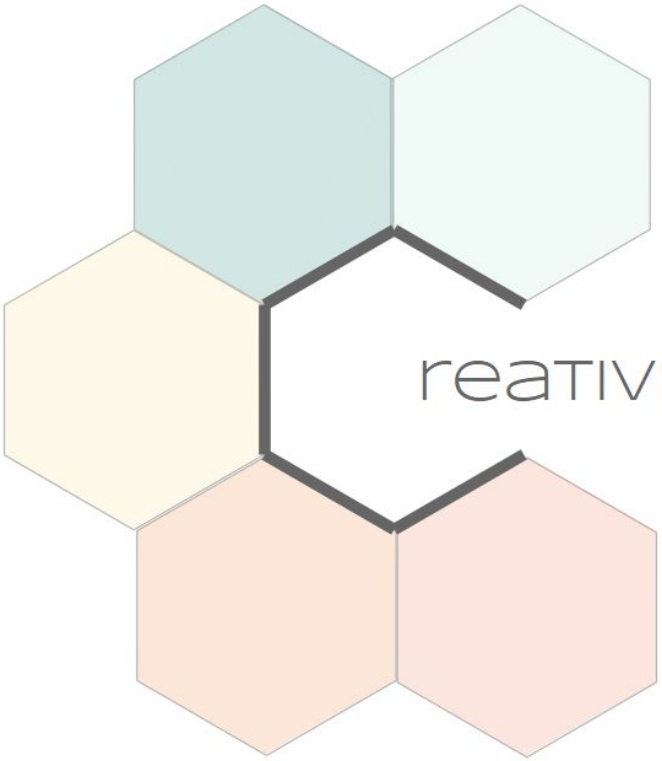

reativity Roadmap

A Handbook to Operationalizing the World's Most Dire Skill

Sponsored by:
The Larry & Helen Hoag Foundation

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MIND Research Institute is a nonprofit, social impact organization committed to transforming education and closing the experience gap for all learners. MIND's flagship program, ST Math, is a PreK-8 visual instructional program that leverages the brain's innate spatial-temporal reasoning ability to solve mathematical problems. ST Math's unique, patented approach provides students with more equitable access to deep conceptual learning.

Our work on creativity was funded by the generous support of the The Larry and Helen Hoag Foundation allowed us to find our own creative breakthroughs and solutions as we took a deep dive into the neuroscience of creativity and the operationalization of those insights. Our goal is to build student creative problem-solving capacity by having students build their capacity to create products and solutions that are actively used by others in real-life. This is of particular salience when applied in mathematical context. MIND is forever indebted to their commitment to our partnership. Without their support, this document and our broader work on our MathMINDs initiative would not have been possible.

Introduction

For 21st Century education, nothing is quite so relevant as creative problem-solving.

The top three 2020 skills give a clear snapshot. The problems we are trying to solve are bigger and harder than previously thought. To tackle these problems, we must be ready for the hard work of creative problem-solving.

There's little dispute that teachers want students to think for themselves, to try things out, to learn from mistakes, to never quit, and to keep going.

Sir Ken Robinson in his 2006 TED Talk said it succinctly, "Creativity now is as important in education at literacy."[13]

From the classroom to the researchers to the workforce, this century needs creative problem-solvers. Making the case for developing students' creative problem-solving capacity is easy. The real question is: How do we develop it? In answering this question, we tackle several huge questions.

- Why are some people so creative and many of us seem not to be?
- How do we measure creativity?
- Why do some people have amazing ideas out of what seems to be nowhere and why can't I do that?

This document focuses on answering these questions via a model of creativity we call the Creative Engine (CE). We will build up the CE with smaller models first and discuss what pitfalls they tend to create and how we can minimally add to the CE to help solve that problem. This way, we look to create the simplest framework for becoming more creative.

Chapter 1: Photosynthesis

Some people seem to be lights-out creative, turning everything they touch to gold. Some of us see nothing but a blank wall. It's a solid brick wall we can't break through. We know creativity is on the other side, but we aren't the ones to get there. For some, that light at the end of the tunnel - it's a train. Creativity is just not for us. We may even say "I don't have a creative bone in my body".

At MIND, our mission is to equip all students to mathematically solve the world's most challenging problems. This mission only happens if everyone can creatively solve problems and can take intentional steps to boost that creativity. To us, creativity is for everyone. Perhaps you and I won't be Einstein, but perhaps we are closer than we think. And even if not us, our students are full of potential and we can bring out their potential even if we were afforded that chance.

The world needs ALL of our students to put their brains on challenging problems. Not just those who are gifted, who have private tutors, or who join a robotics team. Every single student has everything they need to solve challenging problems. It's up to us to put those assets and potential to use to make great change. For this reality to put into practice, we need to understand creativity and how to operationalize it.

Before getting into creative problem-solving, let's back up and look at why, without training or effort, some kids are seemingly creative and others are seemingly not. We may have even said or heard something like "My middle school, kids lose their creativity".

Humans have the ability to photosynthesize creativity. With the right conditions, we are like plants that grow. With the right soil, amount of water, and sunlight plants do their thing. With creativity, humans will too. Without these conditions, their creativity wilts.

The good news is that the "bar" for what constitutes the right conditions is fairly low in that humans are robust flowers finding ways to thrive even outside ideal conditions. This is the first of many messages of hope. None of us have to be perfect.

I pause for a moment and reflect on creating the right conditions. With plants, we need to know what healthy growth looks like. Then, we add more or less sunlight, more or less water, etc. If the plant reacts as we had hoped, we are moving in the right direction. If it continues to wilt, we know something in the conditions need to change.

The first question then becomes, what are the analogous attributes in a student acting creatively? With an answer to that, we can then work to change the contributing factors and look again back at the impact it has on the student.

Baseline Attributes

There are four primary elements that show creativity photosynthesizing in our students.

Just Enough Knowledge

The student engages before they know everything. They feel they have just enough to dive on it.

It is difficult for us to make creative breakthroughs in computer programming if we don't have some understanding of coding. We will be much less likely to make creative breakthroughs in education if we don't have some knowledge of teaching. But, too much knowledge and expert bias creeps in. Why is this?

The reason for getting started before knowing all that much is that in a creative problem-solving environment we never have all the answers. If we did, the problem would

be solved. Creative problem-solving is inherently about learning as you go, each success or failure gives just enough learning to keep at it. While yes, students need some baseline knowledge, they don't need to know it all, nor even all that much. In our attempt to find a cure for cancer, we don't have all the answers. We can't. If we had them all, we would have already cured it. If we wait until we think we know it all before we get started, we won't go very far.

This is precisely why expert bias often stops us in our tracks. We know so much about the situation that everything is well-rehearsed. There's not as much amazement and fascination as when we knew much less. As a result, we spend less and less time searching for novel connections or insights that others have missed. We are simply blinded by the sheer volume of knowledge and years of experience we already have. We have deep, ingrained habits of thought that are hard to change.

A student should dive on it before you've told them everything. They aren't waiting for the problem to be well-defined and the strategy for solving it well-rehearsed. They learn as they go. This constant search for learning and connections is the fruitful work that builds deep insights. In chapter 3, we talk more about what we can do to help students demonstrate this first attribute.

When do we have just enough?

The simple answer is that we have just enough knowledge when we feel empowered to have a go on our own. Suppose you've never shot a basketball, but you are asked to try a free through. Are you gonna go for it, or do you want to make a few closer shots first? Whenever you want to try that free throw and feel you can learn from your shot and eventually make the basket, you have just enough knowledge to get started. If this is too long of a shot, then you may have just enough to start on that short shot.

The ideal answer to just enough is to have very little at all - none, if possible. You know nothing about rock climbing but are willing to try and learn, perfect. You've already satisfied this first attribute. Pragmatically, kids will generally want some baseline knowledge. When giving that knowledge, do what you can to break assumptions by pushing them outside of their normal modes of thoughts. We offer more on this in the appendix as we discuss examples.

In our effort to get kids started, we may try to teach an entire process before they problem-solve for themselves. We explain the entire rubric in painstaking detail so they know what's coming. In our best efforts, we end up training this attribute out of our students.

As a quick example, we don't teach kids to drive a car so they can play with their pedal driven trike bike. Why? Because it's overkill and not needed. In the same way, we want kids to get started as quickly as possible. Less is more.

With a goal of getting started with just enough knowledge,
it's important that we level-in the learning.

Through creative problem-solving students will turn just enough knowledge into deep insights that are undiscoverable by any other means.

Intrinsic Motivation

Having some baseline knowledge doesn't take us very far if we don't want to put forth effort. We know how to do the dishes, but sometimes we just don't want to. We may have the knowledge of changing a tire or of long division, but may simply not want to do it. Creative problem-solving requires grit and resilience. These feelings can't be coerced.

A student doesn't need to have the full measure of grit before engaging in creative problem-solving (CPS) because the act of solving the problem itself builds and matures one's resolve. Like the baseline for deep and novel insights is "just enough knowledge", the seed that becomes grit and resilience is intrinsic motivation.

Intrinsic motivation is exactly as advertised. It's a self-selected willingness to put for effort in the task. Take a hobby, for example. You play golf, trim the roses, take photographs, make wooden art, or take on any action not formally required by day-to-day life because you chose to.

It is important to note that it is exceedingly difficult to have intrinsic motivation on required day-to-day tasks. When something feels required by life, we have to do it whether we want to or not. We feel we have no choice.

However, we can squeeze out some intrinsic motivation out of everyday life. If I have to shovel snow, for example, I would at least like to "own" that chore. I don't want someone

hovering over my shoulder telling me what to do, when, and how. In other words, autonomy over how I tackle the chore aids intrinsic motivation. If we can't choose the task we must do, at least we can own how we accomplish it. One great way to do this is have students work on a problem before they know what to do. They have no choice but to own their actions. This only works, however, with informative feedback. If we can't learn from what worked or not and why, then owning one's action is also not motivating. We feel like we can't learn.

In math class, this is often exactly how students feel. We teach them the algorithm and then ask them to repeat. This offers very little student choice over how to solve the problem. As a result, intrinsic motivation fades and process-reliances bubbles to the surface. Students wait for the teacher to spell it out or to spoon feed them on a silver platter before tackling a problem. This is a clear sign that intrinsic motivation is lacking. Intrinsic motivation feels like recess or a game. You want to do it. It'll be hard, but you want it that way.

Another boost to intrinsic motivation is to remove external reward.That is, sometimes we actively inhibit intrinsic motivation with extrinsic factors. This happens, for example, when our family math nights have raffles in the hopes of driving interest. Whenever you motivate a task by something outside of the task itself, intrinsic motivation is replaced with extrinsic motivation. This is one of the most common creativity killers. More on this in the appendix.

Another extrinsic motivator, is the expectation of evaluation. Math is only ever talked about or engaged with in the context of grades, worksheets, and algorithms. In sharp contrast, literacy is full of student-books of all types and for all ages. There's rhyming stories, documentaries, spelling books, romance novels, spy mysteries, and the like. All of these are engaged as a family because people want to and because families value the task itself. Math needs more experiences like this so that the story of mathematics includes noticeable experiences of intrinsic motivation. We can't continue to rely on dense textbooks, worksheets, and high-stakes exams. Math needs to take a page out of the playbooks of reading, or sports, or food, or music and offer much more than singular content-types. Math in the classroom will benefit when outside of the classroom math flourishes in people's hearts and minds.

Expectation to Grow

Intrinsic motivation is a huge component, but it doesn't mean that learning will happen. As mentioned at the beginning of this chapter, students need to continually be learning and growing. Sometimes, we can be drawn in to a task - even our favorite hobby - but we quickly plateau. We intrinsically do it, yet we aren't growing. Creative problem-solving is about breaking plateaus. It requires non-stop growth. Just because we feel stuck in the mud doesn't mean we'll stay there. Creativity requires that we relentlessly pursue growth and improvement even when we feel that all hope is lost.

As before, students don't need to have the full measure of devotion to the problem right out the gate. What they do need is a willingness to grow. Even better, they should have an expectation that they should improve. A task without a sense of growth is demoralizing. We need to grow and we need to feel that growth. This all starts when we tackle a new challenge and tell ourselves that we will grow. With this expectation, we'll zero in on more and more impactful ways to grow. One example is the concept of deliberate practice formulated by Anders Ericsson in his book *Peak*.

But as a baseline, we don't need to know all the best techniques for every possible type of problem. We simply have an expectation that we must grow and improve or we are wasting our time. Maturing this expectation becomes a multi-year endeavour. Without direct learning moments, there's no sunlight for creativity to photosynthesize.

One reason we may not have the expectation to grow is the task itself. If you are playing a basic math game, for example, that feels fairly simple then we have no expectation to grow because the experience makes it clear we don't need it. If we've driven home from work a million times, are we pushing ourselves to become a better driver? If instead on my drive home I pushed my skills, perhaps by staying as close to perfectly center in the lane as possible, now I have a chance to learn and improve.

Another reason some of us don't have the expectation of growth is that learning and growing can make us feel vulnerable. Imagine the student who just finished a drawing of a horse and they show it to you. Deep down, they want you to validate them. They are great, they did a good job, you are proud of them. Often, we want validation, not vulnerability. We share ideas, not to get feedback, but approval. Validation is not inherently evil, but when it comes to creativity we will almost push beyond what people "get" right away. We may even experience immediate push back. This is a good thing. Immediate acceptance of an idea is nearly always a sign that the creativity was not involved.

Despite our best efforts and purest intentions, sometimes it's our top performers that are the most negatively impacted. When it comes to equity, sometimes our A-students have the least equitable creative environments. This is because, any of our A-students are looking for a good grade (validation) not a learning moment. The continual pursuit of grades and achievement is not conducive to creativity.

Another very practical concern is busy work. If we are giving kids assignments to keep them busy or constantly doing the chores of life, we struggle to value the time and effort it takes to embark on a task that requires failure and learning. It is supremely difficult to be creative when life is full of partial attention that ends up filling our minds like a spoon-full at a time fills a bathtub. It's important to give kids down time and space to put the tug and pull of school life aside. Not only is this refreshing, it allows us to be creative.

Purpose Beyond Oneself

A student loves basketball. He plays every-waking moment. He spends effort focusing on his free throws and layups. He likes basketball, but more importantly, he values the effort he puts forward to get better. He eventually becomes the starter of the high school team and has a gaze set on the pros. In the NBA, he gets some floor time, but doesn't really stand out.

Why are there the best of the best playing in the NBA, but yet Kobe Bryant and Lebron James are standouts among the pros? One reason is drive, sure. But we've already answered that with intrinsic motivation and a relentless pursuit of growth. An insane drive alone isn't enough. The best become the best because there's a purpose bigger than them.

They play for their teammates or their coach. They play for the moms and dads spending hard-earned money to give their son or daughter an exciting time at the stadium. They play for all those that come after them so that the younger generation can see what is possible and find even higher heights. While a relentless drive is important, without purpose, it's a cake without icing. That doesn't make for a great birthday.

Value + Purpose → Mastery

When you are driven by something bigger than yourself, you are a part of something significant. You feel so alive when it's not about you, but about other people. This kind of

purpose, supplements drive and carries it along when times get tough. When you want to quit and give up, when you feel that you don't have what it takes, when you are demoralized and want to curl up in a ball, it's your purpose that carries you. When drive fades, purpose shines. In creativity, you need to find your purpose. This is almost always in the form of other's-focused purpose.

One reason this kind of purpose is important is mastery. But in a tie for first place, this purpose is important because solving the world's most challenging problems will require you to come face to face with your believed ceiling. You will feel like you aren't good enough, you can't do it, you've been defeated, you are not the right person to do it. If you've never felt that way, you aren't pushing yourself hard enough. If you have felt that demoralizing sense of being not good enough, embrace it. As weird as it sounds, you aren't pushing hard enough until you've felt defeated and pushed on anyway. It's like the football team down in the 4th quarter playing with passion and effort. Creativity, though, is even better because there is ALWAYS a come back. When you don't feel that this is true, it's a purpose bigger than you that is your only fuel.

