Knowledge for the Age of Artificial Intelligence:

What Should Students Learn?

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January 2018

CENTER FOR CURRICULUM REDESIGN

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With Special Thanks to:
Dirk VanDamme (OECD), Courtney Hall, Brendan Griffen, Eron Gjoni, and Stuart Licht for their contributions

EXECUTIVE SUMMARY:

Purposes of Education

The purposes of education originally evolved around imparting religious knowledge, and basic skills of literacy and numeracy. As the structure of society changed, education began to take on other practical, social, and emotional functions. Practically, school is seen as a gateway to higher education and ultimately financial independence. In this view, education serves primarily as a "seal of approval," signaling to future employers that prospective employees have met some minimum social standards of quality control. The social conception of educational systems has slowly matured as the needs of individuals in society, and society itself, have evolved; education is both a way to mold students to fulfill the needs of society, and a means by which students may become empowered to best fulfill their own needs. Finally, school is also perceived in emotional terms, as a place to be inspired and fall in love with learning (which, in a world requiring ever-more continuous adaptation, becomes an essential characteristic). Because learning is now a lifelong endeavor, it is reasonable to consider the differences between the goals of education at the primary and secondary (K-12) levels, and the goals of learning later in life. Learning later in life tends to be necessary for three reasons:

1) **Economic**: specialization for careers, as the opportunities of available jobs continue to shift,
2) **Civic**: staying informed about voting issues as the explosion of information continues to grow, and facts continue to become more difficult to pin down, and
3) **Personal**: for the personal pleasure of picking up new hobbies and continuing to grow and challenge oneself.

Primary and secondary school learning, by contrast, is specifically focused on developing the **foundation** for all future learning, both in terms of knowledge and competencies:

1) **Foundational Knowledge**: a solid base of knowledge on which to build when it comes time to learn more, or from which to apply what was learned in a real world setting.
    a. **Core Concepts**: The most important concepts that students must understand in order to be able to make connections and meaning resulting in transfer.[1]
    b. **Essential Content**: The most important content knowledge that students must know (rather than looking it up) in order to learn concepts and make informed decisions throughout their lives.
2) **Foundational Competencies:** motivation and ability to effectively activate knowledge when relevant and to learn more when it becomes necessary
    a. **Skills:** What we do with what we know
    i.e. Creativity, Critical Thinking, Communication, Collaboration
    b. **Character:** How we behave and engage in the world
    i.e. Mindfulness, Curiosity, Courage, Resilience, Ethics, Leadership
    c. **Meta-Learning:** How we reflect and adapt *i.e. Metacognition, Growth Mindset*

The focus of this paper is Foundational Knowledge; Foundational Competencies are covered in our other papers.[2]

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[1] Transfer: the process of making use of knowledge outside of the context in which it was learned
2 Bialik, M., Fadel, C. (2015) Skills for the 21st Century: What should students learn? Center for Curriculum Redesign.

Let us briefly consider an example. Although Calculus is helpful for the 20-30% of bachelor's degree students who enter college with a STEM major and are expected to take Calculus,[3] what is the experience of the other 70-80%? Further, what is the experience of the ~30%[4] of high school graduates who do not enroll in college? **Currently, even in the best case scenario, students are still spending the majority of their time on material they will never use again once they choose a specialization.**

Knowledge taught in schools must be reorganized such that it is relevant to all students, while at the same time giving each student the opportunities to study in depth the prerequisite knowledge they will need for whatever career trajectory they choose. This is a balance well worth striving for.

Base Knowledge: What do students need to learn?

Overview of Core Concepts

What is learned in school ought to be useful to people well after they finish school. Approaching any new situation that requires using one's knowledge, whether it is a real-world application or learning a more advanced topic in a given discipline, involves leveraging what one has already learned. In either case, existing knowledge must be effectively used in a new context. The more robust a mastery one has developed of the fundamentals of a topic, the easier it is to leverage it to learn even more.[5] By internalizing the most important concepts of each discipline and across disciplines, which we will call **Core Concepts**, students are better equipped to deal with multifaceted problems and have a more diverse set of tools with which to interpret the world.[6] The question thus becomes, how can students' understanding be developed in such a way that it is *useful*?

In his book, *Future Wise*,[7] Harvard professor David Perkins makes the case that curriculum should work toward **expert amateurism** rather than try to instill expertise within subjects. While expertise privileges technical depth, expert amateurism aims for "robust and flexible understanding of the fundamentals".

But the trap of the **coverage mindset** "in which students march through a textbook, page by page (or teachers through lecture notes) in a valiant attempt to traverse all the factual material within a prescribed

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<http://curriculumredesign.org/wp-content/uploads/CCR-Skills_FINAL_June2015.pdf>
Bialik, M., Fadel, C. (2015) Character Education for the 21st Century: What should students learn? Center for Curriculum Redesign.
<http://curriculumredesign.org/wp-content/uploads/CCR-CharacterEducation_FINAL_27Feb2015-1.pdf>
Bialik, M., Bogan, M., Fadel, C., Horvathova, M. (2015) Skills for the 21st Century: What should students learn? Center for Curriculum Redesign.
<http://curriculumredesign.org/wp-content/uploads/CCR-Meta-Learning-FINAL-Nov.-17-2015.pdf>

3 Chen, X. (2013) "STEM Attrition: College Students' Paths into and out of STEM Fields. Statistical Analysis Report. NCES 2014-001." National Center for Education Statistics

4 National Center for Education Statistics <https://nces.ed.gov/fastfacts/display.asp?id=51>

5 Bower, G. H., & Hilgard, E. R. (1981) Theories of Learning. Eaglewood Cliffs, NJ; Prentice-Hall

6 One important consideration, then, is that the world is changing rapidly, and the knowledge that is necessary to interact with the world is thus changing accordingly (more on that later).

