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Enhancing Informal Stem Learning Through Family Engagement in Cooking

Bradley J. Morris*
Kent State University
bmorri20@kent.edu

Shannon R. Zentall
Independent Scholar

Grace Murray
Kent State University

Whitney Owens
Cincinnati Museum Center

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Informal learning has the potential to play an important role in helping children develop a life-long interest in STEM (Science, Technology, Engineering, and Mathematics). The goal of this review is to synthesize the evidence regarding the features of effective informal learning, provide effective ways to support learning within these contexts, and illustrate that cooking is an optimal opportunity for informal STEM learning. We review evidence demonstrating that the most effective informal learning activities are authentic, social and collaborative experiences that tap into culturally-relevant practices and knowledge, although there are limitations to each. We propose that cooking provides a context for authentic, culturally-relevant learning opportunities and includes natural supports for learning and engagement. Specifically, cooking provides many opportunities to apply STEM content (e.g., measuring and chemical reactions) to an existing foundation of knowledge about food. Cooking is also a family-based learning opportunity that exists across cultures, allows for in-home mentoring, and requires no specialized materials (beyond those available in most homes). It may help overcome some limitations in informal STEM learning, namely scalability. Finally, cooking provides immediate, tangible (and edible) results, promoting interest and supporting long-term engagement.

Keywords: Informal learning; science of cooking; authentic learning activities; STEM learning; lived experience.

1. Enhancing Informal STEM Learning Through Family Engagement in Cooking

STEM education provides considerable direct and indirect benefits for societies. STEM-educated workers provide economic benefits by generating technology and other durable goods, patents, and employment from manufactured goods these benefits are particularly acute for developing nations [2]. STEM education also creates indirect benefits by strengthening

*Corresponding author

support for science research, economic opportunities across a wide segment of the workforce, and more informed individual and public health decisions [1]. Informal STEM learning can span a wide variety of possible activities –but which ones offer the most promise for accessible and engaging participation? This paper reviews evidence that family cooking provides a valuable context for informal STEM learning, offering opportunities for authentic, social and collaborative experiences that tap into culturally relevant practices and knowledge.

1.1. *Leveraging authentic STEM experiences for children*

Children and adults are naturally curious about the world around them. The drive to learn about our environment, seek information, and generate explanations that provide understanding form the basis of scientific curiosity [3, 4]. Curiosity is both a threshold for information seeking, [3] and a strong driver of engagement, which is a significant contributor to learning, [5] particularly learning about science [6]. Once engaged, the learner can seek information to fill gaps in their knowledge, even without explicit awareness of the gaps [7]. Because of this drive, children engage in STEM learning well before they begin formal education.

Learning about the world takes place in a variety of settings (e.g., homes, museums) and takes place within multiple social contexts such as families, friends, and formalized learning relationships (e.g., teacher-student). Considerable attention has been paid to learning science within formal contexts such as schools; however, children spend most of their time outside of formal settings [8]. Children may be more motivated to engage and learn through informal experiences driven by their own interests [9]. In the US, student interest in science tends to decrease during school years, with steeper declines in interest during middle school; girls experience steeper declines than boys [10, 11]. One possible intervention for countering this decline is to provide opportunities for students to learn STEM content informally, by focusing on the learner's interests. To that end, we suggest that cooking can provide learners with interesting, STEM-relevant experiences that promote the acquisition of culturally-relevant knowledge as well as authentic life skills.

1.2. *Informal STEM learning*

Informal STEM learning (here after ISL) is driven by the interests of the learner, is often collaborative, and lacks formal test-based assessments [12]. This contrasts with traditional, formal science learning in school classrooms that is compulsory, driven by external standards at the state or national level, and formally assessed through grades and standardized tests. Because ISL is learner-driven, curiosity plays a strong role in the topics, frequency, and conditions for learning [13].