Students don't need, as before, the complete maturity in this. But, they do need a seed that fuels them when they are stuck and demoralized. To creatively solve a challenging problem that does good for the world, you need to be doing something for others.

The science fair project all about my presentation skills and that gives grade for hypothesis testing could be an awesome project. But, where's the purpose beyond my own grades? We often make a stab at purpose, by saying real-world. Maybe if students solve a real-world problem, they'll be motivated. This can have some benefit, but rarely fuels us through sustained effort and uncertainty. More on real-world problems in the appendix.

A better strategy when it comes to building creativity is to set up the project so that students produce something for others to use. For example, perhaps in math class you ask a student to create an acronym for PEMDAS to hang on the wall. This is not an inherently bad task, but it's missing purpose beyond oneself.

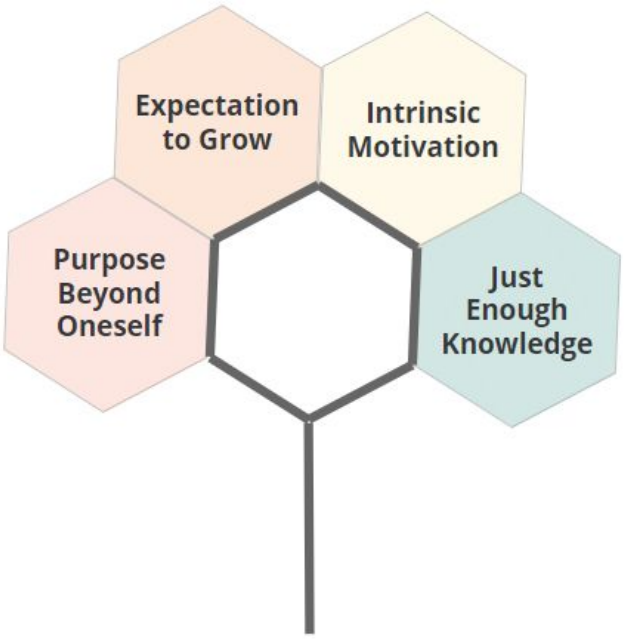
Instead, we could implement a simple change: *Create an acronym for PEMDAS that makes the front office staff laugh.* Now, you aren't just saying "Pink Elephants Mostly Do Annoying Stuff", you are thinking about what makes people laugh, who the front office staff are, what do they like, etc. It would be even more motivating if the front office staff recently went through something challenging and could use a laugh. But regardless, we don't need

monumental changes. As we'll discuss in Chapter 2, it's better to iterate an idea than to toss it out wholesale.

Don't dumb all your projects and start from scratch. Perhaps there's a simple and insightful tweak that does the trick. To find out what those tweaks are, sometimes we just need to be aware that purpose is more important than practical, even real-world, benefit to oneself.

How do I Implement this in a Practical Way?

Without these four attributes in place, it's hard to be creative. The reason some of us appear to be naturally creative is a combination of nature and nurture allowing us to embrace these attributes intentionally or otherwise.



Without meeting these four thresholds, creativity will wilt. But, the good news is that (a) we don't have to be perfect in all of them and (b) the bar is not out of reach. In many ways, the answer is to get ourselves out of the way. Too often, we simply design these out of learning moments.

But, this does raise an important question. How do we continually improve at making these four happen?

To do this, it's nice to think about these four in a simple way. The single most important personal characteristic that predicts creativity is openness to challenge. When you want something new and unfamiliar to be challenging, then you are open to challenge. If you can do this in a social setting you introduce purpose and have struck gold.

You don't have to be a starving artist nor an eccentric billionaire to be creative. You can become more creative simply by embracing the new the and the uncertain. Take up something challenging for you. You could learn to drive stick shift, take your first rock climbing lesson, learn to ski, paint your house on your own.

The beauty is that openness to challenge is transferable. You can practice it in any activity and see improvement in others. One reason we don't see transference, especially in math, is because math experiences design creativity out. Students, then, can't photosynthesize it in mathematics. Another reason is that most don't have the mindset or awareness that being open to challenge is so important. Armed with this knowledge, you can take on any tough task and embrace it. When you do, you'll see dividends.

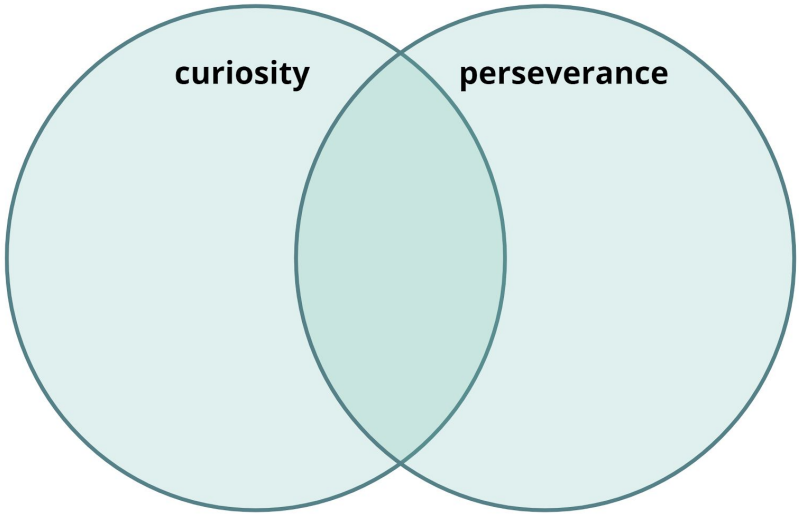
The key though is taking up something that is hard for you to do. You can't throw a ball to save your life, great. That's a challenge. Perhaps you are learning to ski and it's easy for you. Rather than pat yourself on the back, push yourself. Get out of your comfort zone. It's easy to think that throwing a ball or sliding down the snow doesn't help you be a better teacher. Truth is, if it helps you become open to challenge, it actually does help. It's incredible how transferable openness to challenge is when we are intentional about it.

This has a few important implications. First, students need deep and diverse challenges otherwise they only accept a singular type of challenge. Second, action beats exposure. You may take a child to a STEM museum, but they aren't doing anything challenging.They simply walk around gaining passive exposure. Exposure is not a bad thing. But, action is better. To build creativity, students need active environments. You can't be open to challenge with something challenging to do. You can't do something challenging without putting forth effort. Passive environments offer little to no challenge. Action requires investment of emotional and physical energy. Exposure requires very little. Without effort and investment, you aren't truly open to challenge because you aren't being challenged.

So great, we are looking for students to demonstrate and openness to challenge. But, how can we design for this to happen? How can we quickly assess if it's happening or not?

Openness to challenge manifests itself in two primary ways - an intense curiosity and a seemingly limitless perseverance. Based on research, these are the two most important mindsets required for being creative as they are most closely related to openness to challenge. These are easier to look for. If a child is doing the worksheet (perseverance), but doesn't ask a single question or is simply going through the motions, there's no curiosity. If you are at a math or STEM night and kids are bouncing around from table to table

(curiosity), but only stay for 1 to 5 minutes there's no perseverance. We need to find a student simultaneously demonstrating both. It's much easier to find examples of curiosity without perseverance or perseverance without curiosity. It's also easier to design for one without the other. For example using "cool-factor" and calling it curiosity, or using "rigor" to count as perseverance. You'll have found the sweet spot of chapter 1 if you can see both curiosity and perseverance dancing with one another as if they couldn't possibly exist without the other.



Conclusion

To see creativity photosynthesize, we must ensure that all students access ongoing, equitable, and diverse challenges that they engage with voluntarily, with sustained effort, and ideally in social settings. When an openness to challenge becomes a socially expected behavior, we've built a culture of creativity. WIth this in place, we can now see creativity photosynthesize. When you do this, all four attributes are sure to appear.

Self-involvement on a task is also helpful, so don't shy away from time alone - reading, solving a puzzle, etc. This has a time and place as well. But, when engaged socially, the students themselves become the change agents. This makes a more lasting, sticky culture around creativity. With this culture in place, creativity is photosynthesizing. Now we are ready to begin pruning ourselves like a gardener trims for plant health.

Chapter 2: Pruning

Making the decision to act creatively is often made below our consciousness and can be easily reversed. In the blink of an eye, kids can jump right out of this decision and shrink away or freeze up...adults too. Creativity needs to be cultivated and given space to be put to use. It remains very fragile, especially in mathematics, for quite some time - years.

If step one is to allow creativity to photosynthesize, then step 2 is to prune it for growth. Plants are not conscious and thus can't prune themselves. But, as conscious creatures, we can learn to prune ourselves for creative problem-solving.

At its simplest, self-pruning looks like productively managing missteps. More than the rest of us, the highly creative people

- are willing to make mistakes.
- are willing to see their own mistakes and call them out.
- are willing to change course when they see a mistake.

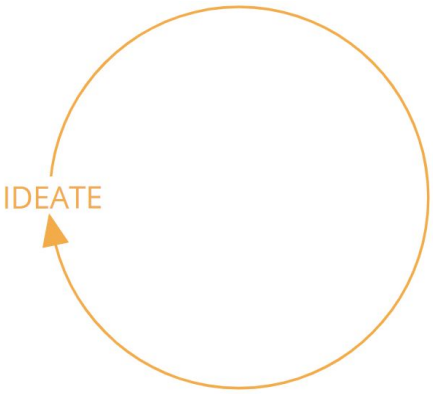
While many of us are trying to avoid mistakes (and in some cases like driving a car on a narrow mountain road it's a good thing) creative people aren't at all hindered by mistakes. Rather than avoiding mistakes they embrace them and mature into desiring early mistakes. The best creative problem-solvers tend to solve the problems better than we do because they fail more often and learn more quickly.

So, let's talk through how many of us tackle a new problem and how we can develop our own ability to solve it creatively. We start with the most obvious concept related with creativity (ideation) and then add to the model only as pruning is needed. This way the model stays as lean and focused as possible. Otherwise, we end up making something unwieldy to understand and thus impossible to implement.

Instead, let's be much more surgical and add to the model only when pruning is necessary.

Ideate

Most of us see creativity as coming up with a big idea, or one great insight. We fall in love with big ideas. We love big ideas. We romanticise the loan genius. We think that if we ideate over and over, we'll eventually land on the motherload. The problem that we run into is that no idea is guaranteed to solve the problem.



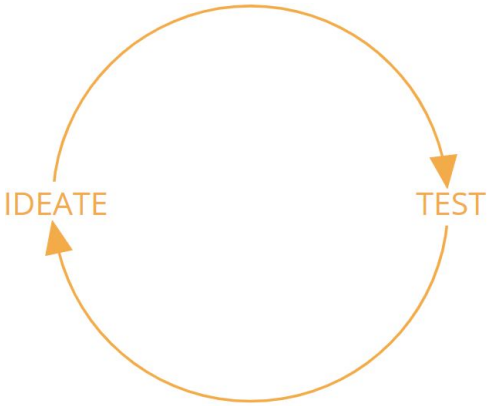
The famous 2,000 attempts to build the light build weren't just random or different attempts for no reason. Each one built on top of the successes and failures of prior attempts. In the same way, creative problem-solving is about us directing our own learning.

We must have our eyes wide open in full expectation of learning something and putting those new ideas to use. If we merely ideate again and again, we fall into the trap of thinking that creativity is strategy-free hard work followed by a stroke of genius.

It's time to quickly prune this misconception. We need to introduce testing out our ideas.

Test

Creativity requires that we fall out of love with big ideas and in love with iterating on what we have. To build our creative muscles, it's better to start with a bad idea and find ways to make it better than it is to start from scratch with a better idea. This is because we need to learn to improve something otherwise, we get the toss-out effect. A student tries out their idea, it doesn't work, they toss it and start again.



While testing is important, we now see an immediate misconception to prune. If we only ideate and test and re-ideate and re-test, it's easy to start from scratch every single time.

Instead, we need to test to find strengths and weaknesses and then decide what to do about it. In order to make the simplest, most useful pruning, we need to explore testing a little more.

If we don't test out our ideas, we cannot be creative. But, if we test without intentionality, we fall into the same misconception as before. Namely, "Creativity is about big ideas. The idea should just work or it's not a good idea. So, when I test my idea, I need to see if it's working or not. If yes, my idea was creative. If not, it's a bad idea and needs to start over". This misconception, even if subtle, is quite a common one for our students. To figure out what to do about this, let's talk through a few well-known types of tests.

The first kind of test is to have some barrier to entry. When I go to the DMV and take a driving test, it's not time to be creative. The test exists as a benchmark so that the DMV has some degree of confidence in my knowledge of driving. This filters out clearly unqualified candidates. There's no expectation of using the test to iterate.

There's also scientific tests. We could conduct an experiment to test out our hypothesis. That helps us answer yes/no or to reject or not. But, often, it doesn't tell us why. Why was cookie A better than cookie B? Hypothesis testing helps make a decision between two options, but then we are done. We have our answer. As above, there's no iteration.

We could conduct a statistical survey and capture all kinds of data. The data could tell us if the solution worked or not, but it often ends up being information to also justify a yes/no answer. Do we reopen schools or not during the pandemic? Do we give a timed exam or not? There are all kinds of important yes/no questions. But that's not quite what creative problem-solving is looking for either. Creative problem-solving requires we put the test to use and iterate. There's nothing wrong with using data to make a decision, but that's not creativity.

Beyond having data to make decisions, there's something that all of the useful tests in the context of creativity would ideally produce for us.

Insight

If we reopen schools, it should be for an insightful reason, not mere ideology. Same if we keep them closed. If the airbags on our prototype car didn't perform as anticipated, why? What went wrong? In every test, we want to see deeper than the statistical numbers so that we have an idea of what to do to fix the issue.

Jay Baer, on the Hall of Fame for Marketing says it this way

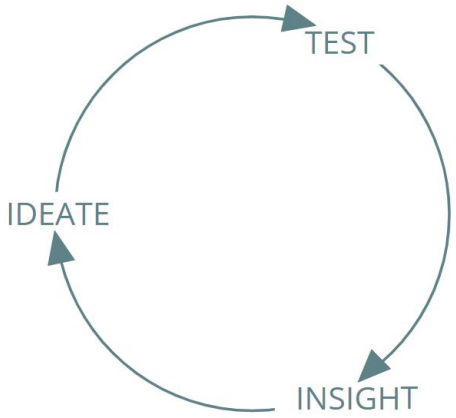
We are surrounded by data,
but starved for insight.

You can't be starved for something you don't need. Being starved is to lack necessary nutrition and sustenance. The gold standard of any test in creative problem-solving is insight. For this reason, we keep this two-part cycle still in orange. This cycle is not worth teaching to students without another key ingredient - insight.

It's time to add another surgical trim as we prune the model.

Insight

To be creative, ideas must be tested. Tests must produce insight. That insight must be put to use to re-ideate. So often, the best test is quick and simple. It only needs to be big enough to learn one thing, not everything. KISS - keep it stupid simple.



We often make testing the most rigorous part of project-based learning. We make it a long and drawn-out phase filled with all kinds of data analysis. But, if the goal is to produce insight - that ability to see what could be, even when not fully clear - the moment we gain insight we move on.

That is not to say that all insights are correct. In fact they are almost always naive. They see something, but not the complete picture. That's OK because they can't see the full picture. You are looking at something that doesn't exist and yet you see a glimpse into the future of what can be. That will almost always have caveats we can't yet see. That's why we re-ideate, re-test, re-gather insight, re-ideate, re-test, and so on.

In this model, you want a test to be as quick and simple as possible to learn something. Ideally that insight happens in real-time. We often delay or obscure insights with big, bulky, formal tests that require a dose of analytics.