7 Perkins, D. (2014). Future Wise: Educating our children for a changing world. John Wiley & Sons.

time" is difficult to avoid.[8] Even frameworks that start with the important concepts typically break them down into minute topics that are not taught in the context of the broader disciplinary or subject concepts, and assessments often cover material only at the most granular level.[9]

While experts readily understand the connections between content details and higher-level concepts, novices do not automatically make those connections. If novices are only taught and assessed on detailed fragmentary knowledge, they may appear to understand the material but are unlikely to be able to make use of what they have learned. In order to use content to build larger understandings that will be useful and transferable, content should be connected with concepts in a way that helps students to create meaning. (See Appendix 1 for an example of tying topics to important concepts). One difficulty is that the most useful knowledge is that which experts apply without a second thought, the knowledge that defines their field and is usually "left unsaid". This is what makes it difficult for experts to create a curriculum that is truly geared toward developing expert amateurism. They know how to expertly work with the content, but they cannot necessarily state the concepts that lead to that expertise explicitly.[10] Imagine being asked to explain how to balance while walking, or how to chew. This is one of the greatest difficulties in creating a K-12 curriculum that builds a foundation for learning in students.

Overview of Essential Content

If students will be expected to build on the base of knowledge they develop in school, one important characteristic of this base will be that it is sufficiently representative of all the ways students could choose to build on it. In other words, by exposing students to many fields of human endeavor through pairing **Core Concepts** with **Essential Content,** schooling can allow children to survey the different possible life and career paths so that they may eventually make informed decisions as to which endeavors they would be best suited to.

In the slightly less long-term view, content must be reconsidered on the basis of society's new relationship with information. Storage of information was scarce for most of human history, but became abundant with the mass production of books. With personal computers, there became an abundance of resources to manipulate information as well. Any simple piece of information can be found quickly online, and powerful computational tools are easily accessible. In addition, the evidence suggests that individuals forget academic content at the rate of 50% every two years,[11] and that what is known in a given field changes over time such that a predictable fraction of what is learned in school will be outdated by the time it would be useful in a professional setting.[12] In such a context, what is the Essential Content that is worth knowing, and not just searching for when it is needed, or learning if one chooses to specialize?

Some content will be the medium that the concepts are taught through, and some limited, appropriate amount of content is worth internalizing to automaticity to build up more complex knowledge later, or to use

8 Wiggins, G., & Mctighe, J. (2005). Understanding by Design, Expanded 2nd Edition.

9 Cooper, M. M, Posey, L. A, Underwood, Sonia M (2017) Core Ideas and Topics: Building Up or Drilling Down? Journal of Chemical Education.

10 https://en.wikipedia.org/wiki/Curse_of_knowledge

11 Subirana, B., Bagiati, A., & Sarma, S. (2017). On the Forgetting of College Academics: at "Ebbinghaus Speed"?, (68), 1–12.

12 Arbesman, S. (2013). The half-life of facts: Why everything we know has an expiration date. Penguin.

in daily life. Content may serve as the way a concept is introduced because it is most exemplified in that context, or, it may demonstrate the generalizability of a concept to near or far contexts (discussed in more detail later). This will allow students to apply concepts to relevant situations they encounter in the future without being explicitly prompted.

In order to maximize its relevance for a rapidly changing world and society, content should be modernized in two ways. First, key modern disciplines (engineering, wellness, sociology, etc.) which haven't had time to be included into the curriculum must be added, and decisions must be made about what parts of the current curriculum should be de-emphasized or eliminated. Second, the way in which (both traditional and modern) disciplines are taught should be modernized. For example, students may be asked to compose a set of tweets Plato may have sent out, or to make a Facebook page for Cleopatra.[13]

Beyond these practical goals, it is generally deemed valuable that students have some capacity to appreciate the fields they are not actively pursuing, for civic engagement as well as for developing a multi-faceted sense of personal meaning.

This is a large set of goals, and in the process of making sure students are exposed to the wide range of ideas and topics in a given discipline, classes are often accordingly designed to be sweeping surveys of the field. This in itself is not necessarily problematic, but presenting students with fragmented information (a common consequence of such a course design) makes it difficult for them to develop conceptual frameworks that they can later use to understand new information or to build upon existing information.

The opposite of fragmented information is meaning. In his book, *Realms of Meaning*[14], Philip Phenix makes the argument that making meaning is the essential human activity, and that education should help students learn the different ways that humanity has successfully developed to make different kinds of meanings. In this view, it may be said that students should get sufficient exposure to the different realms of making meaning, which are related but independent of each other at the most basic level. In building a foundation for future learning and appreciation, meaning is a useful guiding principle, as it is closely related to feelings of purpose[15], understanding[16], and engagement.[17] This type of meaning-making and deep understanding of the logic of a field of study is exactly the type of thing that one cannot simply search for when needed, but rather, must know intuitively when and how to apply. It is also the type of thing that, unlike fragmented knowledge, is not easily forgotten, or changed, with time.

