planning.

Risk exists when any of the variables in the causal model represent unmet conditions (e.g., designers *don't* know the root cause of the CP's need, or the user *doesn't* value the design solution) or unknown conditions (e.g, designers are unsure if they are right about the root cause, or they don't know if the user values their solution). Downstream variables are closer to making impact than upstream variables, so downstream variables have a more direct causal effect on making impact and thus matter more for risk. For example, solvers can only achieve a relatively small decrease in risk by working on the Know User Need variable, because even if they understand the user need perfectly, there are many downstream variables that can interfere with making impact.

Table 2: Expert model of risk detection in social impact design

Identify and estimate the level of risks associated with the *Community Partner (CP)*.	
Experts ask themselves: Have we specified the CP's need well enough to begin thinking about its root cause (or are there significant remaining risks)? *Why it matters (connection to Figure 2: causal model of risk):* Clearly articulating the CP's need makes it much easier to think about the fixable root cause(s) of that need, which makes it much easier to think of design solutions that will address the CP's need. Precisely defining the CP's need helps to narrow down the massive pool of potential design solutions, so solvers can avoid wasting time working on totally off-base solutions.	*Common sources of risk*:* • We haven't made contact with a real person at a partner organization • We can't specify the partner's need (either as a concrete "job," "pain," and "gain," or a clearly measurable social impact goal) • Our ideas about the partner's need aren't reasonable (they conflict with data and/or common knowledge) • When we cite data, we don't specify both its content *and* its source
* i.e., conditions that may threaten impact by interfering with the variables that lead to impact (shown in Figure 2)	

This explains why designers cannot sufficiently reduce risk by spending *all* their time understanding the problem (by interviewing the partner and users, and defining desired impact): an understanding of the problem does not guarantee a working solution. For this reason, designers try to move as quickly as possible to building and testing potential solutions to see whether users and CPs *actually* value and adopt the solutions, and whether the solutions *actually* achieve measurable impact. In other words, designers plan by weighing the risks inherent in different potential plans; they must judge whether they can achieve impact most quickly by building and testing a solution, or whether spending time understanding the problem will save precious time by avoiding "building the wrong thing." These questions rarely have a clear right answer, if ever. However, designers use the process of risk analysis to discriminate between more and less reasonable answers, based on their knowledge and experience. This involves detecting and prioritizing risks. In our study, expert designers (i.e., the authors) detected risks by analyzing aspects of the problem space, using knowledge of the process of risk analysis, the principles justifying it, and common sources of risk (Table 2). The full expert model of this knowledge does not fit within the page limit, but Table 2 provides an excerpt. The experts then prioritized risks and set goals using additional knowledge of the process and principles of risk analysis (Table 4).

Novice challenges in risk analysis

We found that students struggled throughout the process of risk analysis. Students faced challenges in risk detection (Table 3), risk prioritization, and goal setting (Table 4). In some cases, students skipped steps in the process of risk analysis (e.g., not attempting to detect risks). In others, students' reasoning did not align across the steps of risk analysis (e.g., setting a goal that did not address high-priority risks). In still other cases, students struggled to complete the steps of risk analysis in a way that would be useful (e.g., setting a goal that is too vague to guide the rest of planning). Students also struggled to identify all of the risks we noticed in their problems, and they often struggled to make reasonable estimates of risk level.

Table 3: Novice model of risk detection

	Novice Challenges in Risk Detection (frequency observed)				
Problem Aspects	Don't attempt to detect risks	Don't both identify risks *and* estimate the level of risk.	"Risks" identified are not truly relevant.	Did not identify certain salient risks.	Estimated level of risk is unreasonable.
Community Partner (CP)	20	22	27	29	29
User Access Plan	12	17	23	24	25
Demoing Plan	14	24	21	29	27
Desired Impact	18	21	23	28	25
User	10	17	19	25	21
Root Causes	14	24	25	28	23
Value Proposition (VP)	12	20	18	26	26
Existing Solutions	8	15	24	27	26
Implementation Strategy	11	22	22	26	28
Impact	24	26	26	30	28