Nobel Prize-winning Chemist Ernest Rutherford goes so far as to say

If your experiment requires statistics,
You ought to have done a better experiment.

That is, you should be learning something in real-time through the experiment. Statistics may help you understand what you've learned, but tests do more than offer information.

To be creative, an idea is of little value unless it's tested.
A test is of little value unless it produces insight.
Insight is of little value unless we do something with it.

I want to point out here that insights almost always come with a feeling of joy and excitement. This is a good way to know that you've learned something. But, in our elation, we often think that we've found the right answer. Caution yourself. You found an insight, but it needs some good old fashioned hard work. The joy of insight can be misleading - more on this in the appendix.

What about the Scientific Method?

I can hear the healthy skepticism again. We teach students about hypothesis testing, we have them conduct experiments and share their results. Are you saying that this is wrong?

No.

What I'm saying is that when our focus is on building creative-capacity, science projects in their current form aren't the answer. Science projects can, for example, teach students to not believe something because they "think so". It helps them put away opinions and find facts. It helps them see why we want to change just one variable at a time vs everything all at once. BUT, if a student does a test or two and answers yes/no or reject/not, they didn't have a chance to put their data to use. Why was the answer yes or no? What can we do about it? To be creative, insight has to drive the next round of ideation. Whatever data you collect needs to be actionable. If you can't put any insights you glean to use, we short-change creativity.

For example, say a student does a project about cookie A or cookie B tasting better. They use the same recipe for both with the exception of butter. Now they run the experiment. Cookie B tests better and the results are statistically significant. Awesome. But, there's no

re-ideation. Why did cookie B taste better? Could I make a cookie C that beats them both? The project itself doesn't drive a need to iterate.

It's good to find scientific reasons to believe something or not.
It's creative to do something about it.

A creativity-build task could be something like this: Create a cookie that uses no butter at all and tastes better than both cookies A and B.

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This three-part cycle is already of great value for students, and to be honest, even as adults aren't great at this. We say things like data-driven decisions, but it almost always is used to reinforce one ideology or another. It becomes an excuse to not change our minds because there it is - THE DATA - it's telling me what to think. The problem is that it's easy to use data to "prove" what we believed already. It's another thing entirely to look beyond mere numbers and find nuggets of insight about it. Data shouldn't just be option B is better than option A because - yada, yada, yada. It should instead be about finding the right solution to the problem even if both A and B are off target.

So, what do we do about it? How do we begin to tease out options C, D, E and so on? This is where the cycle so far, although highly valuable, breaks down. We put this cycle in green for the first time because it is the smallest nugget worth teaching to our students. But, that doesn't mean we are fully pruned.

If I can't see the solution yet, how am I supposed to self-direct myself there when I don't know where I'm going? What if the tests, ideations, and insights send me into a forever loop of running in circles going nowhere? How do we make sure we aren't running in circles?

It's time for another pruning.

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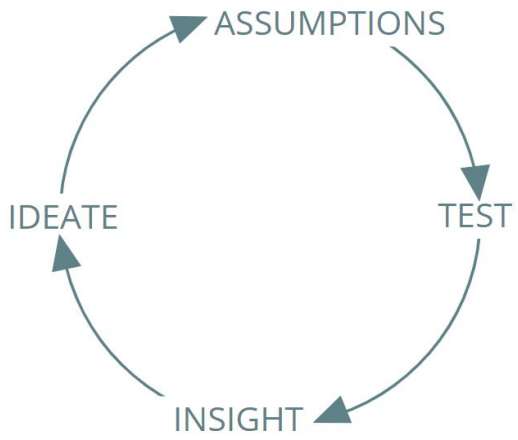
Assumptions

Every time we conduct a test, gather data, use that data to figure out what to do next we incorporate bias. What should we test for? What should we ignore? How do we know we are taking a snapshot of the complete picture?



Every experiment that controls the variables makes assumptions about what variables should be accounted for and which ones don't matter. We can test and test and test all day long and still run in circles.

To be creative, we must challenge ourselves and others beyond the status quo. By definition, the status quo isn't creative because there's little to no iteration happening. To break these conventions, we have to look deeper. We need to be jolted out of everyday thinking.

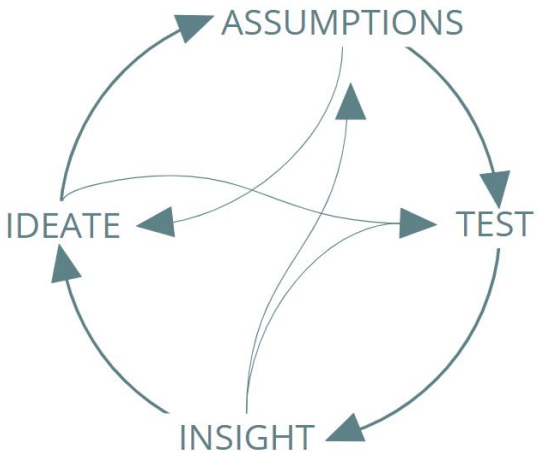
The number one threat to a person's creativity is unexposed assumptions - those hidden beliefs, expectations or "have-to-be's" that go unchallenged. To break out of this rut, find your assumptions and keep the light shined on them.

We should spend more time testing our assumptions than our ideas. Assumptions are the ingredients we use to bake up ideas. If we don't know the ingredients, we have no idea what we are making.

In Chapter 4 we focus on how to train students to do this. For now we continue pruning so that we have a clear view of creative problem-solving. Before we introduce more trims to prune our model, we simmer in what we've already covered and synthesize key takeaways.

Measuring Creativity

Now armed with assumptions acting as a superfuel on our creativity, we can introduce more connections between the concepts. Rather than talk through every single one, it's worth asking ourselves what it looks like to act creatively.



Simply put, using this model, creativity is about fluidly flowing through this cycle - always spinning clockwise. There's all kinds of closed loops, and as we develop our problem-solving skills we'll have a better feel for being at the right place and flowing through it at the right pace.

A creative person knows when to sit in their assumptions for a while, when to test their idea, when their test isn't producing the insight they need, and so on.

As a person builds their smooth flow through this cycle, their creativity is off the charts. One person is more "creative" not because of brains, IQ, or genius but because (consciously or not) they more fluidly or naturally flow through this cycle.

This also means that, with a cycle in our back pocket, we can build our own creativity by going through this cycle to the point it becomes automatic. Creativity can be taught, trained and developed because

Creativity is something we do,
not someone we are.

You will be more creative as you spin through this more naturally and quickly. To build this ability, it's likely better to think of it as *slow is pro* or *slow is smooth and smooth is fast*. As it begins to feel more natural, you'll speed up.

Immediate Questions and Key Takeaways.

We finish off this chapter with discussion of a few questions. Perhaps you are asking yourself where creativity starts - the idea, the assumptions, the test? Perhaps you are thinking that if creativity looks so effortful then why do I get my best ideas on a walk or in a shower? We briefly talk about those now and end with a discussion of key insights and practical implications in the classroom.

Where Do I Start the Cycle?

One potential downfall of using a cycle as a model is that there's no clear beginning or entry point into the cycle.

Where does creativity start?

The simple answer is: It doesn't matter.

You could be in the test phase for project A and — bam — out of nowhere it feels like you get an insight for project B. But the "creative moment" of seemingly pure bliss and genius isn't creativity persay. What you do with that moment determines if you'll be creative or not. You entered the cycle at the insight stage, so just keep going.

Regardless of where you entered, just keep cycling.

What About Downtime?

Everything we've mentioned so far is about flowing through the cycle. It'll take conscious effort and practice to get to the point of feeling smooth and natural, which sounds like a lot of hard work. You are right. Creativity is mind-bendingly effortful. You come face-to-face with your own vulnerabilities and yet hopefully you keep going. Your head will feel sore from banking it against an unbreakable wall. You'll want to quit. Don't listen.

But this sounds like a sharp contrast to those *eureka* moments of euphoria in the shower or while on a walk. What's the deal with that?

Creativity requires both. When taking any sort of downtime whether sleeping, talking a walk, talking a shower, or doing any low-lift mental activity, the brain isn't actually taking downtime although it feels that way. The brain engages a neural network that's usually not engaged with busy work or goal-oriented activity. The network in the brain associated with times of "low mental lift" is called the Imagination Network - sometimes called the Default Mode Network because it's what your brain does by default when not busy on other things.

When you have been stuck and struggling on a problem and you feel that your brain hurts or is tired, take a break. This allows the Imagination Network to get busy consolidating ideas and experiences. This network seeks to consolidate experiences and struggles of the day and searches for novel connections that we would otherwise not accept. For example, the Imagination Network is active during sleep and boy do we get some weird dreams. As our neural, task-specific inhibitors (the ones saying "this idea is no good", "no don't do that", etc) mellow out a little bit, our brain frees itself from "the obvious".

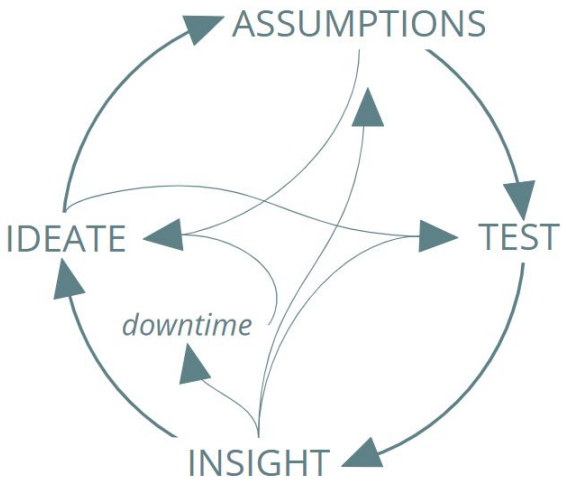
This is why brain breaks are a good thing. They let your mind imagine. The reason that a shower or a walk seems particularly effective is that they bring with them a dose of novelty - sights, sounds, smells, sensations - and time alone. Even a simple change that is perceived as different gets our minds out of the rut of what "must be" adding raw materials to the Imagination Networks goal of finding what "could be". The Imagination Network is particularly active during alone times. So, if you can, take a walk alone.

New sights, new sounds, new sensations all help us find new ideas, but there's a catch. In order for those *eureka* moments to happen, we need to have done a lot of work. That is, you don't come up with great ideas being habitually lazy on the couch. The Imagination Network needs some raw tools to work with - you create those tools when flowing through the Creative Engine while being stuck and struggling.

Highly creative people have ridiculously high work ethics. This provides them more raw tools for their Imagination Network to play around with. Also, things like coming up with jokes or finding funny, unexpected connections are all ways to give your Imagination Network more tools. If you can find unexpected connections intentionally, your brain can find even more unintentionally.

Another important component is that this downtime is almost always done alone. Taking a walk by yourself is generally better than with others. This is one reason why showers tend to be specifically useful. To kick your Imagination Network into high gear, free yourself of distractions. This also means that constant collaboration is detrimental. Creative

problem-solving requires self-reflection and time alone. We can't be creative if everyone is doing everything together all the time.



Downtime, when managed well, is a well-spring of creativity. With this in mind, we can now present the entire Creative Engine.

Key Takeaways: Chapters 1 and 2

So far, we've talked through the need for baseline attributes that determine a lot about if a kid will be creative out the gate or not. Then, we refine our creative endeavours by flowing smoothly through the Creative Engine. This offers us photosynthesis to fuel growth and pruning to refine that growth.

Here's a collection of insights from the first two chapters.

- Humans photosynthesize creativity. Give people the right conditions and you'll find amazing bang for the buck.
- Action and effort are necessary to build an openness to challenge. Exposure is OK, but it's best if tied with voluntary and sustained effort.
- When math class is all about the siloed self (own work, own grades, copying is cheating), there's little room for an others-driven purpose. Engaging with math socially is a step towards breaking those silos.
- Fall out of love with big ideas and in love with iterating them.
- Insight is the driving force, not information nor data.
- Iteration is insight-driven re-ideation.
- Assumptions are a secret weapon. Hidden assumptions are silent killers.

- Downtime, used properly, is as important as digging in and pressing on. Well-used downtime is the life-force of creativity.
- A “bad idea” iterating 10 times is more creative than the best of 10 initial “good ideas” because you must flow through the cycle to be creative.
- Being creative is supremely human and we can all learn to act more creatively.
- Creativity is something we do, not someone we are.

Conclusion: Creativity, School, and Feedback

Several longitudinal studies on creativity reveal a fairly striking pattern. Slumps in creativity tend to coincide with major changes in school — e.g., a student entering kindergarten or transitioning to middle school. In 2015, two researchers Zi-Lin He, Poh-Kam Wong found the major reason for these predictable slumps is student assessment of school life. In particular, negative associations with school make the transition-slumps more severe.

One could interpret it as a child’s negative relationship with school erodes his/her tendency to act creatively. Perhaps this is why so many people believe that kids lose their creativity by middle school.

If we want students to creatively solve problems, we have to build and sustain positive school culture. To nurture this kind of environment, one strategy empirically shown to nurture creativity is to encourage curiosity and exploration. If our projects suck the curiosity out of our students, it also smothers their creative development. Our classroom environment matters as much as the creative steps we take.

No single experience is enough to get to a point of maximal creativity and stay there. Creativity develops over the course of our lives. In one study, a creative-peak happens around age 40 and stays equally strong until around 70. Your students’ creative journey is just beginning. It’s better to sustain growth, even if slow, than to speed it up and have it burn out. It's a classic tortoise and the hare scenario.

Many of our students have views of creativity that say “Don’t put yourself out there. If people don’t love it, you aren’t creative.” Creativity though, requires the opposite. In fact, initial widespread praise for an idea is a death sentence. You are virtually never creative if everyone “gets it” right away.

Some students will freeze up and not engage in a creative task. Creativity scares them. This is a learned fear, often trained through rigid process reliance in math class. The expectation of being told what to do before doing anything is one of creativity's kryptonite. Even so, we can greatly reduce the number of students freezing up with the right classroom culture (curiosity and persistence). This is, by far, the most important first step.

Research has shown that effective feedback strategies also promote student creativity. In creative problem-solving, this kind of feedback should generally focus on the work (what work, what didn't, and why) to help build insight with the least amount of new knowledge possible. It should generally come with enough encouragement for the student to not freeze up while at the same time not so much encouragement that they are convinced they are so good that they don't need to iterate and grow. Feedback should also leave open possibilities.

Meaningful feedback is focused on the work.
It is specific, illuminating, and appropriately encouraging.
It tends to happen best in real time.
It opens the mind to new possibilities.

Giving good feedback is a selfless act. It's about what to say and how to say it for the benefit of the recipient. Feedback is best given when it is others-focused. The goal is to use feedback to edify and lift up, not destroy or assert dominance.

Feedback is such an important component not just of taking creative steps but of the classroom culture. Based on research by Ronald Beghetto in 2006, middle school students rate teacher's positive feedback on their creativity as the most important single predictor of their belief in themselves as being able to be creative. They didn't give top marks to training to think of lots of ideas or training to execute the perfect test. Teacher feedback takes the prize.

As you give feedback, keep in mind that constant praise, too strong of praise, or complete lack of praise can cause students to play mental games with themselves. When giving feedback, give just enough support for kids to keep going on their own and just enough encouragement to feel OK even if their next idea flops. Too much knowledge narrows the mind and too much encouragement can bloat the ego - stopping creativity as fast as negative encouragement turns us into deers in the headlights..

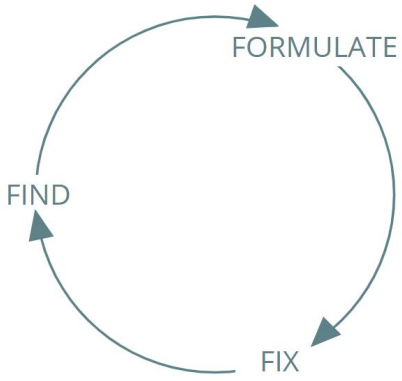
Creativity is both a self-expression of our uniqueness and a relevant attempt to tackle the problem at hand. I need feedback and I need room to be myself.