For these reasons, supporting and promoting science learning outside of formal settings has the potential to augment learning [13] by helping children develop a life-long interest in STEM. STEM learning is an iterative process of acquiring the practices and knowledge of science. [14] That is, learners acquire information by applying scientific methods and principles (e.g., Newton's Laws) and defining and testing hypotheses (e.g., designing unconfounded experiments). In this paper we discuss benefits of ISL – as well as some potential limitations, particularly scalability – then discuss how cooking, baking, and food science (hereafter, cooking) is a culturally relevant, potentially scalable, and effective context in which families can engage in ISL.

1.3. *Why is cooking a rich context for informal science learning?*

As a context, cooking can help democratize access to high-quality STEM engagement: activities are authentic, social-collaborative, derived from culturally relevant practices, and present in most homes as an essential practice. As a STEM activity, cooking can create strong ISL benefits – and as an everyday activity, it has significant potential to scale to many different kinds of families. We use the term *potential* because presenting information to a learner does not, on its own, result in learning but creates *potential learning* situations. Potential learning is analogous to the concept of potential energy in that both describe situations in which qualities can be realized in a future state [15]. As we will detail below, providing simple supports could go a long way toward embedding STEM learning within cooking and offers productive avenues for future research, building on a few initial investigations [16] in an under-researched area.

1.4. *STEM components of cooking*

Cooking's natural links to science (e.g., chemistry of baking, biology of plants) and mathematics (e.g., measurement, fractions) make it a context ripe with potential learning opportunities. Take popcorn, for example, which educators and caregivers can use to demonstrate multiple physics concepts. For popcorn to "pop", the small amount of moisture within the kernel heats to a sufficient temperature (optimally around 180°C), which turns the moisture to steam, exploding the kernel and illustrating concepts such as the properties of matter [17]. Learners can also investigate optimal conditions: for instance, popcorn pops best when there is approximately 13–14% moisture, an intact kernel, and a moderate, steady application of heat [17]. Similarly, frying an egg provides an excellent opportunity to explore chemistry. The globular proteins that make up an uncooked egg are unconnected to other proteins within the liquid of the yolk. When heat is applied, it agitates these proteins until they come into contact with each other, forming bonds. The longer the heat is applied, the stronger the bonds, which explains why overcooked eggs have a "blubber-like" texture [18]. Yet another example is exploring how cooking is related to cultivating ingredients (botany). For example, chocolate comes from the cacao bean, which is strongly influenced by other plants (e.g., coffee), growing near it [19]. Tasting chocolate from different locations allows the identification of flavors from those neighboring plants. These are just a few of many possible cooking connections to science. In addition, there are links to many other science fields such as ecology (How is a tomato grown?), climate (Where do peas grow best?), distribution and logistics (How does a strawberry get to my grocer?), and engineering (How does hydroponics work? [20]. For these reasons, cooking constitutes an island of expertise, or a rich context for learning STEM through informal experience [21].

1.5. *Lenses to investigating and creating informal STEM opportunities*

ISL has a sizable literature base; a single theoretical framework to guide investigations does not exist, however. Rather, ISL has traditionally been investigated through two primary lenses: the cognitive developmental approach and the sociocultural approach. The cognitive developmental approach focuses on the underlying processes of learning and development [22]. Researchers might focus on the operation of cognitive mechanisms, such as encoding information in memory, within individual children and how they scaffold the construction of scientific reasoning [23]. For example, prompting caregivers to ask their children questions about their experiences in science museums helps improve children's encoding and retention of these experiences [24].

The sociocultural theories of learning suggest learning and development are the result of a child co-constructing their knowledge with people in their social contexts [25]. Specifically, culture creates impressions on people through their participation in cultural practices, not through the possession of traits shared by a community [26]. Investigating the everyday, lived experiences of children and families is a promising way to deepen our understanding of such practices. Thus, the sociocultural theories of learning discussed here refer to a body of cultural knowledge and social practices that shape how learning occurs among individuals.