Motivation and Ability to Learn More:

It is not enough for students to build a solid foundation if they do not then use it. In addition to acquiring the raw conceptual and content knowledge, they must be prepared to use it and extend it further. For example, they may need to be curious enough to seek out new information, resilient enough to not give up when it

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13 Jacobs, Heidi H. (2011) TedXNYEd https://www.youtube.com/watch?v=XsUgj9_ltN8

14 Phenix, P. H. (1964). Realms of Meaning a Philosophy of The Curriculum For General Education.

15 Frankl, V. E. (1985). Man's search for meaning. Simon and Schuster.

16 Understanding is in a very real sense equivalent to making meaning, since it must always be active on the part of the learner.

17 Shernoff, D. J., Csikszentmihalyi, M., Schneider, B., & Shernoff, E. S. (2003). Student Engagement in High School Classrooms from the Perspective of Flow Theory. School Psychology Quarterly, 18(2), 158–176.

doesn't come easily, and metacognitive enough to understand they are missing information.

According to UNESCO:[18] "Quality education systems have to enable learners to continuously adapt their competencies while continuously acquiring and even developing new ones. These competencies are diverse in scope; ranging from core skills, content knowledge, cognitive skills, soft skills, to occupational skills, they enable us to meet a complex demand or carry out a complex activity or task successfully or effectively in a certain context. Their typologies and approaches are as diverse as the entities—countries, organizations and individuals—that define them."

In "*Four-Dimensional Education*"[19] the Center for Curriculum Redesign (CCR) synthesizes the curricula from 35 jurisdictions and organizations around the world, and together with input from teachers and administrators, as well as reports on expectations of employers, economists and futurists, creates a unifying framework that is

- **comprehensive**: no major elements missing
- **compact**: actionable and deployable
- **uncorrelated**: no duplication or confusion
- **abstracted to the appropriate level**: organized
- **globally relevant:** for broad acceptability

This framework breaks educational goals into four dimensions: **Knowledge** (what we know and understand), **Skills**[20] (what we can do with what we know), **Character**[21] [22] (how we behave and engage in the world) and **Meta-Learning**[23] (how we reflect and adapt).

The first dimension, Knowledge, is the focus of this paper.

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18 UNESCO, www.unesco.org/new/en/education/themes/strengthening-education-systems/quality-framework/desired-outcomes/competencies

19 Fadel, C., Bialik, M., and Trilling, B. (2015) Four-dimensional education: The competencies learners need to succeed. Center for Curriculum Redesign.

20 Bialik, M., & Fadel, C. (2015) "Skills for the 21st Century: What should students learn?" Center for Curriculum Redesign.

21 Alternatively called socio-emotional skills, non-cognitive skills, soft skills, etc. for more info see: http://curriculumredesign.org/wp-content/uploads/CCR-Decision-matrix-for-Character-terminology-FINAL.pdf

22 Bialik, M., Bogan, M. Fadel, C., Horvathova, M. (2015) "Character Education for the 21st Century: What Should Students Learn?" Center for Curriculum Redesign

23 Bialik, M., & Fadel, C. (2015) Meta-Learning for the 21st Century: What Should Students Learn?" Center for Curriculum Redesign.

PART 1: MAKING MEANING AND THE IMPACT OF ALGORITHMS

Since ancient times, schools have been tasked with helping students build a foundational understanding on which they can later rely when they hone their expertise. The importance of relevance, or meaning, to education and the usefulness of knowledge has always been crucial for making sure that what is learned in school is transferrable. And yet, there is a particular urgency to the question now, especially as it relates to climate change, social disruptions, technological breakthroughs, and the changing landscape of employment opportunities. Although not the only important consideration (consider personal and civic functions described above), one of the most worrying implications of this question has to do with the changing landscape of occupations as algorithms become more prevalent.

Employability

One difficulty with designing curricula to expose students to what they will need to know for their careers is the rapid change in the landscape of available professions due to automation and offshoring; preparations we make to ready students for the world of today will be outdated by the time they graduate. However, automation is not affecting all types of jobs equally. So far, the types of jobs that can be automated are ones that involve routine tasks (Figure 1).[24]

Tasks that are routine are easily automatable, since a computer program can learn to execute a series of steps and follow rules (an algorithm). This is evident in the changing proportions of types of jobs in the figure below; the two types of jobs that have increased have been non-routine interpersonal (such as a consultant) and non-routine analytic (such as an engineer). Routine manual (such as factory jobs) have decreased, as have non-routine cognitive (such as filing paperwork). Non-routine manual jobs (such as plumbing) did decrease but then seem to have hit a plateau, as there continues to be a baseline need for them.