Chapter 3: Creative Problem-Solving Framework

Let's assume we have the creative culture in place and our ability to flow through the Creative Engine is smooth and natural - so much so we don't even know we are doing it, like tying our shoes or driving home from work. This is a huge milestone. Few of us ever reach it. But, we still need more pruning.

In every case so far, we could still be posing fairly well-formed questions or problems to our students. The real-world isn't so clean cut. We all see problems in the world around us, but they rarely directly illuminate the root cause. Starvation, murder, manipulation, world wars, the list goes on and on. But we can't solve any of these until we know what the root problem is. Why is starvation happening? Why does murder still happen? We need the ability to apply everything we've built so far to highly open, vague, and big problems. These problems have multiple moving parts and may take decades or generations to truly solve. When you really start thinking deeply about any problem, you find that there's more than what we see on the surface or in the 5 second snippet on the evening news. To solve these problems, we have to first wrap our brains around what the problems are at their core.

I recently spoke with a lead, C-suite executive at a global company. We talked about problem-solving and the use of data on his team. This C-suite executive can hire the cream of the crop; the best of the best. What is still nearly impossible to hire is someone that can find the actual problem and formulate it in a meaningful way. New hires at this company have to take a specialized course in problem finding. These hires can crunch any number you want and know every statistical formula and relationship you can imagine, but they leave the best universities in the world still unable to solve problems that are clearly and perfectly defined for them.



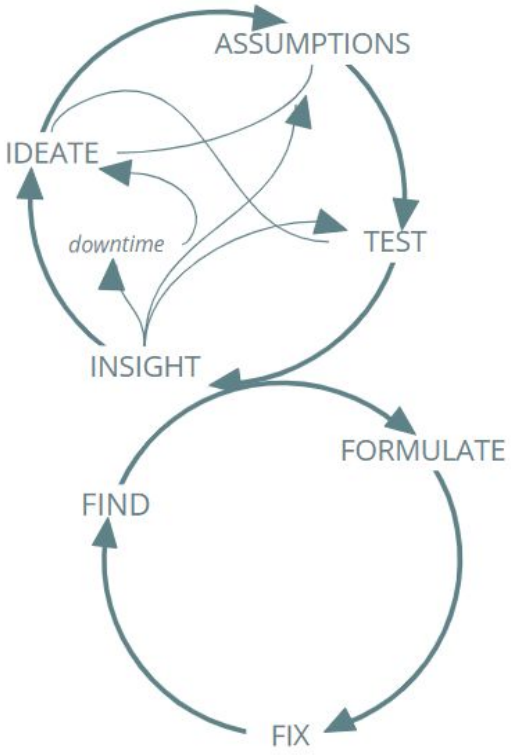
To solve a problem in the real world, we have three main tasks. We can't solve a problem if we don't know what it is (FIND). We can't solve a problem we know of unless we understand it well enough to formulate it in a clear and solvable way (FORMULATE). Even if we know the problem and can understand it in a solvable way, we need to create an actual solution (FIX).

We write this as a cycle as well because neither phase is clear cut or complete and put to rest. Most of the time we start solving the problem and along the way realize the problem is more nuanced than before. We'll need to re-find or re-formulate.

In Chapters 1 and 2, our focus was on the creative steps necessary to fix a problem. So, what happens now that we have to find the problems for ourselves and understand them well enough to do something about them? How do we know when to jump out of the fix phase and re-find or re-formulate?

The answer is exactly the same as before. Use the Creative Engine in every single phase. Most of the time, we think we must define the problem first and that this definition is set in stone and then we embark on finding a solution. In the real world, this is rarely how problem-solving happens. We should use the Creative Engine to iterate as we find and as we formulate the problem. We also use it to decide which phase to be in and when to switch out of it.

In all phases of problem-solving, a creative person tends to reject assumptions that others accept at face value. We all have assumptions that impact our views of what the problems are and what we should do about them. Don't be so quick to define the problem and strap boundaries on it. Use the Creative Engine to play around with all three phases of problem-solving and use it to flow into the next phase.



This now gives us the complete Creative Problem-Solving Framework. In every phase, look for more than the quick answer or the easy-to-accept idea. Challenge yourself, test your assumptions, ideate with intentionality, drive ideation with insight, decide if you are ready to move forward or if you need more cycles in the current phase.

Perhaps you need downtime to shake things up a bit and allow your brain to think more deeply, but you are still in the find phase. That's not only acceptable, it's preferable. Don't rush your way through problem-solving. The problems we have yet to solve are challenging. If they were easy, we

would have solved them. Creative problem-solving is not a race. It's about self-management through the framework to the point that it feels natural and smooth. It'll take time to build a feel for it. But, no matter what, keep moving forward.

We now have a well-pruned tree. The more and more we practice it the better and better our pruning becomes. We'll find it natural and flow it smoothly. When this fully matures, we'll cycle through it quickly.

It's important for students to build metacognition for what creative problem-solving feels like. They need to own it for themselves. It'll take small steps and tons of practice. It's not completed in a single project nor a single grade-level. This is a long-term maturation throughout a child's entire educational journey and into adulthood.

The question then switches to how to operationalize this framework in our students.

Chapter 4: Operationalizing Creativity

To operationalize creativity in our classrooms, we need to remind ourselves of offering just enough knowledge. Much like math concepts build on each other other time, so will metacognition around creativity. Our students are on a longitudinal journey, as are all of us, to further develop our ability to tackle hard problems.

Progress is more important than perfection, so we should take this one step at a time. This is the purpose of our Creativity Roadmap.

It allows you to take just one step at a time. It's better to walk slow and keep going than to run fast and burn out. Before going too far, I want to point out that it's not about doing each step perfectly. We'll discuss each of the five components separately because they warrant separate

conversations. But, all ships do rise here. You can, for example, continually be improving your culture of creativity while also developing your feel for the Creative Engine. While the steps generally build on one another, you'll quickly see that it's more about 5 aspects to bolstering creativity than it is a step-by-step robotic recipe.

Component 1: Creative Culture

Before worrying at all about the Creative Engine, any sub-cycle of it, or the three phases of problem-solving, we need to photosynthesize creativity. It's important to bring out a child's natural creative inclinations. To do this, we need to treat the soil and photosynthesis does its thing. First and foremost, build a creative culture.

These can be daily habits and activities in the classroom and should happen in all subjects, not just mathematics or art.

Building a culture of creativity that enjoys lasting photosynthesis has three core components, called the Three E's - experiences, emotions, and environment.

With each one, we are looking to live in the intersection of curiosity and perseverance.

Creative Experiences

It is quite easy to design for engagement at the expense of effort or for rigor at the expense of curiosity. As it relates to creativity, though, these tasks have a down side. It is very unlikely that we can have one experience that builds curiosity and another one that builds perseverance, then hope that students develop the ability to exhibit both on the same task. For example, we are rigorous during a worksheet but rarely curious.

The good news is that students prefer tasks that live at this intersection. Case in point: video games. They are challenging and long (perseverance). They don't spell out the steps, so we have to be curious to find them. Even as adults, this intersection happens in our lives

all the time and we find it desirable. Think of your favorite hobby that requires focus, skill, and effort. When you engage in that activity, before you know it you've lost track of time and you feel effortfully refreshed. The best hobbies require our complete attention so that we push aside the ins and outs of daily life. This is what the intersection of curiosity and perseverance feels like. It's like effortful play.

These types of experiences, beyond improving our mood, are foundational for creativity-building. You can think of creativity as curious rigor. Mathematics needs experiences that feel this way. If you have a task that is wonderful for curiosity, look for ways to make it more effortful without killing engagement. If you have a task that is very effortful but fairly dull, look for ways to tie into a student's curiosity.

There are times for routine work; learning scales on the piano, learning how to spell your name, or practicing multiplication facts. These are not inherently bad tasks. They're actually important for building baseline knowledge (chapter 1). But to directly tackle a creative culture, we need experiences that merge curiosity and perseverance.

Creativity-building experiences merge
curiosity and perseverance.

One thing to keep in mind is that creativity requires high expectations. But, we often create them through high pressure. As teachers we feel this pressure all the time. This often, though, hinders curiosity. When the pressure is simply too high to take a risk or try something new we fall into old habits and allow creativity to get dusty on the shelf - more on this at the conclusion of the chapter . To develop or implement creative experiences, tease the two apart.

Have high expectations and
low pressure.

Play is a perfect example.

Creative Environment

Research suggests it's better to enhance creativity by changing conditions in the environment than by trying to make people think creatively[1]. One good argument for having a strong culture of creativity in our classrooms is that creativity is fragile. Kids can seemingly turn it off very quickly and for a variety of reasons. To build and sustain growth in our students' creative capacity, we need to make sure we have a culture that allows creativity to thrive — much like plants. For plants to grow, you treat the soil. In the same way, students have inherent creative capacity. But, they need the right environment to see it grow.

This is great news! We don't have to learn a million ways to come up with genius ideas or learn the absolute best way to conduct a scientific test. We simply need to, as a first step, make sure we aren't designing creativity away. A student's environment is their soil. The environment we seek is one that promotes both curiosity and perseverance. We can take a few steps to help make this happen.

First, try to **minimize distractions**. Don't offer every color of paper possible, or every game piece or trinket you can think of. If a kid decides she needs something, then she can find it or make it. The reason for this is that in a child's curiosity over the new things, they become distracted. In this case, curiosity can actually work against perseverance. The other reason to minimize distractions is that creativity is evoked primarily when there's a high expectation that requires complete attention. Creativity happens when we sustain both curiosity and perseverance. You can't be distracted and do this.

Second, **minimize consequence**. Missing the free throw while shooting blind-foled at recess is much less of a consequence than bombing the midterm math test or changing lanes abruptly on the freeway. When consequences are high, we often feel as though failure is overly detrimental or that we have to fit into whatever box that takes the consequence away (e.g., just do what the guy at the DMV says so you can go home or always stop when you see a red light). These are good things, and there's the right time and place. But when it comes to creativity-building, don't make your tasks too heavy.

Real-word tasks are great, but sometimes they feel so paramount that the consequences are high. The goal is to create an environment where students feel free to take appropriate risks. Creativity happens when, instead of avoiding mistakes, we embrace them. More on real-world problems in the appendix.

Another way to go about this is to make sure no one person, not even the teacher, is seen as the expert. This way, students feel free that we can all mess up together. Your job, when it comes to creativity, isn't to have all the answers, but to facilitate students in finding their own.

Third, **amply offer novel, non-routine challenges**. Students need to be thrown into a brand new situation and figure out what to do about it. For example, make a fun challenge out of writing with your non-dominant hand. It's so weird yet approachable (novel) that a student needs to give it full attention (no distractions) and every single one of us expects to mess up. This helps us find value in the mistakes because they'll be funny (mistakes embraced and desired).

Finally, **value autonomy and feedback**. Students need to have a sense of control or agency over their actions. It's not enough to give them choice over the project they do. When doing the project, their actions need to be entirely their own. More specifically, even when kids aren't sure exactly what to do, they engage with the activity on their own accord and keep working to figure it out. If you are giving a project overview, give the least amount of information you possibly can that gets them going. This way students feel a refreshing sense of autonomy.

You get bonus points for doing these four with **strong social interactions**. This helps your environment become an ingrained culture because students become the transmission agents of the environment. Plus, it's too hard and unreliable if you are the only change agent. To bring students along in the shift, have them engage with others in positive ways. When this happens throughout your entire classroom you have built a culture of creativity. This will make a noticeable impact in your daily math class even after the project is over.

A creative environment
sustains curiosity and perseverance.

Creative Emotions

Emotions can be tricky. They can also evolve well beyond feelings — what starts as emotions can develop overtime into mindsets and resilience. But, within the world of social and emotional learning, we need to accept the role that initial, early emotions have. From a neuroscience standpoint, these "onset emotions" serve as a kickstarter to creativity. In

particular, the decision to be creative isn't purely rational — it involves the emotional centers of your brain.

According to Robert Sternberg, "...the major variable in creativity is simply a mindset towards thinking in novel, surprising, and compelling ways — and this mindset can be taught." (10)

Creativity starts with a choice. Some experiences and environments make this choice easy, some make it challenging. But even in the best case scenarios, many of us unknowingly convince ourselves out of being creative. You've probably heard the phrase "I don't have a creative bone in my body." If you think you aren't creative or can't be creative, you likely pigeonhole yourself out of doing it. We all have the capacity to be creative, but our emotions can be our own worst enemy.

You don't have to be a starving artist or an eccentric billionaire. You don't have to be rich nor poor. Creativity is available to all people. There's not a single person that can "never be creative."

There's no one perfect emotion to have in order to be creative, but there is a preferred class of emotions. These are

"go for it" emotions.

These are emotions, positive or negative, that drive us to immediate action in direct pursuit of the challenge. They are the feelings that encourage us to be both curious and persistent.

Fear for example, a negative emotion, drives us to avoid the challenge at hand. We back off, we shy away. We aren't creative when we are fearful. On another hand is anger. Still a negative emotion, it drives us to direct action towards the object of our anger. We don't always put creativity to good use in this emotional state, but we are driven to be creative. Interestingly, calm and relaxed are not conducive to creativity because they are passive in nature. Creativity is action.

There are tons of emotions that we'd be happy seeing in our classrooms that drive us to productive creativity — elated, happy, physically ecstatic, loving, supported. Playing games can also produce "go for it" emotions - delight in harmlessly duping another; urgency, but not stress, etc.

To make the choice to act creatively, most of us need a spark of these "go for it" emotions. Two things all "go for it" emotions have in common is that they are intrinsically motivating and create a sense of urgency.

Creativity-inducing emotions should
spark curiosity and perseverance.

You've Got It When ...

There are so many things bombarding our days and it's not helpful to memorize some new set of principles that gets lost in the noise of everything else. So, to be helpful, here's a fairly simple metric you can use to get a benchmark as to when you've found the sweet spot in the Three E's. You know you've got it when you see...

voluntary, sustained effort
on non-routine challenges.

But Math is Different?

I can hear some of you say, "But math is different, wouldn't creativity in math be built differently?". If you are asking this question or perhaps asking a host of other questions stemming from a healthy skepticism and with the goal of learning - not merely being a killjoy - we are on the same page. Mathematical thinkers and problem-solvers don't just take someone's word as gospel, nor do we believe something simply because it's easy or popular at the time.

In the way we are discussing creativity, math is not different. In fact, the best way to predict if a student will develop and demonstrate creativity in STEM isn't test scores or getting an "A" on every assignment. It's intellectual curiosity - quite literally an openness to intellectual challenge.[9]

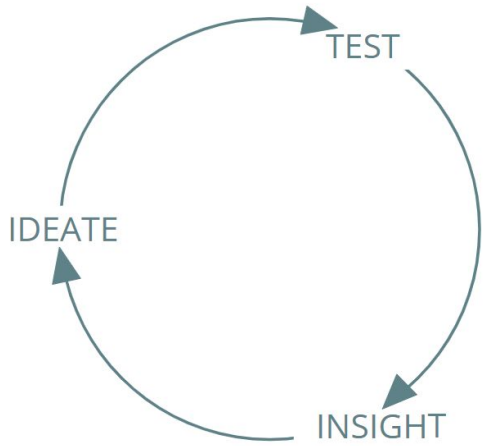
If you want kids to become better STEM students, and in our case math students, we can't settle for exposing them to new ideas. While this is great, if something lacks challenge it also lacks the ability to build an openness to challenge. Exposure is just fine, but if we are talking about building creativity, our efforts need to zero in on ways in a mathematical context to have students voluntarily put forth effort and to sustain that effort as they tackle

equitable challenges.