Although these lenses have operated largely independently, recent work has begun to integrate the two. For example, a large-scale, museum-based program provided ISL activities that focused on learning mechanisms within culturally relevant traditions [22]. Specifically, the intervention supported individual exploration of gears to promote exploration within the social context of family engagement and conversation. Another intervention prompted caregivers to ask questions that helped their children remember events in the activity, which promotes a focus on improving encoding and retrieval cues by enhancing social supports [27]. The synthesis of these theoretical perspectives suggests that intrapersonal mechanisms (i.e., encoding) of learning, engagement, and motivation operate within interpersonal (i.e., social, cultural, and historical) contexts [28]. This review will attempt to synthesize research from these perspectives to identify the qualities of effective learning contexts.

1.6. *Characteristics of quality ISL opportunities*

What makes an informal learning opportunity effective? In the following sections, we provide evidence that effective ISL opportunities are authentic, social and collaborative experiences that tap into culturally relevant practices and knowledge.

1.7. *Authentic learning opportunities*

Authentic activities must be driven –at least in part –by student interests, must be at least somewhat open-ended, and must be relevant to students' lives and experiences [29]. One of the criticisms of formal (i.e., school-based) science instruction is that students are often presented with "inauthentic" activities in which students are asked to "solve" problems with well-known answers [30, 31]. Authentic activities provide a more potent opportunity for learning because they present challenging components that motivate children to engage in learning [29]. For instance, geometry is a subject that is traditionally taught using abstract examples, which are difficult for novice learners to understand [32]. A recent study demonstrated that embedding geometry instruction in authentic activities (e.g., measuring the area of a triangle that is a building ramp) was associated with better learning outcomes than the same instruction using only decontextualized examples [33]. Similarly, learners who were given authentic activities for learning about the physics of inclined planes demonstrated greater learning gains than those using more traditional materials [34]. This evidence suggests strong links between authentic activities and participant learning.

1.8. *Limitations of authentic learning opportunities*

Although authentic activities do show benefits for learning, they are not a panacea. One potential limitation is that the large problem space for authentic activities – in other words, all possible options during problem solving – can be overwhelming for novice learners [35]. For example, imagine asking a young child who has never cooked to make pancakes from scratch: even getting started requires some knowledge of the tasks' sequence of events (e.g., locating a recipe, collecting ingredients). Even with a recipe, the child may struggle and/or lack relevant knowledge, such as the right temperature to heat a pan before cooking, or cooking time before flipping a pancake. Another limitation is that the order in which ingredients are added sometimes makes a difference. For example, combining baking soda and buttermilk makes fluffier pancakes because their reaction releases carbon dioxide bubbles. If the batter is left to sit, however, these bubbles will release before cooking, leading to flatter pancakes.

One way to help define the problem space is to provide direct instruction that helps learners gain enough background knowledge to use effective solution techniques [36] and avoid being overwhelmed by complexity [37]. When learners explore authentic activities without guidance or feedback, they are more likely to fail to learn, draw erroneous conclusions, or affirm their misconceptions [35]. Further, a meta-analysis demonstrates that students with minimal guidance are less likely to have learned content, and in some cases, show declines in learning over the course of activities [38].

It is possible that allowing learners to make decisions about their own learning will lead to suboptimal outcomes [39]. Returning to our example, our novice pancake maker might decide that they can substitute ingredients, perhaps using milk instead of buttermilk. An experienced cook would recognize that the acid in buttermilk reacts with baking soda to release carbon dioxide in the batter, make "fluffy" pancakes, and attenuate the bitter taste of baking soda. This choice is based on prior knowledge, which limits the set of possible options the learner might choose [40]. Limited prior knowledge often leads to confirming existing biases and rehearsing familiar approaches to solving problems, rather than evaluating and adapting [41]. For these reasons, effective guidance within authentic problems is necessary to provide support for learners.

1.9. *Supports for authentic opportunities*

. One approach to support learning in authentic contexts is "tell then practice" [42]. Telling, or providing some direct instruction, can be highly effective, particularly when it helps students learn methods for constructing their own knowledge (e.g., conducting unconfounded experiments; [43]. Unguided exploration (i.e., pure discovery learning) may increase subsequent exploration and engagement [44] but has not provided evidence for improving learning, [35] creating opportunities for misconceptions to form and suggesting that some direct instruction supports learning. Returning to our example, telling a child the order in which to mix ingredients when making pancakes will define the problem space and increase their knowledge about the process. Explanations help learners understand why these steps lead to better outcomes (e.g., overmixing the batter traps the CO_2, leading to flat pancakes).