Table 4: Expert and novice models of risk prioritization and goal setting

Planning Step	Expert Model	Novice Challenges	Count
Risk Prioritization	*What experts do:* Experts review the risks they identified, prioritize those risks, and select a set of high-priority risks they can address in 1 iteration (1-2 weeks). Often, experts look for economies of scope using a concept called *slicing*, which involves creating a single plan to address multiple risks across the problem. Further understanding of slicing is crucial, but beyond the scope of this paper. *Why it matters:* Selecting the greatest risks from across the problem space each iteration allows experts to shift their efforts in response to new knowledge. This minimizes their chances of failing to solve the problem.	Do not attempt to select high-priority risks	10
		Spontaneously generate risks (rather than selecting risks identified by analyzing the problem space)	20
		Do not prioritize selected risks (among the high-priority risks, which are the most important to address?)	25
Goal Setting	*What experts do:* Experts construct a goal that will guide the rest of their planning. This goal takes the form of a conclusively answerable question, or a falsifiable hypothesis or design argument. *Why it matters:* Having the right goal is crucial because goals inform planning. Useful goals involve resolving questions and hypotheses about important unknowns in the problem space. Experts use such goals to craft plans that will reduce the biggest risks threatening their success.	Goal is not framed as a question, hypothesis, or design argument	23
		Goal is too vague to conclusively reach it (e.g., hypothesis is not falsifiable, question is not answerable)	25
		Setting a goal that will not reduce the selected risk(s)	15

Externalizing students' risk analysis using problem space templates

Recall that we designed 2 tools to surface teams' reasoning about risk analysis: the Design Canvas (DC) and Iteration Plan (IP). These tools are necessary because when an instructor or coach advises a team on their iterative planning, they typically ask a series of questions to surface the team's reasoning. Likewise, to assess the reasoning behind students' plans, we need a way to surface that reasoning. In risk analysis, this includes design teams' knowledge of the problem space, such as their knowledge about existing solutions to the problem (Table 1). It also includes how design teams analyze this knowledge to identify risks in the problem space, select high-priority risks to address, and then construct near-term goals that will reduce those risks.

Students planned each week by filling out the DC and IP. The final version of the DC works by externalizing what students know about the problem, and what risks they have identified. The DC is a poster-sized template with boxes for each of the key schema components we identified as central to how the expert designers assessed risk in the problem space (Table 1). Students worked in their design teams to fill in the DC by placing sticky notes in each box to represent their knowledge about different aspects of the problem space. Each box in the DC also contained a section for risks, where students placed sticky notes identifying risks in that aspect of the problem space. In a subsection of the risks section, students could rate the risk level as low, medium, or high.

The final version of the IP works by externalizing what students plan to do next, and why they think it is important. The IP is a poster-sized template with boxes for each key component of students' plans. The IP included boxes for Selected Risks, Goals, Design Method, Metric, Criteria, and Tasks. For assessment, we focused only on Selected Risks and Goals because these determine whether students have begun crafting a plan that links back to major risks in the problem space. In other words, this is the heart of iterative planning. To be effective, students also need to construct coherent plans; they need to choose the right methods, set relevant metrics and criteria, and accurately plan specific tasks. We have evidence that students struggled with these steps, but here we focus only on risk analysis; a discussion of how experts and novices construct coherent plans is outside the scope of this paper.

Assessing students' risk analysis by using a rubric on problem space templates

Once students have externalized their reasoning using the DC and IP, we can assess it using a rubric that sensitizes assessors to the concepts that experts use in iterative planning, and then directs assessors to check for specific, common novice challenges. The rubric has 3 sections. The first section asks assessors to assess the risk in the problem space, and supports this by providing assessors with heuristics for risk detection taken from our expert model (Table 1). This is necessary before assessors can judge how well students have assessed risk in the problem space. The second section asks assessors to check how well students have assessed risk. Assessors check for each of the challenges listed in our novice model of risk detection (Table 3). The third section asks assessors to check how well students have selected risks and set goals. Assessors check for each of the novice challenges listed in our novice model of risk prioritization and goal-setting.