What's even more exciting is that as we continue talking about creativity, we will see that mathematics is one of the most creative human subjects. Moreover, it's one of the ideal places to train student creativity - although society doesn't see it this way and as a result, we tend to train creativity out of our students as they develop mathematically.

Component 2: Productively Manage Missteps

Once we make the decision to engage in something creative, we need to be able to manage the ambiguity and uncertainty inherent in doing something we don't yet know how to do.



We need to remain open to challenge, and we need to productively engage with that challenge. The biggest way to productively interact with the challenge is to learn from our mistakes. You shoot a free throw and it's too far right, you can now aim a bit left.

Productive management of mistakes lies in learning what happened, why it happened that way, having a hint of what to do about it, and testing it out again. Most specifically, it lies in the smallest chunk of the Creative Engine (chapter 2) that's worth sharing with students.

To operationalize the ability to productively manage mistakes, we offer a shift in perspective. Instead of the three nodes in this cycle, focus on the links between them. Creativity lies in flowing through the cycle, not being forever stuck on any one node.

Focus on the Links

Building creativity is not having the perfect test, nor ideating like it's no one's business. Transitioning between phases (the links) is where productive management of the unknown lies. It's common for us to ask "How do we perform a good test?" We even dive deep and focus on it in several project-based learning environments. But when it comes to building

our creativity, it's generally better to first ask ourselves "How do we get students to test their ideas?" If they can repeatedly test out an idea and learn something, they'll also become better at testing. So, let's switch our focus away from the nodes and towards transitioning between them.

This shift in perspective is freeing. We don't have to be robotic in our classroom. We don't have to do everything right the first time. We don't have to prepare all the supplies and lessons with painstaking detail before kicking the project off. Creativity is not about baking a cake by following the recipe to perfection. Creativity is much more human and messy. In creativity, we are free to be ourselves, to try things out, to learn from them and keep going. As a facilitator, your role is to help students get the cycle spinning. There's no need to be rigid and formal.

So, we want to find ways to reduce friction in the cycle so that kids can get spinning. This requires that we both remove actions that get in the way (things that have created friction) and add in actions that actively reduce friction (things that can lubricate the engine).

Link 1: How do we get students to test their ideas?

Testing an idea requires that we actually test it, for real. Any project in the classroom that artificializes the test or makes testing arduous or virtually impossible, breaks the link. Any project that makes testing unnecessary (e.g., coming up with a mnemonic for PEMDAS and coloring in a PEMDAS outline) breaks the link.

To encourage students to test their ideas, make sure to build a desire and expectation to test, followed by a way to test, for real. Rework any project or challenge that guarantees success — either by being too easy or by merely jumping through hoops.

Any project that gives an "A" by completing the 10-step-rubric or by creating any acronym you want for PEMDAS isn't inherently bad. These just aren't the types of projects that live at the intersection of curiosity and perseverance. Sometimes simple changes can make a big difference. For example, instead of creating a PEMDAS acronym, change the challenge.

- Create the funniest PEMDAS acronym that makes the front office staff laugh.
- Create the weirdest PEMDAS acronym that is a phrase you can't forget.
- Create the most memorable PEMDAS acronym.

Now, all of a sudden I have a reason to test. I even want to test. It sounds fun. The way to test is simple. For example, give or say the acronym and see if someone laughs.

When you remove barriers to testing, you'll find that testing is more natural and desirable than it is unnatural.

There are all kinds of projects in which students test. Perhaps you are thinking of a school science project. Those aren't easy tests and they tend to be rubric-heavy (formal). You are correct. And they can be very valuable projects. However, they aren't the kind of project that builds transferrable creative capacity. When looking at the linkages, no phase exists in isolation. The kind of test we are looking for is one that produces real-time insights.

Link 2: How do we get students to gain insight from their tests?

In the context of building our creative muscles, a test should focus on building insight. This is, and should be, different from hypothesis testing. Not all good tests are the right kinds of tests all the time.

There's a time and a place for formal, robust research-like testing. There's a time and a place for validation testing. There is also a time and a place for testing just to figure out what's going on. In the kind of testing I'm talking about, if you are gathering data it needs to be actionable not merely analyzable. Nobel Prize-winning Chemist Ernest Rutherford goes so far as to say

If your experiment requires statistics,
you ought to have done a better experiment.

His point is that tests that give us information don't necessarily give us insight. A science fair project is good and well and its tests use data to help us make up our mind. But they often stop short of producing insight as to why the hypothesis worked or didn't. Why does cookie A taste better than cookie B? And more importantly, what can I do about it to make an even better cookie C?

Often, the best way to gain insight from a test is in real-time, right there, in front of your eyes. This insight comes from meaningful, in-the-moment feedback. Sometimes we are able to get this feedback on our own, but often we need others to help us - for example, a coach of your basketball team. Either way, meaningful feedback is the kind of feedback that helps you wrap your brain around what worked and what didn't as well as why. It helps you refine your thinking. It also tends to have just enough encouragement so that the receiver doesn't feel trapped, belittled, or ganged up on.

A practical way to tell if you've gained insight from your test is when you have an intuition about these three questions.

What happened?
Why could it have happened this way?
What **might** I be able to do about it?

If you have a stab at answering these questions, you likely have enough insight to re-ideate. Insight is not a moment of perfection, but of illumination. As you continue to cycle, your illumination will become stronger and stronger.

To encourage students to learn from their tests, make sure they gather real-time, meaningful feedback. Remove any test that is too infrequent, too late, too large, too formal, or just to gather data. **Gather insight as cheaply, quickly, and often as you can** so that you keep cycling. This is how your creativity grows.

Don't overthink or over plan it. Sometimes the old-adage is true. KISS - Keep It Stupid Simple.

The thought leaders in 21st century entrepreneurship say basically the same thing. A startup is only as good as the number of pivots it has left to make before it runs out of money. Instead of getting more funds, a startup can figure out how to fail and pivot more quickly and cheaply. By being lean and scrappy, they have more life in them than one that is slow moving and well-funded.

Sometimes, kids will have that "ah-ha" moment of insight but when probed more about it they have no idea how to fix it. This isn't the end of the world, after all they are in a creative problem-solving environment. It's supposed to be hard. But, it highlights the importance of turning insight into iteration (a.k.a. re-ideation).

Link 3: How do we get students to put their insight to use?

This is perhaps the most important link of all. You can do the others all you want, but until you turn your insights into something, you aren't being creative. Ideas are cheap compared to actions.

This is also where students tend to exhibit a fatal flaw when tackling difficult problems. When they find an issue in their idea, they want to toss it out wholesale and replace it with a new one. This is not cycling. This is the termination of the cycle you are on and starting a new one. In many ways, it's the antithesis of creativity. Insight gives you a peek into what worked and why, what didn't and why, and offers a first glimpse of what to do about it. Without insight, there's no way to truly iterate. Tossing out an idea wholesale should never be a quick or hasty decision. It should only come after nurturing your current idea(s).

Iteration happens when insight picks up enough knowledge to do something about it. Creativity requires some set of baseline skills or knowledge. You can, and should, pick that knowledge up as you go. Those trying to cure cancer are learning a lot along the way. Those trying to get to the moon didn't have all the answers on the outset. Creativity doesn't require you to know it all, but that you pick up what you need as you go.

In fact, having the "complete knowledge set" right away is not helpful. We often feel the need to give students a detailed picture upfront, before they start their work. They need to know the project, the steps in the design principles, how it will be graded, and so on. This will overwhelm the student and take away room for their own curiosity. Too much knowledge can narrow assumptions and drown out creativity - expert bias.

To counter this, I propose "just in time" knowledge. Students figure out what they need, or we help them with ongoing knowledge only as they need. To be creative, give students just barely enough to fail forward. Giving them just in time knowledge without pigeonholing their thinking is the best use of feedback and examples (more on examples in the appendix). Often, students need a lot less information upfront than we think.

Creative problem-solving requires
just-in-time learning as you go.

Component 3: Learn to Leverage Assumptions

Assumptions are one of those areas of extreme value once a person is OK with mistakes and can learn from them. The third component in the road map is to bring in assumptions.

One of the toughest challenges with assumptions is that most of us never see them. Playing with assumptions allows us to probe an idea without making a judgement of its validity, because we are playing "mental pretend". In other words, we can ideate intentionally and suspend judgement.

For example, suppose we are trying to save fuel in a gas-powered car. We could look around and see that people are sitting at stop lights idling fuel away without going anywhere. We could save fuel by having cars run on battery power when stopped. This, in fact, is one of the most common features in any new gas powered car.

But, let's try to tease out the assumptions being made. Then we'll play around with them and see what shakes out.

- We are assuming that cars need stop lights.
- Stop lights are used for cross traffic and for pedestrian crossing.
- So, we are inherently assuming that stop lights should still be used for pedestrian crossing.

In other words, our solution assumes that people and cars share the same road. In the days of walking and horses, it made a lot of sense. In the 21st century, do we really need to be sharing the road? This assumption is so strong that we add more and more stop lights all the time. This makes fuel consumption worse. One one hand we use a battery when stopped, but we stop more often. Stops require acceleration. Acceleration is the biggest

fuel burn of all. If we could do a better job of maintaining momentum, we could likely be more efficient.

Not that it would immediately be easy to do, but we could now begin to look at fuel consumption from the standpoint of momentum. Do we really need all those lights? Is there a way to remove a few that are particularly annoying? Can they be programmed in a smarter way? How can we get people to cross the road without stopping dozens of cars?

Think of the time lost even when a car stops. For one person to cross the road, you may easily have 30 cars or more stopped for 2 minutes. That's 1 hour of a human life just to cross the road. Fuel aside, that seems awfully expensive and wasteful.

None of this is to say that the right answer is to end all traffic lights. I simply share an example that changing our assumptions completely changed the way we look at the problem. We don't even have to accept these assumptions, because we are playing an intentional game of "what if". We aren't brainstorming, we are ideating.

Let's talk through exposing and messing with assumptions a bit more via two very simple games.

Exposing Assumptions

Here's the first game. We pose a statement that, on the surface, is completely believable. If possible, see which assumption(s) make it true. But then, change the assumption to see if you can find how the statement could be wrong. The first statement is:

Red means stop.

This is easily believable. But, what assumptions am I likely making for this to be true? This statement is true if we assume we are driving a car looking at a traffic light or stop sign, or even brake lights. Now that we know it, can we find a compelling example outside of driving in which red does not mean stop?

Here's an example,

A flare gun fires a red shot.
Red means come here.

Are there other places where red is used besides stop or come here?

On a boat or plane, red tells you the side of the plane/boat.
Red means portside.

On a sink, red tells you the side for the hot water.
Red means hot.

In just one simple example, exposing assumptions aids in ideation. We've come up with compelling uses for red that aren't out of thin air. It also allows us to see beyond what has to be.

Let's try one more example.

Underwater too long and you'll drown.

What assumption(s) make this true, and can it ever be broken? Try a few yourself before continuing.

Fish live underwater and they don't drown.
The statement assumed it was a mammal.

Seaweed lives underwater and does just fine.
The statement assuming it was an animal.

A rock is underwater and never drowns.
The statement assumes the object is living.

A diver could be under water with an air hose to the surface.
The statement assumed we were holding our breath or using an O2 tank.

People are underwater in their homes and still have the physical ability to breathe.
The statement assumed it was actual water.

We aren't trying to be cynical or combative. We don't want our answers to feel made up. We are trying to find the assumptions we made when we first believed the statement. By breaking the assumptions, we can find other scenarios that are valid possibilities even

though they dispute what we believed at first. Often, what we think is true or what must happen is merely a result of our assumptions. By intentionally changing these assumptions we can get out of the rut of what has to be and ideate on what could be.

Challenging Assumptions

One thing that separates the extremely creative from the rest of us is that they see connections that the rest of us write off or can't see at all. If we can practice finding otherwise far out connections that are actually quite believable, then we can build our ability to find distant connections that people overlook. This is why humor is often associated with creativity. The connection is far enough out to be believable, which allows it to be funny.

We'll demonstrate finding distant connections with a second game. We start with three basic assumptions that describe an object. Your job is to first off state what object most obviously fulfills those requirements. Then, find other objects that fit as well - that are equally believable, but not immediately seen. Let's try one.

I have 4 wheels.
I have a motor.
I am a form of ground transportation.
What am I?

Of course, the immediate answer is a car. Now that we know the assumptions and the common answer, can we describe another outcome of the exact same assumptions? Again, offer surprising or insightful results that are immediately believable. Here's a few, you may have found some even cooler ones.

go-kart, electric skateboard, quad/ATV

This demonstrates the concept above. Once we know our assumptions, we can use them to ideate. We can even keep our assumptions the same and still find unexpected connections. We would have likely written off the connection between a car and an electric skateboard mostly because we look for what makes things different. Creative people look for what unifies two things - like we just did.

Now, let's take it a step further. Let's intentionally challenge one of the assumptions. Again, be as believable as possible. Bonus points to any answer that's so insightful it's funny or enjoyable.

I do NOT have 4 wheels.
I still have a motor.
I still am a form of ground transportation.
What could I be?

Try it out before reading on.

We are looking for motorized ground transportation that doesn't have four wheels. Some fairly quick examples come to mind, some take a little longer to imagine.

a bus, a trike bike, a train, a motorcycle

And there are tons of others - the last of which is my personal favorite.

a segway, a tank, a big rig truck, a snowmobile, a moving sidewalk at the airport

Not a single one of us walks around thinking that a car, an electric skateboard, a tank, and a moving sidewalk are more alike than they are different. By leveraging our assumptions, we've many dozens of creative connections we would have written off just 15 minutes ago. This is the power of assumptions. They let us peer to otherwise distant connections. This, in turn, boosts creativity.

Mathematicians use this strategy time and time again. We find the smallest, simplest assumptions involved and build on them. This is precisely the kind of thinking of *Euclid's Elements* and the cornerstone of today's high school geometry class. We even take it so far as to assume something we want to be true is false. A famous example is √2. Can it be described using place value (rational number) or not (irrational)? In proving that it is indeed irritation, we start with "Suppose that the √2 is rational." In other words, we allow ourselves to explore the exact opposite of what we want. In our daily lives, most of us aren't willing to entertain something we disagree with. But, creativity requires it.

The waters muddy quickly if the assumptions are too big or too vague. So, in math we strip the problem down to its essential assumptions (often called axioms). Like how

chapter 2 built up the Creative Engine, we want to keep things as small and manage as possible. It's surprising how powerful this strategy can be.

The more and more students practice bringing assumptions to the surface and leveraging them, the more their creativity will mature and flourish.

This also suggests that brainstorming could use an overhaul. Brainstorming is a goal for idea generation by delaying judgement. But how do we generate those ideas? It feels a lot like strategy-free hard work hoping for a stroke of genius. Assumption-based ideation also delays judgement, but goes even further - it outright challenges the status quo and explores the opposite of what we initially expect. In other words, we are being intentional in how we delay judgement by giving a way to come up with ideas outside of the norm. The beauty of assumptions is that we look for similarities when others look for differences. This allows us to find connections others might miss which, in turn, helps us become more creative. More on brainstorming in the appendix.

At this point, it's important to remind us that how we manage ourselves during the busy, effortful, exhausting work of being creative is as important as how we manage breaks and downtime.

Component 4: Downtime

We live in a society full of busy-ness. Kids are busier than ever. They have almost no time to themselves. As adults, it's even worse. The grind of daily life can put us into a mental daze. We go through the motions, we never stop. We think that to be productive is to be successful and to be successful is to be happy. We carry over lots of unused sick time, we don't want to be caught dead on social media while in the office, especially not by our boss. We want to look busy at all times.

While hard work and a relentless work ethic is admirable and important for creativity, we must also remember balance. Creativity, in many ways, is about balancing all that makes us human. One of those balances is downtime.