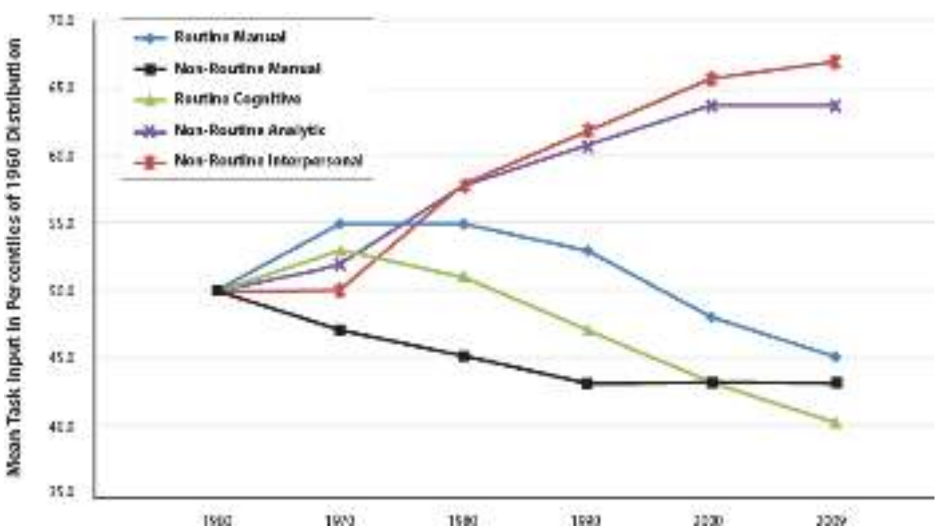

Figure 1: Changing prevalence of types of tasks required for work over time
Source: Autor and Price

24 David H. Autor and Brendan Price, (2013), "The Changing Task Composition of the US Labor Market: An Update of Autor, Levy, and Murnane (2003)," MIT Mimeograph

Several organizations (Oxford University[25], OECD[26], PWC[27], McKinsey[28], and others) have tried to quantify the impact of automation on occupations, with a growing concern about "jobsolescence". Their numbers range from 9% (OECD) to ~50% (Oxford University). The subject has also recently gained the public's attention, with articles ranging from describing a doomsday scenario to a cheerful utopia, and those trying to describe various nuanced positions in between.[29]

The progress of artificial intelligence ("A.I.") has been nothing short of stunning to a large segment of even the technologically literate.[30] [31] One way to examine this trend is through the lens of Bloom's taxonomies for the Cognitive,[32] Affective,[33] and Psychomotor[34] domains. These were made to understand and categorize increasing complexity in thought, emotion, and movement, respectively. The figure below shows that *existing* algorithms already encroach on significant portions of human capabilities, and that is only the beginning of the impact:

25 Frey and Osborne (2013), The Future of Employment: How Susceptible are Jobs to Computerization? University of Oxford.

26 Arntz, M., T. Gregory and U. Zierahn (2016), "The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis," OECD Social, Employment and Migration Working Papers, No. 189, OECD Publishing, Paris.

27 Berriman, Richard, and Hawksworth, John (2017) Will robots steal our jobs? The potential impact of automation on the UK and other major economies. UK Economic Outlook.
https://www.pwc.co.uk/economic-services/ukeo/pwcukeo-section-4-automation-march-2017-v2.pdf

28 McKinsey Global: Automation and The Future Of Work - Briefing Note Prepared For Necker Island Meeting On Education, March 2017

29 e.g Chui, Michael, Manyika, James, and Miremadi, Mehdi (2015) Four Fundamentals of Workplace Automation McKinsey Quarterly
http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/four-fundamentals-of-workplace-automation
Surowiecki, J. (2017) "Robopocalypse Not" The Great Tech Panic of 2017. Wired.
Hensel, A. (2017) "How robots will really take our jobs" VentureBeat
Shewan, D. (2017) "Robots will destroy our jobs – and we're not ready for it" The Guardian: Technology
Jones, M. (2017) "Yes, the robots will steal our jobs. And that's fine." The Washington Post.
Swarte, J. (2017) "The Seven Deadly Sins of AI Predictions" MIT Technology Review

30 It is estimated that historically the exponential acceleration of technology is due to three main factors: ~66% due to hardware speed, ~20% due to solid data sets, and about ~10% to the algorithms themselves. But now, advances in the fundamental algorithms for learning are becoming the main driver of progress.

31 Anthes, G. (2017) Artificial Intelligence Poised to Ride a New Wave. Communications of the ACM, Vol. 60 No. 7, Pages 19-21
https://cacm.acm.org/magazines/2017/7/218862-artificial-intelligence-poised-to-ride-a-new-wave/fulltext

32 Krathwohl, D. R. (2002). A Revision of Bloom's Taxonomy: An Overview. Theory Into Practice, 41(4), 212–218.

33 Krathwohl, D. R., Bloom, B. S., & Masia, B. B. (1964). Taxonomy of Educational Objectives, Handbook II: Affective Domain. New York: David McKay Co. Krathwohl's Taxonomy of Affective Domain.

34 Simpson, E. (1971). Educational objectives in the psychomotor domain. Behavioral objectives in curriculum development: Selected readings and bibliography, 60(2).

Figure 2: Developments in the Automation of the Cognitive, Affective, and Psychomotor Domains
Source: CCR

How clean is this divide between human tasks and computer tasks? Once a task has been automated, is there any role left for humans? Chess is a game that one could imagine playing in a human, holistic way using intuition, or in a robotic, algorithmic way using powerful calculation. In 1997, the computer Deep Blue beat the world champion, Garry Kasparov, at chess, seemingly adding chess to the list of activities in which humans have been outpaced by computers. Similarly, the game of Go has been conquered in recent times, to the point of algorithms even designing innovative strategies that have not been used by human players.[35]

However, while it is true that computers can now beat humans at chess, combinations of the two appear to be stronger than either alone. The results of freestyle competitions have shown that amateur chess players using computers can beat computers alone, grandmasters alone, and even grandmasters using a weaker computer.[36] This is a great example of a situation which appears on the surface to be yet another case of computers encroaching on what was once deemed a uniquely human challenge, but turns out to be an opportunity for humans to use algorithms as tools for doing what humans do best, even better.