A second approach is to provide some initial exploration and then direct instruction, questions, or discussion [42]. In this approach, learners are given an opportunity to become familiar with the problem itself and to acquire tacit knowledge. One method constrains the problem space so that learners work through an authentic-yet-simplified problem to focus on a small amount of relevant information [45]. Another method provides difficult problems that learners are likely to fail before providing instruction [46]. Productive failure has shown evidence of improving learning because learners become attuned to the relevant features of the problem and often show increased motivation to solve the problem on which they previously failed [48]. Allowing a learner to make pancakes with different ingredients provides an opportunity for productive failure. For example, a child may not want to add baking soda to the ingredients, which will yield dense, pale pancakes. A comparison between these and pancakes made with baking soda sets up an opportunity to discuss why the texture and color were different.

Guided play is an instructional strategy that combines elements exploration and direct instruction approaches into a coherent framework [48] allowing for curiosity-driven engagement while constraining it with learning goals through mentorship from a more knowledgeable individual. As such, guided play allows exploration of a problem, collaboration in learning, and support for motivation and emotional reactions during the learning process. Cooking as a family is a prototypical guided play activity. Knowledgeable individuals provide guidance for novices to learn a practical life skill that is deeply embedded in STEM content. For example, making lemonade is a simple recipe for a popular drink. Although the recipe is simple, the process of making lemonade involves the opportunity for a mentor to help the maker learn about concepts such as the nature of solutions (e.g., why do we heat the water and sugar?), pH, and why we perceive tastes as "sour".

1.10. *Social-collaborative opportunities*

Social interactions support learning [49, 50] and can improve learning by bolstering the conditions under which it occurs [51]. Social interactions can increase learning motivation by increasing interest and engagement. For example, mutual collaboration increased students' engagement and learning in a university level course [50]. Social interactions can also help students regulate their emotions while engaged in learning opportunities [52].

During learning, social interactions may occur among peers or mentors, including family members and non-family mentors. Extensive research suggests the presence of mentors improves learning outcomes by providing learning opportunities within a relationship that supports and sustains the learner cognitively, socially, and emotionally [53] Successful mentoring relationships share characteristics of successful caregiving relationships in that both include stability, nurture, responsiveness, and clear expectations [54, 55]. Mentoring relationships help participants maintain their motivation for engaging in and learning content and can help them achieve mastery-learning by: setting goals to learn, improve, and understand setbacks and failure as part of this process [56] helping students monitor their progress by setting goals and monitoring and evaluating their progress [57] and providing feedback from a knowledgeable, trusted source [58].

Mentors — particularly those who share characteristics with the learner — can foster identity, or a learner's belief that they can succeed in their area of interest [59, 60]. Identity is particularly important for students from underrepresented groups [61, 62] Children's identities develop, in part, through an acknowledgement that they themselves are capable of success, but also that a trusted other in their lives also believes they are capable of success [63]. Finally, mentors co-regulate emotional reactions or arousal levels that occur during the learning process by providing coping strategies for students (e.g., helping work through frustration by finding solutions) [53]. There is a range of optimal arousal for learning that is associated with better learning outcomes [64]. Children visiting a zoo demonstrated high levels of physiological arousal (via a heart monitor) at an exciting demonstration with birds of prey that appeared to interfere with their attention [65]. Mentors can help learners regulate their arousal levels into this optimal zone of attention.

Although the evidence presented above demonstrates the value of social-collaborative learning, there are potential limitations to implementing this approach. One potential limitation is that it can be difficult to engage children in effective, collaborative learning [66, 67]. Collaborations are sometimes difficult because they are often ill-structured to allow participants to contribute equitably –and equitable participation leads to the most effective outcomes [68, 69, 70, 71].