Downtime is also neuroscientifically necessary. As we discussed, the Imagination Network needs a chance to kick in to gear. When your brain isn't focused on a specific task, it looks for connections and meaning. Our minds aren't like a computer hard drive that stores random bits of information. The human brain is a connection-finder, a meaning-maker. In

order to allow our minds to take on this task, we need to take a break from extreme focus on the problem at hand.

Remember that downtime pays the most benefit after having struggled on a problem to the point of feeling worn out. Downtime has little value if used as a way to avoid effort. It's effortful work that creates the raw materials for the Imagination Network to work with.

Also, the Imagination Network is generally most active when one has time and space to think on their own or when involved in self-reflective tasks (like meditation). When feasible, try some of these examples out alone. This is also why kids need some time away from group collaboration.

Here's a few particularly noteworthy examples on uses of downtime. While these are generally helpful, it doesn't mean that all work for you nor that you have to do every single one to robotic perfection. For example, it's not that a walk is a magic pill. It's those activities you can engage in that shake up your day, can be done alone, and aren't cognitively demanding. These categories of experiences allow your mind to seek out novel connections and consolidate learning. You may not be able to go for a walk, or you may simply not want to because it's pouring down rain. This doesn't mean you can't be creative when it's stormy outside. The walk isn't the only fix if you can replicate the same concept by another means.

Sleep	Your brain is very active during sleep - so active your eyes move along as if the dream is happening for real (REM = rapid eye movement). During these kinds of moments, your brain consolidates memories and efforts of the day and looks for meaningful connections. The lack of inhibition allows for more distant/novel insights.
Talking a walk, talking a shower	These types of tasks change up the routine, require minimal cognitive load and can be done alone. This frees up your Imagination Network in a similar way as sleep. Even simple ways to change it up - sights, sounds, smells, etc - can be all your Imagination Network needs to be free.

Meditation	By focusing your mind in just the moment, minutes and hours blurr. Your brain practices complete focus in a way that is freeing and self-reflective. Some of the best ideas come after mindful self-reflection and quiet time.
Hobbies	Similar to meditation, hobbies allow complete focus on something else. This offers an enjoyable jolt of novelty and a chance to further learn something new. Openness to challenge is about always pushing oneself to learn and improve. Hobbies can be an enjoyable way to practice this.
Learn something new, challenge yourself in something not in your wheelhouse or comfort zone.	Any time you learn something new, you disrupt the familiar and feel empowered by your new horizon. Any chance to disrupt the familiar helps with novel-connection-finding. Also, overcoming a hurdle you would otherwise have ignored is empowering. It reminds you just how capable you are. Don't settle for easy, overcome the hard.
Push aside busy work.	The relentless tug of partial attention never allows full attention on anything. Creativity requires complete attention and intense focus. You won't be able to do that if you never have your attention freed up. Find ways to clear your plate of busy work, even if for a short, specified period of time.
Let it simmer	Don't rush to judgement in a flood of emotion. Insight often feels euphoric, but it's also naive. It sees a glimpse or a partial view, yet emotions tend to convince us that we've found the jackpot. Downtime can be a pause so that you can look at the situation without emotions blocking your view.

Vacation and other brain breaks	Put the problem away for a bit, perhaps put all of life away. When you can change it up and slow down, your Imagination Network kicks into high gear allowing for creative sparks that you'd otherwise miss. Don't feel guilty about those afternoons or weekends off. Don't hoard your vacation time when you know you need a little extra time away.

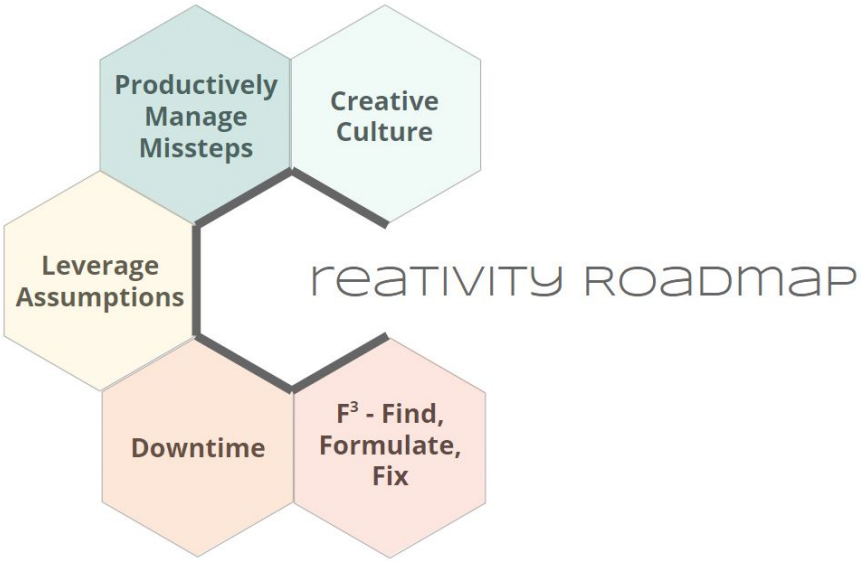
Over time, you'll know yourself better and be more equipped to make the right use of downtime at the right time. It's not just about sitting or physically resetting. Downtime is not idleness. As a creative problem-solver we need to learn to manage when to dig deeper in the problem and when to take a step away.

Practically speaking, students need to be given time and space to put away the curriculum - not just at recess, but during math class itself. We often keep our students busy for fear of wasting time, but always being busy in the context of creativity is itself a waste of time.

With these four steps, we have the complete Creative Engine. Students can creatively take on whatever problem they are given. The next step is being able to find and set up those problems for themselves.

Component 5: F^3 = Find x Formulate x Fix

Everything we've covered so far can be done in various projects of varying lengths and in fairly controlled environments. But there comes a time to take the training wheels off. Students need to be able to do more than fix a problem. They need to be able to seek them out, find the real problem, and wrap their brains around it well enough to meaningfully do something about it.



At this point, it's important to note that you can't solve a problem until you've made a final solution. You've seen it through to the very end. Often, we try to simulate these big, wicked, thorny problems with something real-world that ends in a report. For example, solve the water crisis in California by writing a letter to your congressional official. This sounds nice, but a letter doesn't solve a problem. To solve this problem, the water crisis would need to be eradicated. You can't halfway solve something. You solve it or you don't.

It's important to remember that when you go so open, you don't have to be so big. You want students to practice fully solving a problem, not halfway solving it. When opening the floodgates so to speak, you'll still want to help direct the flow of water. You can still make open ended problems that increase ambiguity without being unreasonably large.

For example, instead of solving the water crisis in California, have students solve the water usage in their home. They now have to figure out how water is used, decide when it's necessary or not, formulate the problem in a solvable way (ex, when they save 25% on our utility bill), then go about iterating on ways to see that formulation happen for real.

You can also implement small changes to existing Science Fair projects. Rather than hypothesis testing and a tri-fold presentation, help students rephrase their question or perhaps find something around the school campus that they want to fix. Help them formulate the problem in a way that they can gauge their own success. In this case, it's nice to note that it's better for students to learn to gauge progress more so than solve it. Gauging progress is of immense value, and they can be very scientific about it.

For example, instead of testing cookies A and B, suppose a kid is diabetic but loves cookies. Create a cookie recipe she can eat that fits within her dietary needs. Maybe the slide on the playground gets too hot. Have them find the root cause, formulate the problem in a solvable way, implement a fix and see if it works. For example, they likely can't move the slide out of the sun, but can they somehow test out ways to block it? Does a tarp help? A white bed sheet? Does it require more bed sheets? A tree? Using the Creative Engine, they'll be able to re-find, re-formulate, or re-fix.

At the very least, have a task for which students determine what success looks like. Sometimes we don't know what the answer is, but we'll know it when we see it and we can sense if something sounds perfect on paper but feels off. Sometimes we can fix this with the way we word a challenge.

For example, it's fairly straightforward to know what the "fastest car" means. But, what about the "coolest car"? How would you know if people found your car the coolest? What goes into people thinking something is cool? How can you tell if your iterations are becoming cooler or not?

In these cases, the kid will feel like a horse running free. The fence-line is there to keep them in check, but they don't immediately see it. It's camouflaged. This way, you can have students fully solve problems and see them to the end without making them so large that no one can actually solve it.

Conclusion: A Final Encouragement

Doing any of these steps in the roadmap will help with the others. As you guide your students through their own creativity, yours will develop as well. Make mistakes, learn from them. Don't be afraid of mistakes, even if public. Being human is about progress not perfection.

Go after educational improvement and don't stop. Creative problem-solving requires relentless pursuit of personal growth. The only real failure is stopping. Your kids are resilient, they don't need you to be perfect. They need to see what it's like to be human and you are the role model to make that happen.

We all feel insecure when we make big mistakes, especially when others are watching. We feel unable to try new things when we are pigeonholed or when the pressure is too high. Recent research suggests that when teachers are told they are responsible for students achieving at a high level (very high pressure), student learning falls. The high pressure pigeonholes us into talking twice as much, giving three times as many controlling statements and two and half times as many criticisms, and offering less student choice. [17]

In other words, the pressure placed on us flows through us and to our students. Sometimes it's enough to know this and help shield our kids from it. We can also choose to not let the pressure control us. Try new things even if you feel you don't have the space to. Give yourself the space by giving yourself permission to act creatively. Regardless of the craziness of life, you have the ability to act creatively. Sometimes you just have to take that freedom. It's not always given freely. If the environment isn't giving you permission, give it to yourself. Give yourself permission to push the pressure aside and be creative. You will be happier and your students will be better for it. It may feel like going out on a limb, but that's the only way to smell the leaves.

You got this.

Appendix: More on Creativity

In this section we curate various conversations about creativity that didn't quite fit in the main chapters. Many of these conversations were mentioned early, but some were not.

Our Core Assumptions About Creativity

Humans enjoy discovering new things. Look at a young child endlessly asking "why?" or the sheer joy we all experience in an ah-ha moment. This form of creativity is intrinsically rewarding.

Humans also enjoy making things. Consider the popularity of television shows around making music or food. Making things is fundamental to what it means to be a human. We make tools, music, food, stories, and more. We find it so valuable that we put forth incredible effort to produce creative outputs; sometimes we even devote our entire lives to it regardless of material benefit.

Creativity is intrinsically rewarding.

Creativity in the form of problem-solving is key to humanity's survival. It always has been. The 21st century problems are hard to solve. If they were easy, they probably would have been solved already.

Creative problem-solving is necessary, intentional, and effortful.

Creativity isn't a black box which some lucky ones have ample access to while the rest of us don't have a "creative bone in our body." Yet some seem to be deeply creative and, no matter what they touch, they make an impact. This is in no small part because they've developed the skills and mindsets to relentlessly pursue ingenuity.

Creativity is something we do, not someone we are.

While it is true that creativity in one area doesn't automatically impose creativity in another, there are certain mindsets and skills central to creativity that cross multiple domains. That is, we aren't limited to only being a creative engineer or a creative artist or a creative (insert your favorite hobby here).

Creativity can be developed and is transferable.

Creativity also requires a climate that supports the decision to "be creative." This climate can be macro (e.g., classroom, school, district, community, news outlet) and micro (e.g., our families, our own minds). Even the most creative among us, don't "turn it on" at the DMV and come up with clever names or birthdays to put on their driver's license.

Creativity can be turned on or off, and is especially fragile in students.

While we cannot control every possible moment of a child's life, as educators we can make a huge impact on building the creative problem-solving capacity of our students. To do this, students don't need to memorize 7-step principles. They need to build a feel for creative problem-solving and self-management. That is, students don't need to memorize recipes for problem-solving and rather how it feels to flow through the Creative Problem-Solving Framework.

Building creativity capacity should be about metacognition, not recipes.

Mathematics and Creativity

In today's math classroom, students find math to be a course in procedure-completing. Mathematics lives in a world of high-stakes testing and standards we can't cover in time. The last thing we have time to do is associate mathematics with creativity. Even if you and I do as adults, perhaps we only do so academically because it's the en-vogue thing to do. Even if that's not true of us, our students surely don't see the connection.

If we back up several decades, mathematics was a humanities with the express goal of building up people's ability to tackle difficult problems and to think through them carefully while also seeing the beauty of the human mind to make deep (even if abstract) connections. This feel however is rarely seen before you are a junior math major in college.

Something striking happens when a student enters a math degree, they are confronted with the notion that mathematics isn't all arithmetic. They take courses generally called something like *Introduction to Mathematical Thinking*. At this point, many leave the major because it's not what they are prepared for. Because of this, all but a few of us never see mathematics beyond formulas and number sense. This is a travesty and needs to be

corrected by slowing down the standards so that students can simmer in ideas rather than be rushed through the algorithms. Creativity can't be rushed, so our standards can't build problem-solvers if they are so dense that we have to rush.

We can't change standards right this second, but all me to offer a glimpse into what mathematics feels like when arithmetic fades away. Once the numeric and calculator-heavy work is done, mathematics switches its focus to understanding how and why things work the way they do. We turn commonly accepted notions upside down to see if there's insights to be had. For example,

- What if addition worked differently?
- What if multiplication is not commutative?
- Can we over force two numbers that aren't zero to be zero? (axb =0, but neither a nor b are).
- Why exactly does the distributive property work?

We flip assumptions are their heads and see which ones offer meaningful shifts of perspective. Every argument now has to be built overtly on assumptions. What are you allowing to be true, what are you not willing to rely on? We don't allow any assumption to go unnoticed.

Quite literally, we are trained to cycle the Creative Engine, although we never overtly say that, nor do we use the word Creative Engine. Nevertheless, mathematics becomes a training ground for creative thinking. Mathematics then, has to be one of the most creative of all human endeavours.

The fact that the curriculum and standards hasn't yet fully teased this out and brought it into all of our daily mathematical classrooms will, in my opinion, become one of the most important curricular problems of our century.

The Tale of Two Companies

This is adapted from *Creativity and Innovation* by Mihaly Csikszentmihalyi.

Two companies, Company A and Company B, are essentially equivalent. They have the same disposal cash. They have equivalent human talent. They are the same size. They are in the same industry. They are working on the same problems. However, one company

produces creative solutions. The other does not. What questions would you ask in order to figure out which company is producing the more creative solutions?

Chances are, you would ask something along these lines:

- Which company has better data in their field?
- Which company focuses more on research than on product marketing?
- Which company proactively seeks new, relevant, and novel ideas?
- Which company makes it easier to test, fail, and learn?
- Which company offers chances for curiosity and exploration?

The punchline here is that the company that values creativity enough to seek out original and pertinent ideas that can be readily tested and iterated is probably the winner here. This is because central to any creative process is testing and iterating. We need to build a culture of expecting and desiring not being right the first time.

Creativity Is Intentional and Effortful

Using the Creative Engine, creativity requires overt and intentional cycling. You can't just turn it on and force it in the moment. It's also important to take breaks. Sometimes the best way to cycle the engine is to take a break. Breaks and sleep, for example, are an important part of unconsciously and involuntarily consolidating ideas and making connections. Part of creativity seems to involve memory consolidation through the hippocampus that comes specifically with taking breaks from the problem.

This also contributes at least a partial answer to why taking walks can be so creativity-inducing. The walk, being only mildly strenuous, allows the brain to consolidate behind the scenes. A breath of fresh air and a change of scenery can be just enough newness or novelty that the brain is free to do its thing with a boost of new ideas. This opens the mind to make connections you may have otherwise inhibited.

Creativity seems to involve three mental stages that bounce back and forth between one another.

1. Intense concentration
    a. Conscious effort, extreme struggle, unclear of what to do, sustained confusion
    b. Often prolonged, requiring we change views and challenge assumptions

2. Breaks
    a. Put it aside for a bit. Sleep, rest, talk a walk, or do something else
    b. The key is a brain break - processing without "knowing it"
    c. Boost the brain break with a dose of novelty, even in simple way (seeing something new on a walk)
3. Insight
    a. Associated with feelings of pleasure, but are often incomplete and require more conscious effort to solidify and flesh out.
    b. We want to be aware of our emotions, but can't just live in excitement. Oftentimes excitement turns to exhaustion because progress is always effortful.