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35 https://en.wikipedia.org/wiki/AlphaGo

36 Brynjolfsson, E., & McAfee, A. (2014). *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*. WW Norton & Company.

Entity	Advantage	However…
Computer	Fast generation and testing in big search space of solutions Fast processing over big data	Solution generator is incomplete in the open world Data not a full representation of the open world
Human team	Life experience in the open world Diverse experience of cross-disciplinary teams in multiple domains	There are coordination costs
Human Computer team: (Highest performance)	Complementary kinds of cognition compensate for each other's failure modes and enhance performance	We need a better theory and practices for building human-computer teams

Table 1: Comparison of computers humans, and human-computer teams
Source: Adapted from PARC[37]

A similar process applies to many professional shifts. Calculators didn't replace mathematicians, but rather boosted their abilities. Word processors did not replace writers, but rather gave them more power. Even though the changes taking place now due to A.I. are likely more transformative than those shifts, that does not mean that A.I. will not also be used best as a tool, if the next generation is trained to make use of it.

So where are machines best suited, and where could humans expect an enduring role, and leverage the power of machines? Our summary is as follows:

Areas in which *machines* best *humans*:

- repetitive/predictive tasks
- tasks that hinge on computational power
- classifying huge amounts of data and inputs
- making decisions based on concrete rules

Areas in which *humans* best *machines*:

- experiencing authentic emotions and building relationships
- formulating questions and explanations across scales and sources
- deciding how to use limited resources across dimensions strategically (including which tasks machines should be doing and what data to give them)[38]
- making products and results usable for humans and communicating about them
- making decisions according to abstract values

If all tasks were perfectly algorithmic and able to be subdivided, robots could handle it all. But most of the time, humans are required to frame the problem, choose the data, decide how the pieces fit together,

37 Kefik, Mark (2017) "Half-Human, Half-Computer? Meet the Modern Centaur" PARC Blog

38 Additionally, humans have biases, and their algorithms and data sets can reflect them, so it will be important to account for unintended consequences of the way information is structured and combined.

communicate its value to others, make judgments according to values, and so on. Although many *parts* of jobs are likely be automatable, there is still an important role for humans to play, if they are properly prepared to play it.

Implications for education and what students need to know

Considering the exponential advances of A.I. and its disruptive nature on occupations and tasks, as well as all the other factors of social and personal instabilities, what is a wise strategy for humans to adopt, when it comes to education? Certainly education cannot solve everything – there are political and legislative discussions that must be had – but the focus of CCR is on education.

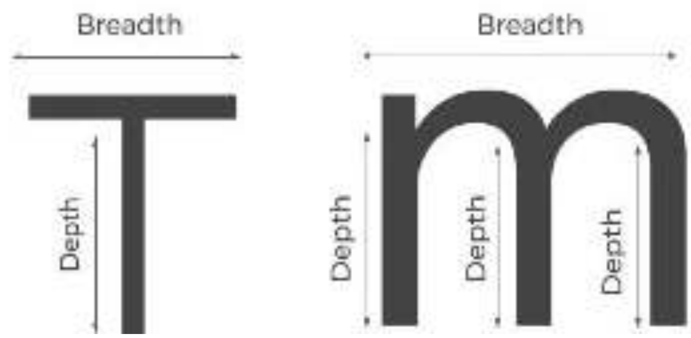

Figure 3: T shaped and M shaped person, for comparison | **Source**: CCR based on Spohrer

Logic would indicate that, in times of unpredictable change, adaptability and resourcefulness would be essential. This in turn makes a case for a more *versatile* education, where one could be broadly trained in a number of domains, and with the skills and character qualities needed to thrive and adapt to other endeavors. This is in a sense what education had always tried to achieve – a solid foundation that translates to preparedness for future challenges – but this has to be done more effectively than ever, given the magnitude of the disruptions.

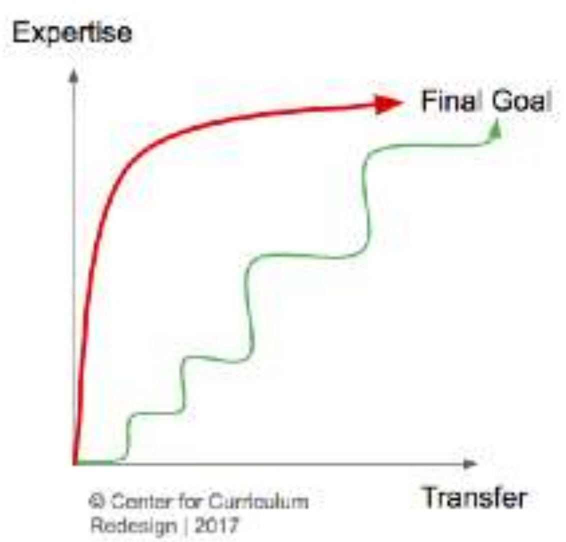

Figure 5: Two ways of reaching the goal of K-12 education: the traditional method, which assumes that transfer can only be a result of expertise (Red) and the proposed method which alternates between gaining transfer and expertise (Green)
Source: CCR

IBM's Jim Spohrer has coined the term **T-shaped person**[39] to indicate the cognitive profile of someone whose knowledge is both broad and deep, not one or the other. To include the projected changes in the workforce, CCR expands this model by describing an **m-shaped person,** who develops several "depths" over their lifetime.