Cultural differences in collaboration also exist, meaning the type of collaboration in one intervention may not benefit all children. For example, Indigenous North American children collaborate more effectively than children of European decent [72]. Specifically, children of European decent collaborate by assigning roles and dividing work, rather than by collaborative turn-taking and goal-setting, suggesting a need for possible training intervention. In fact, in many cultures, children see their role as participating in family work and chores [73]. This may suggest that family learning may be particularly effective, especially when such activities align with cultural practices [74].

1.11. *Supports for social-collaborative learning*

Cooking is a common and optimal context for social and collaborative activity [75]. Meal preparation presents a large goal – e.g. a multi-dish meal – with many subgoals – each step to prepare each dish – and is thus ideal for social collaboration. To explore this opportunity, we will first discuss general cooking learning, then STEM-focused learning.

The mere presence of a caregiver during an informal activity increases the duration of and quality of engagement with the activity beyond that of a child on their own [76]. Conversations between caregivers and children do not need to provide exhaustive or even accurate explanations to provide benefits for children. In fact, many explanations that caregivers provide during such activities are incorrect, yet still may be beneficial [77]. Caregivers can help children set goals within activities that guide their subsequent information-seeking [48, 78]. For example, caregivers can ask questions about how or why something occurs (i.e., why oil and vinegar separate in the salad dressing bottle), suggesting goals for investigation [79]. Conversations with children can help guide children to important features of problems and suggest possible explanations [80]. In addition, conversations provide cues for children that help them remember the problem and experience more effectively [81]. The process of generating an explanation, even an explanation that is incorrect, can benefit learners because the process of generating an explanation activates relevant information and prompts an evaluation of coherence [82]. Finally, lacking knowledge of a phenomenon can provide an opportunity for the type of information-seeking that is common in the practice of authentic scientific investigation. Just as scientists seek information about unknown phenomena, children are curious about problems without answers. Not knowing an answer sets up an opportunity for *information seeking*. Depending on the setting in which ISL occurs, caregivers may model information seeking.

Caregivers with greater STEM knowledge help children explore STEM activities more effectively and ask better questions; they provide better support for STEM learning than caregivers with less STEM knowledge [83, 84, 85]. For example, those who held advanced degrees in science reported that family-based experiences and attitudes played a significant role in their interest, engagement, and attitudes about science [84]. This finding highlights an issue with ISL, which is that ISL disproportionately benefits those with greater resources, including greater financial and educational access and flexible work schedules [86]. The results from a large survey of families in the UK demonstrate that although most families would participate in ISL opportunities available to all, they perceive many ISL opportunities as requiring specialized knowledge or resources, making them only accessible to the most privileged [86]. While both of these facets – advanced STEM knowledge and access to resources – pose challenges to STEM-based collaborative learning, cooking presents an opportunity to address them, as we will discuss herein.

1.12. *Culturally relevant opportunities*

Cultural relevance refers to meeting students where they are by making learning pertinent to their lived experiences and cultural knowledge, rather than making assumptions about students' knowledge and values [87]. One example of culturally relevant learning is by connecting learning with familial and cultural sources of knowledge, known as their *funds of knowledge* [88]. Funds of knowledge provide subtle supports that augment learning, such as drawing on culturally-relevant examples, [89] conversational styles, [90] and vocabulary [91] that connect new information to a learner's background knowledge. Evidence from decades of research demonstrates the importance of relevance for effective learning and motivation: it gives students a stake in what is being taught[92, 93, 94].

According to sociocultural theories of learning, children co-construct their knowledge in collaboration with people around them [25]. There are cultural differences in how caregivers teach their children: for example, Maya children often learn by observation and imitation, engaging in participatory learning driven by their natural interests [26, 95, 96]. US children, on the other hand, tend to receive child-directed teaching from caregivers [95]. Children who are accustomed to collaborative learning experiences may be more likely to learn and be engaged in such contexts. Although the language of science becomes highly standardized, links between everyday concepts and prior knowledge are shaped by the vocabulary children bring to learning contexts [97]. For example, when Mexican-American families make tortillas in the family home, one step in the process is the creation of small, dome-shaped balls of dough called *testales*, a term that does not have an exact, English equivalent [91]. ISL approaches that connect with learners' funds of knowledge by linking to culturally relevant knowledge, conversation, teaching, and vocabulary are more likely to be relevant, sustainable, and ultimately successful. And the presence of a diverse group of learners increases the richness of STEM experiences for all participants [98].