The assessment tools were reliable when applied by different experts with similar disciplinary knowledge. We achieved a Cohen's kappa = .82 between two researchers testing the final rubric on 5 plans (17% of plans). For each criterion, we coded the plan "yes," "no," or "can't grade." Inter-rater reliability indicates that the rubric provides sufficient guidance for experts to make similar judgements about quality of students' plans. Our primary goal was developing expert and novice models and assessment tools. Therefore, we analyzed all available data as we collected it to iteratively improve the expert and novice models and the assessment tools. We then calculated inter-rater reliability by re-analyzing a subset of that data. This is a limitation that we will address by testing the tools on fresh data in future work. Nonetheless, we argue that we can have reasonable confidence that the tools are reliable because 2 researchers coded the 5 plans independently, we had not discussed specific coding decisions when we initially analyzed the data, and this was the first time both of us applied the final version of the rubric to data.

Discussion and conclusion

This paper contributes: (a) a model of how experts in social impact design used *risk analysis* to inform iterative planning; (b) a model of novice challenges in risk analysis in social impact design; and (c) tools for surfacing and assessing novices' risk analysis in social impact design.

Our expert and novice models identify risk analysis: an important reasoning process that drives iterative planning, and therefore strategic iteration. Our findings build on previous research which showed that experts use iteration to solve design problems, but did little to define strategic iterative planning, or novice challenges in iterative planning specifically enough to guide assessment (Adams, Turns, & Atman, 2003; Adelson & Soloway, 1985; Atman et al., 2007; Crismond & Adams, 2012; Guindon, 1990). We found that strategic iterative planning requires *risk analysis*, in which designers identify risks in the problem space, prioritize those risks, and construct goals to reduce them. Likewise, by showing that novices struggle with each step in risk analysis, we provide a plausible explanation for why novices tend to under-utilize iteration (cf. Crismond & Adams, 2012). Also recall that our normative model of iterative planning seems to define practically useful skills (Rees Lewis et al., 2018; see Data Collection and Iterative Analysis section).

We have also demonstrated that it is possible, despite the ambiguity and subjectivity of design problems, to assess risk analysis reliably using tools for externalizing and evaluating students' reasoning across each step of risk analysis. We have shown that it is possible not only to assess students' reasoning about their final solutions (cf. Jonassen, 2010), but also their reasoning about actions taken throughout problem solving—in this case, reasoning about risk analysis. Additionally, while previous work proposed using argumentation rubrics to assess students' reasoning (Jonassen, 2010), we add that it helps to create templates (the DC and IP) based on expert schemas to externalize the pieces of students' reasoning you wish to assess. Future work should test the fidelity with which the DC and IP represent and convey students' thinking to assessors.

Finally, our tools could support assessment of risk analysis in other disciplines (e.g. science or civics). While we designed tools for assessing risk analysis in social impact design problems, risk analysis does not seem specific to social impact design; rather, its function is making highly complex, ill-structured problems more manageable. Thus, it seems like a critical reasoning process for real-world problem solving in any domain.

In this study, we developed tools for assessing students' planning in learning environments for real-world problem solving. Across domains—from science inquiry, to engineering, to civics—learning scientists are committed to designing learning environments for teaching the highly complex, ill-structured problem solving that constitutes professional practice. This includes designing thoughtful assessments that provide instructors with critical insights on where students need help, but the challenges of assessing real-world problem solving are daunting. Our tools overcome these challenges to enable instructors to understand where students are struggling in the critical reasoning process of *risk analysis*. This may make it easier for instructors to help students develop the knowledge and skills to design solutions to real-world problems.

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