Education has always been about **transfer** (the process of making use of knowledge outside of the context in which it was learned) and **expertise** (a highly developed understanding of some domain of knowledge, including particular ways of perceiving and interpreting information), but now there is more than ever the need to make these the focus of an education[40] in a *deliberate, systematic, comprehensive*

39 https://www.slideshare.net/spohrer/t-shaped-people-20130628-v5

40 Expertise was always understood to be important to focus on, but in the ideal balance, both expertise and transfer

and demonstrable way.[41] The diagram below shows how increasing technological processes provide the opportunity for the emphasis of curriculum to be **flipped** so that students spend more time focused on transfer and expertise via concepts rather than on learning content that can now be easily accessed and manipulated. This is similar to the way that flipped classroom pedagogy incorporates technology for learning content so that class time can be used for activity-based concept learning.[42] Search and A.I. algorithms first encroached on the more fundamental aspects of knowledge (basic facts and processes), but are now reaching the level of specific expertise. Algorithms are expanding upward in their abilities to provide meaning, which can be seen as very beneficial rather than threatening. Rather than spend undue amounts of classroom time amassing information, the time can now be much better spent reaching the more profound goals of an education, namely expertise and transfer, preparing students for the types of tasks they will actually be expected to do in the workforce.

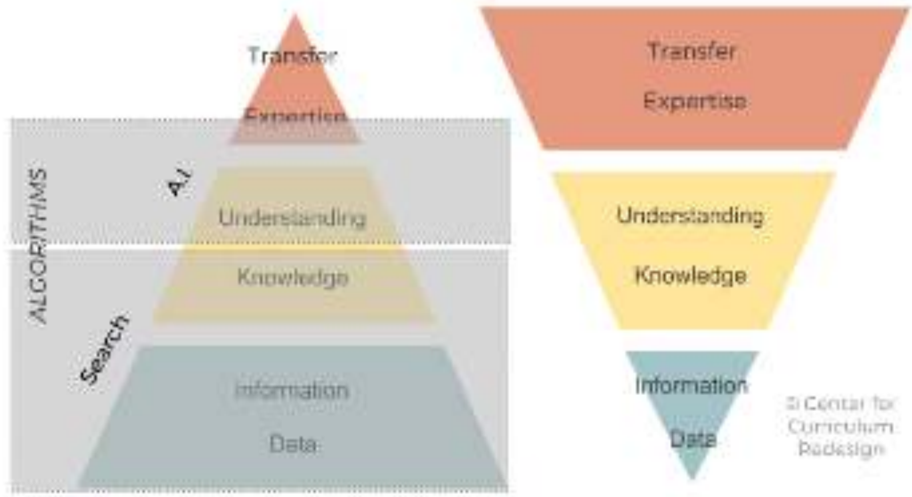

Figure 4: Flipping the Curriculum to account for the encroachment of Search and A.I.
Source: CCR

The main way to reach these goals is to restructure Knowledge around Core Concepts. But content must be modernized as well. One way to approach this is to remove portions of the curriculum that are outdated. A useful metaphor might be one of the game Jenga,[43] where players remove the non-load-bearing blocks without weakening the edifice, thereby keeping the essential structure. (Of course, it is possible to remove too much; the goal is to keep what is essential). Additionally, valuable contemporary topics should be added to the classic content to update its relevance. Finally, the way content is taught should be modernized, making use of new educational as well as professional tools.

The final goal of K-12 education is the combination of expertise and transfer.[44] The relationship between them must also be examined more closely. Just as content can overpower concepts, expertise can become the focus of education, at the expense of transfer. Consider an example from mathematics: drilling procedures for solving trigonometric equations involving arc secants by hand was useful for training land surveyors in a non-digital world, or might have been useful for those who went on to study engineering, just

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would be emphasized.

41 One of CCR's key mantras: yes, here and there, now and then, to a certain extent, such efforts take place. CCR's goal is to make them considerably more "deliberate, systematic, comprehensive and demonstrable"

42 https://en.wikipedia.org/wiki/Flipped_classroom

43 https://en.wikipedia.org/wiki/Jenga

44 e.g. Simonton, D. K. (2000). Creative Development as Acquired Expertise: Theoretical Issues and an Empirical Test. *Developmental Review*, 20(2), 283–318.

as memorizing the Krebs cycle was once useful for those who went on to a career in biology. But for the majority of modern students, both examples often end up serving no real purpose and in fact can be easily accomplished using computers, either using it for search or calculation.

This approach, which focuses on expertise and eventually leads to transfer, is not the only way to reach the goal of combining transfer and expertise, and it has significant drawbacks. Namely, if one stops their development of knowledge within a subject early (as many do, and in most cases K-12 encourages by design), then the potential for transfer remains incredibly low. The detailed understanding remains limited to the domain in which it was learned, and is not useful. It is possible, however, to alternate between teaching for transfer (breadth) and teaching for expertise (depth), such that if one stops early, they've still gained important and transferrable understandings (See Figure 5).[45]

For example, it is possible to gain an understanding of the scientific way of viewing the world by earning a PhD in a scientific field, painstakingly developing expertise by learning the relevant background knowledge, reading dense primary research articles, and designing and executing research studies. But shouldn't the ability to consider the testability and uncertainty of claims – something inherent to science – be internalized sooner rather than later? Shouldn't it be conveyed in every relevant example of scientific knowledge that is taught? Most practitioners of a field will claim that no one piece of information is as important as learning to think in a particular way. Additionally, this "thinking in a particular way" is something that remains inaccessible to computers. Education needs to be restructured to reflect that.