1.13. *Notes on cultural approaches*

While the evidence above demonstrates the value of culturally relevant learning opportunities, it's important to note some caveats in their creation. If those who develop activities do not know the culture in which they will be implemented, those activities are less likely to be effective [99]. One must know a culture to align activities with that culture's funds of knowledge [88] and create successful learning opportunities [87, 89]. Accordingly, learning facilitators should also beware of using materials –particularly assessments –that are assumed to be universal, since they are rarely free of cultural bias and may complicate learning evaluation [100].

1.14. *Cooking supports the benefits of ISL*

Cooking is a truly authentic learning opportunity that one can do independently or with others, with clear links to both cognitive and sociocultural aspects of ISL. It provides repeated learning opportunities woven, by necessity, into daily life; as humans who must eat, we all have some background knowledge about food and cooking. This circumstance makes cooking a promising activity to promote engagement in family homes, accessing both caregivers' background knowledge and children's familiarity with food. Cooking can become an example of guided play for families, in which caregivers are STEM mentors who guide children's experimentation using their knowledge and skill. For example: in a naturalistic observation of caregivers and children baking cookies, caregivers demonstrated their unique ability to scaffold learning. Specifically, caregivers helped children monitor their actions and were less likely to provide supervision when children showed greater skill [101].

Importantly, cooking, more than most other ISL activities, is a cultural and intergenerational practice frequently shared within families [102]. It occurs in every culture [103] and is even an important way to transmit cultures between generations. While the types of tools, techniques, and ingredients vary across cultures, cooking is nearly universal in its centrality to family and social life [102, 103]. In many cultures, cooking is intimately linked to the transmission of cultural knowledge about science. For example, the people of Cuyin Manzano, Argentina, use cooking as the primary means through which they share botanical knowledge across generations [104]. This knowledge transmission occurs through conversations during cooking that focus on ingredients and their histories.

Cooking is also an exemplar of guided participation, in which children learn culturally relevant knowledge by participating in everyday activities with their caregivers [105]. During guided participation, information is not merely transmitted but is co-constructed through the process of engaging in culturally relevant activities [105]. Because there is not just one way to share and learn information, guided participation can include all the approaches described above, including direct instruction, productive failure, and guided play.

Finally, cooking activities are inherently structured; there is an explicit goal, a natural start, and an end, and typically a specific set of instructions (i.e., recipe) that guide you to reach the goal. Recall that setting goals helps learners allocate their limited processing resources more efficiently and achieve more [57]. Goal-setting is also one of the foundations of self-regulated learning because a goal is necessary for planning actions, monitoring progress, and evaluating one's success [106]. Because goals are inherent in the action itself, cooking can provide an opportunity for children to learn self-regulated behavior in an everyday context in which trusted caregivers can help them learn and evaluate their progress. In sum, cooking fully encompasses the benefits of ISL and provides a rich and promising context in which to study learning –a context that may address limitations that other ISL activities face.

1.15. *Cooking addresses ISL limitations*

Earlier, we explored the limitations of some ISL activities –including scalability, authenticity, and cultural relevance. As a context for ISL, cooking overcomes these challenges. It is *scalable* because it already takes place in most family homes in some way, is a critical and embedded daily activity, and may not require additional equipment. It is *authentic* in that it produces a tangible result with the potential to fail: cooks can produce flat pancakes, rubbery eggs, or burned tortillas. And as we've shown, cooking is also *culturally relevant*, offering natural links to learners' cultural backgrounds and accessing caregivers' knowledge and lived experience [74].

Two other common limitations of ISL are interest and time. Studies show that cooking appears to pass the interest test, viewed positively not only by children but also by older family members [107]. Children often have positive views of cooking and food preparation, and these views are more positive when children are part of cooking with family members [102]. Time may be the one common ISL constraint that cooking is unable to overcome – but it at least has the advantage of being a necessary daily activity, providing ample opportunities for STEM engagement through simple, time-efficient supports we explore.