This implies several components of creativity we must accept:

1. Can't just turn it on in one setting
2. Must fall out of love with the exciting idea and in love with iterating it.
3. Need insight, but insight can be naive and needs fleshing out.
4. Creativity takes time.

Creativity can feel very unreliable and slow. As facilitators, we must embrace this ambiguity and confusion. Creative solutions aren't a straight shot to the end zone. It can even take years to produce the level of creative output necessary to open new paths.

Creativity in a Variety of Shapes and Size

There are lots of types of creativity that we should celebrate when we see it. For example,

Changing our minds is creative.
Expanding our thinking is creative.
Making connections is creative.
Making breakthroughs is creative.
Breaking the status quo is creative.
Solving challenging problems is creative.

Creativity presents itself in so many forms, that it's hard to find the unifying features in them. However, in all cases, creativity relies on flowing through the Creative Engine.

The Joy of Creativity can be Misleading

Creativity is often very joyful. The insight that comes through the creative engine often produces a feeling of pleasure. It often feels spontaneous and enjoyable. This highlights why learning, as a creative experience, can be very joyful. But the feeling can also trick us. These sparks of insight are often incomplete. It's why we often stop too soon — especially when we experience deceptive clarity. Deceptive clarity is the joyful sense of insight that we didn't earn like when a teacher explains something and it's crystal clear. You leave the room and you've lost your handle on the concept. Your clarity was deceptive. As a result, learning is fleeting. Vidoes, for example, are rife with deceptive clarity — especially when made fun by a great actor.

It's important to embrace the joy of insight and to share that joy. But those feelings do not mean that your idea is done or that creativity has already happened. It simply means that a wonderfully fulfilling moment, within the broader creative process, has happened.

The most hopeful outcome here is that we can all act creatively. It's not reserved for those with some special gift. We can all learn to do it. Creativity is rarely the work of a lone genius and virtually never the result of a single moment. The most creative achievements often stem from long term, grit-like effort in some areas over years and years. The exciting moment of insight that "came out of thin air" needs cultivation and iteration. It needs to be refined by fire. Getting the cycle spinning offers a way to do this.

Embrace those times of elated insight, enjoy them fully, then get back to work and use that excitement to fuel further iteration and refinement.

Should I Use Examples?

Iteration requires insight to attach itself to enough skills or knowledge to do something about the insight. You don't need to know it all in advance — that typically kills creativity. Creative problem-solving requires a lot of learning as you go. But it also suggests that students need some baseline set of experiences or skills to pick up on early in the process. It's hard to be creative without some sort of baseline knowledge.

One of the most common, and contentious, ways to give students some baseline

understanding is through examples. Some teachers swear by them. Others swear them off completely because it produces 27 copies of the same thing.

It is true that examples can narrow a field of vision. But, they can also be excellent tools. It all depends on how they are used. Examples that reinforce assumptions tend to narrow the field of vision and we end up seeing 27 copies of the same thing. Examples that break assumptions tend to offer a sense of excitement and freedom to explore possibilities we hadn't thought of. When the latter happens, students don't want to copy. They inherently want to produce something new because they feel room to explore.

For example, if you are offering math games that feel like worksheets, calculations, and math facts and then ask students to be creative and build a math game; you'll probably get worksheets, calculations, and math facts. This is because these experiences fit within existing assumptions of what math is.

Examples are tools. Their value lies in knowing when and how to use them. They can be the right tool in a specific context or not. When deciding when and how to use examples in a PBL challenge, consider your answer to these questions:

If "yes", avoid using it.	**If "yes", go for it.**
Does the example reinforce assumptions or define the bar that guarantees success?	Does the example break assumptions that offer freedom to creatively explore?
Does the task and example offer little room for a student to feel a sense of control to offer something unique?	Does the task and example leverage creative expression to leverage our innate desire to do something new?

Test, gain feedback, earn insight, and iterate as you run your applied learning projects so that you eventually zero in on projects and examples that answer "No" to each red question and "Yes" to each green question.

Two Types of Tests

Projects that focus on rapid iteration help take a major step towards building our students' creativity muscles. The key to rapid iteration is rapidly learning. That requires testing ideas

and learning from them quickly. This all sounds very similar to the scientific method because it is.

The main difference is that in a classic scientific method project in school you test to gather data then share the results. You either conduct a test once or the same test time and again. As long as you conduct the test and share data, you pass. Testing within the context of the Maker Cycle is about testing to gain insight, then using it to refine the idea toward a goal for which success is not guaranteed.

For example:

- Scientific Method task: People say that low fat butter doesn't taste as good. Do they prefer cookie A with regular butter or cookie B with low fat butter?
- Maker Cycle task: Create a cookie recipe that doesn't use butter at all and tastes better than both cookie A and cookie B.

The primary difference between these two is what you are testing for. Are you testing for insight or testing to verify or to answer a two-option question?

Test for Insight	**Test to Verify or to Answer**
• It's continuous, ongoing, messy, and often simple. The content should change in real-time if possible.	• A carefully crafted and executed stage on a fixed piece of content.
• The best tests provide real-time and first-hand learning. Often no data analysis necessary	• The best test provides reliable and replicable results through data.
• The goal is immediate, useful feedback that is actionable and offers quick pivots.	• The goal is careful post-test data analysis.
Examples of Each Type	

• Insight
  ○ Doesn't work, but why?
  ○ Entrepreneurs
	• Empirical answer
	  ○ Do I have the flu?
	  ○ How "fast" is gravity?
	  ○ Does this work reliably?

Common Misconceptions
1. Requires a long, initial data gathering and ideation period before you take action. 2. The research approach to testing gives me the best solution.
Need
1. Get testing barriers out of the way. It's better to iterate a first a first idea than to have the "best" first idea. Students need to practice testing quickly, simply, and often. Get the first idea out of the way and iterate it. 2. Test more quickly and in a way that produces insight. The research approach is great to prove robustness. But, it's often too slow to produce the rapid iteration of insight that mathematical thinking desires.

A major difference between these two types of tests aren't necessarily on how you test, but what you look to get out of it. In other words, sometimes insight just requires the mindset to look for it. Both tests are good. Don't pit one against the other. We need both. They each have their proper time and place.

Testing Pitfalls

Regardless of whether you are looking for insight or verification, oftentimes people get neither and get stuck in premature loops and lose any chance for true creative output.

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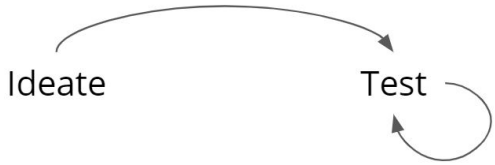
<td> 
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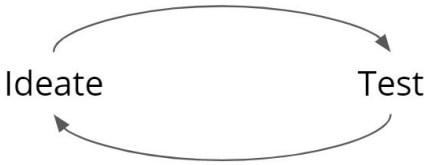
<td> 
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<td>In this case, you ideate once — most likely in either a hurry to publish or an effort to avoid confusion.

You then test and retest over and over. You keep changing the test until you find a glimmer of data that is sellable.

You see this kind of thing all the time when someone is marketing their product based on this “one great study.”

When a company does this, be very wary about the true effectiveness of their product because it’s likely they avoided creative actions and thus don’t have a creative solution. What they are selling probably doesn’t do much of value at all.</td>
<td>In this case, your idea didn’t work. Without data or insight, you change your idea. This often happens when your idea didn’t work and you changed everything about it. You weren’t surgical in what you kept or changed.

This happens when, for example, you lose your keys and have no idea where they are. Instead of testing possible locations smartly, you just come up with a possibility seemingly randomly.

This happens mostly when a test is just a yes/no or right/wrong. You receive no clues about what to do next, you just pick something else.

Lost keys aside, this is very common in student learning products, especially edtech. They give a green check or red x. Then, they try to offer feedback with a standard one-size fits all “hints”. These are not learning moments, nor are they creativity-building.

More on the use of hints in the next section.</td>
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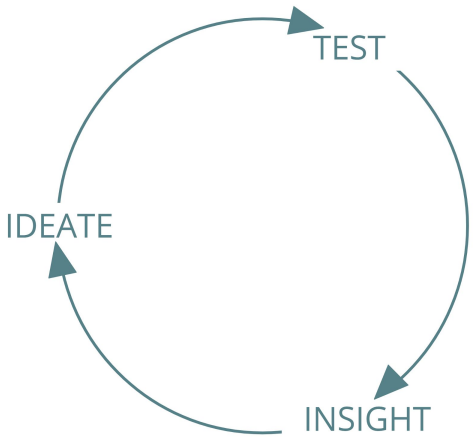
By contrast, the first step in productively managing missteps is the Maker Cycle.



In this case, the test taught you something specific. You get a glimpse of what to keep and what to change, and why. You meaningfully iterate. A key aspect of going through this process is that you improve what you have instead of just replacing it entirely.

As a first step in a maker project, I like for students to cycle through these three nodes at least three times. That is, they take their idea and make at least three meaningful iterations to it. One way to practice this is for students to take something that already exists and, without replacing it, make it better. That is, focus on expanding or nurturing an idea rather than coming up with a fresh one. This helps students get out of the habit of tossing out an idea wholesale.

The way to gain insight from a test is to get useful and informative feedback. Even with this insight, there's still no guarantee of re-ideation. In order for insight to manifest itself into another iteration, you must have enough baseline knowledge to know what adjustment needs to be made. You can get insight into what's working or not and why and yet have no idea what to do about it. This stops the process of actually solving the problem.

To keep it going you need more baseline knowledge. In the case of the maker projects, our baseline knowledge comes from a combination of the play stage, the Maker Story, the quizlets and the Maker Minis. We get informative feedback through having students play tests with other people in real-time and first-hand.

Hints

Let's face it. When we are stuck and someone around us has the answer, we want a hint. In fairness it's usually a trivia game and our hint is a way to phone a friend. I want them too when I'm the odd ball out that doesn't have the answer and people are waiting on me. That's exactly the problem. They are a shortcut around being stuck and stumbling.

Hints create an automatic contract between me and you that I have the answer and you don't yet and so I'll give you the hint so that you are less likely to fail this time. This, in turn, breeds a fear of failure. The whole point of a hint is to avoid failing. This takes away any learning by doing and thus takes away the ability to develop creatively.

Stop right there, you say. Isn't any feedback a form of hint. It shares with the user where they can improve and thus is its own form of contract against failure. Not quite. First of all, we can get informative feedback from others who don't have the answer. This is precisely the concept behind people's infatuation with collaboration. Hints on the other hand means that one person is on the other side of the problem with the solution in hand. Feedback can happen between two of us, neither of which have the answer, as iron sharpens iron.

Informative feedback supports strategy development and helps us refocus our attention and effort. This fuels creative problem-solving. Hints are the opposite. They don't help me re-focus, they by construct, narrow my focus. This destroys autonomy and creative problem solving. Hints encourage me to just get the answer. Informative feedback helps build metacognition for the problem-solving experience so that my capacity for it and my thirst for challenge grow. Simply put, not all feedback is the same.

If you are asking a problem that I have at best a snowball's chance in hell of solving without a hint, it's not a good problem. Hints are a sign of no problem solving. For example, I could guess an answer and get a hint, narrow my selection and guess my way into the right answer. Informative feedback is based on my perceptions and actions and allows me to adjust my perceptions and decide for myself the action to take next. Hints, to me, are a sign of isolated, un-leveled questions that offer me no foundation for making my own decisions and seeing the consequence (good or bad) of them. You can't call BS on one-off questions and be OK with hints. You are on board with both or neither.

Extrinsic Motivators

As a fundraiser, I get it. Raffles offer a quick fix for some intrigue. They let me feel like the fundraiser isn't just screwing me over and taking my money. They get local businesses involved so that all proceeds are indeed profit. That's a nice community-involvement model that is well-respected and understood. I get it.

But at a family event, no way. Raffles only work when my effort for them is minimal. When an experience is intrinsically fun,a raffle is at best unnecessary. More commonly, with a passport model event, the impact is negative. This is just a single example in the broader use of external rewards.

External rewards, especially when used as motivators, have backfired for decades. Not only do they lead to shortcuts like kids getting a stamp as quickly as possible, they lead to shallow experiences. An experience that could be rich, deep, and enjoyable isn't even a consideration. Rewards, like hints, narrow focus. All that matters now is the reward. The effort that the experience encourages is tangential, it's not pertinent to the task at hand. Rather than draw people in to enjoyable experiences, which only happen with effort, we strip away any chance of this happening just to win a bike.

What better way to say "this is super boring" than to offer a raffle to motivate involvement. If the experience can't draw me in to voluntarily stick with it, it's not work doing. In our effort to "make math fun", all we do is say "math is boring, we might as well wrap some "fun" things around it'.

Additionally, external motivators are well documented to errode creative problem solving. Some of these motivators can even be the expectation of evaluation and future benefit, especially "You need this to get a good job".

Action Beats Exposure

I get it. How can we like something or dislike something we've never tried? Maybe our view of math is just so narrow that we need a wider view. I admit, this feels very convincing. There's a fatal problem, and it's a big one.

Exposure requires ZERO effort on my part. If I'm afraid of sharks, you can show me one, tell me how nice they are. Who cares, I'm still freaked out. For me, it's snakes. I don't care how many I see in a glass aquarium, I'm pretty sure that glass is about to break and I'm gonna die. With zero effort comes zero growth.

The only way to advocate in a real way is for people to put forth more effort than they are used to, come away from it feeling like it was fun but challenging and yet with a sense of discovery that leaves me feeling light and free because I took responsibility and action. In other words, I felt effective. This is precisely an openness to challenge. Without effort, you can't have a challenge. Without challenge, you can't be open to it.

Effort-free exposure breeds passive avoidance. Especially in the context of creativity, we have to generate voluntary, sustained, effortful involvement.

Real-World Problems

We want students to leave our classrooms and go into the world and use quantitative and critical thinking to solve problems and as necessary pull from mathematical concepts as necessary to solve those problems. Thus, the goal of education is to prepare you for this. Shouldn't we have real-world problems everywhere? Yes and no.

Real-world problems carry with them a sense of gravitas. They are important, they are big. We can't mess them up. Real-world problems can come off as a superficial motivator. Kids can smell it which means it's an external motivator. Even if we can avoid this, we often use the real-world to apply a sense of urgency - a feeling of paramount pressure. To train creative thinking, we should break away from paramount reality and get as close to play as possible. Play offers tension and a desire to overcome a hurdle, but the consequence of failure is minimal. Students need a relatively safe (low-stakes) environment in which to try out new things. This gives a chance to experiment and avoid the fear and the pain of failure. Real-world does not offer this. Play does.

"Sure, that's fine," you say, "but students can't learn without context. They need to see that what they are doing is practical and good for them." Not true. First of all, when playing a game, all the context I need is that I'm spending time with you enjoying a bit of a break from the concerns of life. Play does this already.

Additionally, recent research sites that using "practical value" as a reason for engaging in an activity is as effective as the external motivators we already discredited. As the user it feels like you are convincing me to do something that isn't worth it simply because it might be useful. Yes, math is useful in the world around us, but arguing for it's practical value makes me cringe. When we do this, we are taking steps away from our goal.

If we want students to actually solve real-world problems, we must stop using them as the "theme" of the problem for which students don't actually solve it. For example, a zero waste challenge or a water challenge. Did the students actually solve a waste problem? Is their solution even less wasteful or did it just sound nice? If real-world problems are so large that they can't be solved in a single problem, they become more or less a motivating theme. The problem is that if there's no actual solution, then success is guaranteed if I just say socially normative words and present something fun. You cannot be creative until the guarantee of success is removed.