The Importance of Meaning

What makes a foundation of knowledge solid? What makes it fragile? The key lies in making **meaning**.

A useful understanding is one that is meaningful: ideas are connected according to their relationships and applicability. In some sense, meaning and understanding can be said to be synonymous. Experts, who have studied their field in great depth and have devoted their lives to a particular way of making meaning, develop an understanding so deep that they are often able to use their intuition to understand how to approach new challenges in their field. Of course, once one has learned a particular concept in great depth from many angles, it is natural that they will have developed an intuition for it.

But can intuition be developed in those who will not go on to specialize in a subject? Can students be educated to recognize situations to which their knowledge may be applicable, and have informed strategies for how to approach the unknown from relevant perspectives, without developing full technical expertise in all subjects?[46] We believe that they can, if knowledge is presented in ways that facilitate making meaning.

Intuition

Suppose you are a local in a particular city, and you have walked the streets your entire life and know them without having to think about it. No matter where you find yourself, you understand the general area you are

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45 It may be the case that different disciplines have slightly different curves

46 Which is of course not possible

in and how it relates to other areas you have visited. You might be an expert in the layout of that city.

Now, suppose you are trying to teach someone who is new to the city how to get around. You could provide them with a map and start at the top and have them memorize it square by square or pixel by pixel. After all, once you've finished this exercise, they would presumably have a very deep, detailed understanding of the city. Alternatively, you could simply convey to them the largest scale of organization and the useful landmarks of the city. For example, you could tell them the river divides the town into north and south, there is a main street with neighborhoods that branch off of it, and there is a bus that loops along the perimeter of the city. This second method provides a foundation of knowledge that is more meaningful and able to be expanded as the stranger learns more about the city, whether they plan on moving to the city or are there as a tourist. The description that provides the most essential components of the city is more useful, as it helps the stranger to develop an intuition for how to approach making meaning from the layout and landmarks of this city. If they find themselves in an unknown neighborhood, they can look for the river, and find their way, adding what they learn from the experience to their understanding of the city.

That is truly the test of a foundation: can it be built upon, or is it going to collapse under the pressure of new material? If all of the pieces have been added in a way that creates meaningful relationships with all the existing pieces, then it is clear where new pieces ought to be connected. If all the pieces are being collected together in the hope of an emergent meaning arising in the future, any addition to this collection will just be another fragment of an idea to remember, and could be easily lost or confused.

It may seem like some topics are so technical that there is no way to preserve meaning in the majority of the pieces as they are added, or to develop an intuition without developing comprehensive expertise; experts built their understanding in the current system, after all, and therefore may often default to believing that their own journey should be the journey of anyone learning their discipline.

It may be, however, that an expert is in the *worst* position to decide how to introduce students to their discipline. It is common for them to succumb to the "curse of knowledge,"[47] by which they are unable see how novices perceive material, and thus how it should best be presented. Someone with a deep passion for the material and to whom it came easily may have particular trouble imagining the experience of someone who just wants a handle on the foundation, or a struggling learner.

Relevance: Mobilizing Knowledge

Research shows that information is filtered through our perception based on our frameworks for understanding it and our goals. This applies to the lowest levels of perception[48] as well as to the higher levels of cognition.[49] If students' brains cannot find the usefulness of information, it is more likely to be difficult to integrate (understand) the information in a meaningful way. For knowledge to be relevant, it does not necessarily have to be useful in a concrete way; it may be useful for solving an abstract problem or

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47 Wieman, C. (2007). "The 'Curse of Knowledge', or Why Intuition About Teaching Often Fails" (PDF). APS News. 16 (10). Archived from the original on 2016-04-10.

48 e.g. Gauthier, I., Skudlarski, P., Gore, J. C. & Anderson, A.W. (2000) Expertise for cars and birds recruits brain areas involved in face recognition. Nature Neuroscience 3:(2):191–97.

49 e.g. Mack, A. and Rock, I. (1998). Inattentional Blindness, MIT Press

understanding a confusing idea.

Furthermore, relevance has a direct relationship with student motivation. The information gap theory of curiosity[50] posits that a powerful form of motivation arises when there is awareness of a gap in one's understanding. The gap, however, must be of manageable size; if it's is too big or too small, students will be uninterested or intimidated, respectively.[51] Additionally, people like to seek out information on topics they enjoy thinking about, and avoid information on topics they don't enjoy thinking about. This last phenomenon, the ostrich effect,[52] is particularly interesting, as it shows that relevance is highly subjective, taking into account emotional valence that may sway the way someone approaches potentially relevant but unpleasant information.[53]

David Perkins says "Knowledge is like a bicycle. That is, knowledge is for going somewhere. If we know something about the French Revolution or the nature of democracy or Bayesian probability or opportunity cost, we want to go somewhere with it. Maybe we want to understand an issue in the headlines or think about a medical decision or get a project off the ground in the most effective way. For any of these missions and thousands more, we want to go somewhere with what we know."[54] Even going on a leisurely bike ride for pleasure requires the bicycle to be functioning. Put another way, knowledge should not be in a void, rather it should be *useful* for *something*. Acquiring this kind of knowledge is critical for complementing, rather than competing with, computers, which are not able to spontaneously see connections and transfer knowledge to new contexts; humans must do this formulation work by defining the problem, and then recruit computers to do the work within each of the problems that requires computational power.