1.16. *How to add STEM seasoning to cooking experiences*

Having a caregiver who is a chemist, physicist, or biologist would certainly help children learn about science through cooking, but (of course) such instances are rare and, most importantly, unnecessary. Though caregivers can provide learning opportunities by including children in cooking activities [76] they can augment STEM learning while cooking by providing guidance, as we shared above [27, 79].

Conversations are one promising way to incorporate STEM into cooking. Recall that incorrect explanations are common during activities [77] and that simply generating an explanation (regardless of its accuracy) benefits learners [82]. Cooking encourages natural conversations as cooks – or learners –undertake series of actions that vary in length from a few seconds (e.g., adding spices to a soup) to a few minutes (e.g., chopping up a vegetable) to multiple days (e.g., raising dough overnight). This time offers intuitive opportunities for STEM conversations: about specific ingredients (e.g., is a tomato a fruit, and why?), processes (e.g., why does toasted bread turn brown?), and ingredient combinations (e.g., using baking soda instead of baking powder). Such conversations can help children generate explanations [80] and spark curiosity about the process of cooking and science more generally.

Beyond providing prompts and initiating conversations, caregivers can encourage exploration and provide guidance through the "tinkering" process inherent to cooking. A recipe provides step-by-step instructions for how to achieve a goal, but experienced cooks often modify recipes through trial and error in ways that improve them. One example is the origin of the Toll House cookie, a popular chocolate chip cookie [108]: Ruth Wakefield, owner of the Toll House Inn, was experimenting with cookies when she ran out of her normal ingredients. She crumbled up a semi-sweet chocolate bar into a sugar cookie recipe and was surprised that the chocolate did not melt, but instead added a unique crunch to the cookie. Families can modify recipes to adapt foods for a gluten-free aunt, lactose-intolerant father, or toddler who refuses to eat anything orange. Experienced cooks even go beyond recipes to create dishes from ingredients at hand, becoming a kind of household *Iron Chef*. Caregivers can create STEM learning opportunities by helping children gain comfort and skill with tools, processes, and ingredients, then allowing them to explore and experiment. This kind of sensitive guidance –providing guidance only when needed –is associated with higher levels of child engagement [101] because it provides feedback that meets children where their current knowledge gaps are.

Although there are not many published ISL activities focused on cooking, one case study of at-risk middle-school children in an afterschool program does provide a relevant example. The authors found that the program not only taught specific cooking skills (e.g., measuring), but also increased self-report of engagement in science class in school [16]. The authors stated that it was the connection to cooking at home, a culturally relevant context, that helped maintain interest in learning. The program incorporated direct instruction (following recipes) and creativity (choice days, in which students could ask and test their own questions). This example suggests promising work to explore further.

1.17. *Instantiating STEM in a cooking activity: French toast*

To illustrate our hypothesis that cooking is an ideal ISL context, let us consider a possible project to engage children and their families in authentic, culturally relevant science: making French toast. French toast is a popular dish around the world [109] that uses few ingredients (e.g., bread, eggs, and milk), requires few materials other than a heat source and a pan, and demands minimal knowledge of cooking techniques.

A bit of global background: although its exact origins are not known, the first records of French toast appear during the Roman Empire [109]. Today, people around the world enjoy the dish, with versions in Algeria, India (Bombay toast), and France (*pain perdu,* or lost/stale bread). Each cultural recipe has its own variations and toppings as cooks connect to family and cultural traditions: Brazilians, for example, serve *rabanadas* as a traditional Christmas dessert, while Hong Kong cooks fill *sāidōsí* with peanut butter or jam and serve it in tea houses.

Cooking French toast involves a surprising number of conversation-worthy science concepts for such a simple recipe. A caregiver making French toast can ask questions about ingredients, processes, and outcomes that engage their child in observation and hypothesizing. They might also ask "wh-questions" (Why, What, When, etc.) to engage children, start conversations, and invite detailed responses [24, 79]. Questions that increase interest and engagement could include, "*Why do you think stale bread works better than fresh bread?*" (seeking explanation); "*When do you think it is done cooking?*" (predicting); "*What do you smell/see while it is cooking?*" (noticing); and "*What is different about the cooked and uncooked bread?*" (comparisons). Parents may know the answers to some of these questions. Other questions are more open-ended, and parents may model good information-seeking by asking children to work with them to find answers.