One way to keep what's good about real-world problems is to change our focus on the problem itself to the solution. Students benefit from making something with real-world implications. This is the first step in entrepreneurship. If you allow "real-world" to describe the implications of your solution instead of the problem type, now you supercharge creative problem-solving.

Here's a simple way to begin to analyze your projects. Is the culmination of the product being actively used by others in real-time or are you submitting online for a judge to evaluate it or for the audience to passively sit and watch (most likely in a competition or judgey type of way)? The former is better. Consider anything with a show-and-tell model less impactful than a share-for-play mode. The latter has your product used live, in real time by other people. That is real-world impact and it's incredibly motivating..

Open Problems

The real world is full of open problems. Some of them are ill-defined or outright undefined. Solving these problems requires that we first know what the problem is at its core; not its symptoms or the popular answers.

In the classroom, we often try to model this with open problems. This is a good thing. But, to implement open problems well, we want to understand their goal. The goal of open problems is to build student capacity to solve problems like they'll see in life and to encourage their development for creative thinking — divergent, novel, relevant, etc. In other words, think about a problem before you have it all figured out. You can't just google the answer.

With this goal in mind, we can analyze our implementation. I often see that many of us pose open problems, but reinforce closed thinking. Knowingly or otherwise, we push toward intellectual conformity. Intellectual conformity arises when we want others to love our idea. We hope for immediate universal applause or a "Wow, that's creative" from our teacher. Students tend to exhibit this kind of behavior when their open problem is heavily controlled with a process or a rubric.

Despite our best intentions, we don't do our students any favors when the open-ended problem has to fit within a narrow view of success. Rubrics, grades, and processes can stifle creativity.

Truly open problems don't have closed solution paths.
If they did, we'd already have the solution and it would be closed.

Students need to tackle the uncertain and unknown, finding a way to gauge success on their own. This is as important, or more so, than all other components of the projects. Students must develop their own ability to gauge progress towards or away from their goal.

The evidence is clear that truly creative ideas require us to defy the crowd, in which case we won't get the praise we initially hoped for. In fact, immediate praise is a tale-tale sign of a non-creative idea. To be creative, we must also defy ourselves. We have to feel hazy and unsure, yet push through anyway. Sometimes the most creative ideas seem bizarre, useless, or foolish — even to the one who had the idea in the first place.

Taking away these hazy moments can fight creative capacity-building. Many of our solutions to help motivate students and help them navigate larger problems — rubrics, step-by-step processes, grades, expected evaluation — tend to backfire. As a result, we avoid them entirely and instead level students through the metacognition of the creative process. This doesn't help our students.

Because of this, MathMINDs |Maker offers a series of maker challenges, without grades or rubrics, that are clear and satisfying enough that you know what success feels like but ill-defined enough that students don't know exactly what it takes to make it happen.

We are OK if a student actually moves AWAY from the goal but can quantify why and has a sense of what they might be able to do about it. At this stage, metacognition is more important than completing the challenge.

Notes on Common Maker Strategies

Many of our common maker strategies have some value, but also various pitfalls. In each case, they are tools, not a goal in and of themselves. Each of the concepts below is a tool. How we use it determines if it will be effective.

Brainstorming

Brainstorming offers the chance to generate lots of ideas, often in a group setting. It is a strategy for divergent thinking by suppressing judgement and inhibition.

Some research suggests that cognitive inhibition actually supports creative thought by weeding out irrelevant associations (10). That is, it helps avoid the trap of being stuck on an idea that is doomed. Brainstorming seems to suppress such inhibition. So while it is a tool, it's not a golden one. Creative problem-solving is about goal-directed behavior on fairly complex tasks, and often time comes with significant ambiguity. Without the ability to exercise cognitive control, our minds would go all over the place and we wouldn't make much progress. If we've brainstormed a dozen ideas, how do we choose one? How do we know if that idea is doomed?

One of the reasons for the general outpouring of support for brainstorming is in its design to boost divergent thinking (DT). That is, coming up with divergent ideas rather than being functionally fixed on a couple. And this is entirely valid. Functional fixedness is a true trap.

But, DT is not synonymous with creativity — at least not at the level it once was believed to be. Additionally, the third step in our Creativity Roadmap (Leverage Assumptions) is specifically designed for this very moment and offers a way to be targeted and intentional in our ideation while at the same time avoiding functional fixedness.

Regardless of how many steps down the Roadmap you've gone, we can still simply measure brainstorming's impact on creativity. In brainstorming, there is no cycling. In fact, we would explicitly not cycle the idea. That hinders a student's ability to spin around the Creative Engine and thus their creativity.

The worst possible idea cycled ten times is
more creative than brainstorming ten "great" ideas.

In particular, to act creatively, focus on nurturing and improving a single idea as opposed to generating lots of them. It's important for students to fall out of love with good ideas and in love with testing and iterating what they have.

When you test your idea, especially early one, you aren't checking to see if your solution works. Expect that it doesn't. Instead, test the assumptions that gave you the idea in the first place. If you have no idea what assumptions those are, test with the intent of exposing assumptions. Don't merely test your idea or to see if your solution works or not. Test with the expectation of uncovering those assumptions you don't know you have. Once you find them, test again to see if those assumptions are valid or not. An incredible number of paradigm-shifting breakthroughs came about by those who had the awareness to see their assumptions and those of their field. Refusing to just accept the assumptions out there, they forge a new path.

Our lack of creativity is often a result of a fixation on an incorrect assumption. To me, a paradigm can be defined as a "fixation on a particular assumption or set thereof". Creatives can see and feel the paradigms that many of us miss and as a result their fixation relaxes, opening the door to creative breakthroughs.

This kind of thinking isn't for the mental elite. It's for everybody. We all have within us the ability to create. That is, creativity is something we do, not someone we are. It's an action

we intentionally take, or don't. Creativity is effortful. In my experience, true creativity is struggle and effort of the most arduous and unending kind. It's constant, intentional hard work for which you aren't even sure you are on the right path. And often you aren't.

Creativity requires testing our assumptions, decomposing and reconstruction the problem with another viewpoint or other assumptions. Creativity is knowing that there's better out there and being hard to satisfy. You push harder than you thought you would. You are relentless. You don't let setbacks convince you that you are no good.

One way to find assumptions is to look at patterns in other's work. Those patterns may reveal hidden assumptions and/or fixations on them. Perhaps the assumptions are right, but blindly accepting so simply because others do is gonna kill your creativity. Instead, hold those assumptions up to the light. Give them an honest look. Hold assumptions accountable. This is the opposite of brainstorming. I'm saying to be critical and analytical. Do NOT suspend judgement. Expose assumptions and get right to the analysis. Refuse to accept them easily. Whenever possible, mess with the assumptions to help generate new ideas.

Very few of the top creative people just come up with a million ideas and hope one sticks. They generally have an insight that occupies their thoughts. They analyze it, they dwell on it, they think critically and rationally, they seek connections with other things "beyond" the problem. They don't brainstorm. They ideate. Brainstorming is a naive ideation strategy that produces routine, lack-luster results. I don't know of a single challenging problem for which we need to creatively solve it with routine, lack-luster ideas. Brainstorming falls flat. Ideation is intentional. It slices through the problem. It's directed and intentional. Brainstorming is the shotgun effect. Ideation is the sniper. Brainstorming is hoping that one of us has a stroke of insight. Mathematical ideation is much more analytical and razor focused on assumptions. Yet again, brainstorming falls apart, "...analytical thinking underlies all solutions to "insight" problems."~Robert W. Weisberg

It's one thing to have an idea, it's another thing all the more powerful to work with the idea well. Students need more practice working with an idea, improving it not just brainstorming a new one. Ideation is the tool to do this. The mathematics classroom could be one of our most precious training grounds for creativity and ideation. We've developed, over centuries and centuries, tools for coping with problems that overload our working memory. We have graphs, symbols, axioms, etc. We employ several ideation strategies in our search for unity and understanding exposing and challenging assumptions, generalization, abstraction, contradiction, contrapositive, induction, etc.

We miss all of this in math class when our focus is arithmetic calculations. We completely miss what mathematics is and what it is really capable of. Mathematics is one of the most creative subjects humans have ever embarked on.

Creativity lives in our prefrontal cortex. This is the part of the brain responsible for planning ahead by imagining something that hasn't happened yet and working to make it happen. In essence, creativity. Creativity is about imagining what isn't real, yet, and working to make it so.

In animal brains, they have a closed loop between input and output. Some input implies a fairly guaranteed output. I'm hungry and I see food (input), I eat food (output). The reaction is automatic. Predictable. The human mind can handle these tasks as well, but has something phenomenal. A slight disconnect between input and output. In other words, we can decide what the output is. Incredible. This seems small, but the impacts are vast. We can now puzzle over ideas and change our minds. We can build new connections between input and output that we didn't have before. We are capable of abstract thought. We can unpin from this moment and think about the future. We can bend the inputs so that outputs change. We can combine ideas, even seemingly disparate ones, and generate something new. We can rise above our instincts. All of this because we have the ability to separate input and output to a degree that other animals cannot.

Using the Creative Engine as a guide, brainstorming suffers in three main ways.

- Brainstorming doesn't filter through informative feedback.
    - In fact, it seeks to intentionally delay all feedback
- Brainstorming ideas don't flow through the Creative Engine.
    - A cycled idea beats a good idea.
- Brainstorming in a group setting often produces mediocrity.
    - Intellectual conformity is common in a group brainstorm session.
    - The idea selected by the team is often the one with lots of praise — generally one of the least creative ones.

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An initial idea, even a "bad one," is an excellent learning opportunity. We can learn what works, what doesn't, and find clues for how to move forward. The more you cycle, the more creativity snowballs getting bigger and bigger as you get rolling and spinning. It can also be

really fun. For example, a wheelchair ramp made of cardboard obviously isn't strong enough… or is it? Create a wheelchair ramp made entirely of cardboard that works.

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Robert Sternberg, in the book *The Cambridge Handbook of Creativity,* points out that brainstorming is a tool and thus has limits:

1. Brainstorming is targeted to groups, but often creativity happens during times of isolation.
2. Brainstorming could delay valid responses to bad ideas and thus those responses may never happen.
3. Brainstorming is a strategy for searching for ideas, not for evaluating them.
4. Brainstorming isn't very specific. It basically says "come up with stuff without rules." Something more specific would be valuable.

Constraints

Constraints, namely resource constraints, are great in that they are efficient. We don't need many supplies. Teachers don't have to buy or store ungodly amounts of dice and cardboard circles. Constraints also model real-world problems such as an astronaut with limited time and supplies or buying a home with limited finances. Scarcity of resources are all around us.

The research shows that resource constraints, especially too early, aren't the right building blocks for developing our creative muscles. These types of problems come better at the end when we already have expertise. Time constraints, for example, become a high stress environment for a novice problem solver, and in exchange they tend to go with their first idea — which we now know is not very creative.

We have to build students up. Resource constraints (time or supplies) aren't always the best way. One big reason for this is that such problems feel unnatural. This tends to narrow a student's thinking.

The best way to use constraints is to broaden thinking or to offer a tantalizingly tricky challenge.

The best constraints expose thinking.
They shouldn't limit it.

We solve this by offering no supplies. The only "supply constraint" is the one you impose on yourself. We don't overtly impose a constraint — either through limited supplies or through a box of flashy and distracting supplies.

If a student needs something, she can get it or build it. She can convert an Amazon box into a game board or cut out custom-made game pieces. This solves a teacher's supply-storage problem without distracting students by some new or flashy thing and without artificially constraining resources.

Collaboration

One of the best things about human communication is that we can talk about a problem before we have the solution. Through each other, we offer informative feedback we would have missed otherwise. Iron sharpens iron.

This is one of the best uses of academic discourse. Through talking it out, we give one another informative feedback that is hard to find in other ways. We are better together than alone.

Collaboration also offers us a division of labor. Neither of us can solve any problem of value on our own. We can't do everything. We don't have the skillset for it and there's not enough time in a day. We need others. No one is an island.

But, large group collaboration often suffers to see these aspects realized. Instead, when everyone owns it, no one does. When there's too many cooks in the kitchen, nothing gets done. We can pass the blame and never take ownership. True problem-solving requires a strong sense of personal responsibility and ownership.

Too often in a group, the best ideas get shot down, the most creative ideas are almost always rejected. Especially in young people, our sense of self-worth is tied to conforming to others and having them like us. As a result, large groups tend to create group-think and produce mediocrity.

We recommend groups of no bigger than two (maybe three) in the MathMINDs | Maker projects. This allows for discourse and feedback without having too many cooks. A group of one is ok, as well, provided that (s)he tests and iterates often. Testing is inherently a social, collaborative experience.

The best collaboration is intermittent and when I have full ownership.
If everyone owns everything, we each own nothing.

Rubrics

Do you see a rubric for how to solve cancer? Do you see a rubric that guarantees we solve world hunger? Me neither. True problem-solving goes beyond the known and into the unknown. Rubrics are too problem-solving as recipes are to cooking. You can only have a rubric once the solution path is known. Following a step-by-step process only guarantees success if someone's already used that process with success. Recipes reproduce someone else's creativity. If we are talking about problems that have never been solved, we obviously can't do this. There simply is no rubric for solving problems for which there is no existing solution.

Rubrics also create an environment of expected, pending evaluation. Of course they do. Every certified teacher had to fill them out at some point in her education training. And we all know we can fake our way through them and get an "A". Of course we can. A rubric, by construct, tells us what a teacher wants to see. Give them what they want and you pass. But, this is directly opposite to creative problem-solving because it creates convergent thinking. I try to figure out what you want and give it to you. Evaluation of this kind is well known to degrade creative problem-solving.

Breakthroughs happen when we violate the norms, the known solutions of the day, the paradigms of the moment. Rubrics train us to act the opposite.

Additionally, rubrics create a guarantee of success. Namely, do what I say and you'll be fine. You CANNOT solve a problem for which success is guaranteed. If you do so, the problem has already been solved. True problem-solving has no clear path. We must stop convincing ourselves that our students are becoming problem-solvers when they work on a project in which the teacher is the gatekeeper of success. When using rubrics in such projects we, again, degrade our students' capacity to truly solve problems.

Finally, you can't issue a rubric for a problem you haven't solved yet either. In any sort of PBL-like project, loosen the reins. Give students tantalizingly tricky challenges for them to work towards and let them work. If you design them well, intrinsic motivation will offer more learning than our external motivators and controls.

Oftentimes rubrics standardized the means to achieving a particular goal. While it is easy to fall into the rubric mindset, we do want them to begin to navigate the unknown and ambiguous for themselves. To build this capacity, rather than standardized the steps to success, take steps towards building a sufficient foundation and support system for students to find their own means. This is the reasoning behind our role as teachers to cultivate a culture of creativity. We own the learning environment so that the students own their creativity.

Creativity Killers

Using the analogy of humans photosynthesizing creativity, like plants do sunlight, we need to treat the soil and plants do their things. Kids will too. And like plants, there's weed killer which sucks the life out of the plant. What are the weed killers to a child's creative development? Here are a few of the most poignant and well-researched.

- Extrinsic reasons for why to do it with no intrinsic motivation
    - Real-world, later pay off, good job
    - When the reason is extrinsic it becomes more like coercion than true motivation.
- Expected evaluation
    - this can be grades, rubrics, competition, or expert judging
- Expected reward
    - This can be external (raffle, candy) or even judging
- Intellectually conforming tasks (follow recipe, follow rubric)
- Perfectly-defined problems — like word problems we learned how to game.
- No baseline knowledge to fall back on
    - Even with feedback and insight, there's nothing we can do about it without baseline knowledge. We can get this knowledge in real-time, but experience gives us a lifelong stockpile to pull from.
- Too much over the shoulder surveillance while doing the task.
- Fear or strong sense of self — afraid of rejection, tie your sense of worth to positive feedback and praise, mortified of negative feedback

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