Making French toast can also help cooks learn more complex information, such as the chemistry of ingredients. For instance, the unique, folded structures of proteins in uncooked eggs change as eggs are heated. Making French toast involves a process of browning –known as a Maillard reaction – which occurs when heat allows sugars and amino acids to combine, produce browning, and create unique flavors and smells [110]. The Maillard reaction, which occurs in many different kinds of food, can be transferred across multiple food types (such as toast, steak, and coffee).

Caregivers and teachers can add STEM reasoning by asking questions initially, then guiding children through observation to help them notice relevant features (e.g., How is the egg different after it has cooked? Why do you think it is more solid?). Simply asking questions and engaging children helps children learn about STEM effectively by understanding and expanding the limits of their current knowledge. Just by working with a child, a caregiver can increase that child's engagement [76] help them set learning goals [77] help them note relevant features [80] ask questions that spur curiosity [48, 79] and help them remember information [81]. Most importantly, caregivers don't always need to have all the answers: it is most important to help children generate explanations, regardless of their accuracy [82].

1.18. *Benefits of cooking beyond STEM*

In addition to the points we have mentioned, cooking is an ideal ISL context because it generates a host of other benefits to children. Cooking is a rich context for sharing cultural practices, dietary traditions, and health information across generations [111]. Cooking as a family has been linked to healthier eating. A survey of over 3,000 fifth-grade children found that children who participated in family meal preparation ate more healthfully, with more servings of fruits and vegetables, than those who did not [112]. Children also were more likely to demonstrate self-efficacy for choosing healthier options [113]. Similarly, in a study with 924 caregiver–child (9–11 years) dyads, caregivers who reported their children were more involved in planning, shopping for, and making meals were more likely to have children who reported liking vegetables [114]. Further, children who reported *liking* vegetables were more likely to *eat* more vegetables at a 10-month follow-up appointment. Finally, the more middle-school children and adolescents participated in meal preparation, the more healthfully they ate, consuming fewer high-fat foods, fried foods, and carbonated beverages; just helping to shop for meals did not demonstrate these positive effects [115].

In addition to healthier eating, cooking is related to less pickiness in children. A survey of 305 caregivers found that children (6–12 years of age) who enjoyed cooking more, were less likely to be picky eaters and more likely to enjoy eating [116]. Experimental studies support these findings. Young children who helped prepare a meal ate more than children who did not [117, 118]. Similarly, 7–11-year-old children who participated in cooking three unfamiliar foods containing vegetables were more likely to try those foods than the control group [119]. Even beyond the nutritional benefits, adolescents with greater self-reported cooking skills had fewer symptoms of depression and higher levels of mental well-being [120]. Moreover, these adolescents were more likely to feel close to caregivers, reporting higher levels of family connectedness.

1.19. *Summary*

We have suggested that cooking is a promising setting for family engagement in informal STEM learning. ISL can support and augment the natural curiosity of children and families to understand the world around them. Effective ISL opportunities meet learners where they are by providing authentic, social collaboration in culturally relevant activities. Cooking is a culturally relevant, everyday life experience for families that can support learning about to physics (e.g., why does popcorn pop?), chemistry (e.g., why do eggs solidify?), and mathematics (e.g., how do we double 2/3 of a cup of sugar?). Most importantly, prior knowledge of these fields is unnecessary as caregivers engage children during cooking: caregivers can be ideal STEM mentors in this context, and family kitchens the ideal labs. Simply asking questions, supporting children's curiosity, and modeling information-seeking (e.g., let's look that up!) during family cooking can provide significant benefits for children's learning, motivation, and emerging identity that can lead to life-long engagement with STEM. When we examine cooking as an ideal ISL context, we believe that the proof here is indeed in the pudding.

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