The idea of functional knowledge is often connected to various pedagogies that focus on **active learning**.[55] As John Dewey said, "only in education, never in the life of a farmer, sailor, merchant, physician, or laboratory experimenter, does knowledge mean primarily a store of information aloof from doing."[56] This was reinforced by the seminal work by Benjamin Bloom,[57] discussed above; in this framework, higher levels of cognitive complexity require greater mobilization of knowledge on the part of the learner, from remembering, to understanding, to applying, to analyzing, to evaluating, to creating.[58] Thus, many people have worked to solve the problem of imparting usable knowledge through pedagogical approaches that focus on the students' active construction and application of knowledge. These approaches shift the focus from

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50 Loewenstein, G. (1994). The Psychology of curiosity: A review and reinterpretation. Psychological Bulletin 116 (1), 75-98.

51 McClelland, D. C., Atkinson, J. W., Clark, P. W., and Lowell, E. L. (1953) The Achievement Motive. New York: Appleton-Century-Corfts

52 https://en.wikipedia.org/wiki/Ostrich_effect

53 Golman, R., & Loewenstein, G. (2013). Curiosity, Information Gaps , and the Utility of Knowledge, 1–50.

54 Perkins, D. (2014*). Future wise: Educating our children for a changing world*. John Wiley & Sons.

55 Including Self-Directed Learning, Experiential Learning, Expeditionary Learning, learning-by-doing, Inquiry Learning, hands-on learning, Project Based Learning, Problem Based Learning, Discovery Learning, and so on

56 Dewey, J. (1916). Democracy and education.

57 Bloom, B. S., Engelhart, M. D., Hill, H. H., Furst, E. J., & Krathwhol, D. R. (1956). Taxonomy of Educational Objectives. The Classification of Educational Goals, Handbook I: Cognitive Domain. David McKay Company. Inc, New York.

58 Anderson, L. W., & Krathwohl, D. R. (2001). A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. Theory Into Practice, Complete e, xxix, 352 and Krathwohl, D. R. (2002). A Revision of Bloom's Taxonomy: An Overview. Theory Into Practice, 41(4), 212–218.

information transfer to student learning, and from “knowing” to “doing.” After all, learning knowledge in a context of its application ensures that it has at least that meaning for the student to use in their conceptual organization. As we will see, however, this is just part of the picture.

Developing a Toolbox of Concepts

Any particular piece of knowledge could in theory be useful in a variety of situations, but it is ultimately up to the student to know how and when to use it, and this is key to the type of understanding that ought to be the aim of education. For example, what use is the knowledge of the definition of “confirmation bias” if a student never checks whether they are succumbing to it? This fits with the common way of describing learning as developing a “toolbox,” meaning each student is honing their proficiency with a set of tools, which are in this case **concepts** they have learned to use appropriately.

There are some concepts, however, that are more powerful than others. The concept of “brute force” vs. “elegance” in mathematics, for example, crystallizes an important idea about the possible approaches to solving a problem; being aware of the type of strategy one is employing (by using this concept as a tool) will help all students, regardless of whether or not they specialize in a STEM[59] field. For this reason, this can be thought of as an example of a “power tool” of thought. Although it was learned in a particular context, it has a *disproportionate amount of utility* for all students.

Core Concepts are the power tools of knowledge and should be of high priority in the curriculum, compared to concepts which offer less leverage for future learning, or worse, fragmentary knowledge which is inappropriately tied to the context it was learned in, and thus difficult to use as a tool in new contexts.

Transfer: Using Learned Knowledge in New Circumstances

Another way to frame this challenge is **transfer** (the process of using a conceptual tool outside of the context in which it was learned). A lot of research[60] has focused on the puzzling findings around the cases in which transfer does and doesn’t occur, but recently, research has suggested that a more productive way to conceptualize transfer is that it is almost always occurring, but it is not always being done in the ways that teachers hope for.

In essence, transfer can be conceptualized simply as activating a set of mental resources to understand some new information.[61] It is a natural process of learning, in which one leverages what they already understand to figure out something they do not yet understand.[62] [63] If students are applying the tools incorrectly or failing to apply them when they are appropriate, that is an indication that the meaning that they’ve made is not complete or accurate in some way. Rather than “failing to transfer,” these students are

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59 “Science, Technology, Engineering, and Mathematics” is frequently abbreviated as “STEM”.

60 e.g. Barnett, S. M., & Ceci, S. J. (2002). When and Where Do We Apply What We Learn? A Taxonomy for Far Transfer.

61 Bransford, J. D. & Schwartz, D. L. (1999). Rethinking Transfer: A Simple Proposal with Multiple Implications. *Review of Research in Education*, *24*, 61–100.

62 Billett, S. (2013). Recasting transfer as a socio-personal process of adaptable learning. Educational Research Review, 8, 5-13.

63 Wiser, M., Smith, C. L., Doubler, S., & Asbell-Clarke, J. (2009). Learning Progressions as a Tool for Curriculum

simply transferring a tool in a way or to a context which does not apply. It also happens to be exactly what computers cannot do: figure out how to do something they have not been trained on without learning it from scratch.

How does transfer take place? When confronted with some new problem, situation, or information, the first thing our brains do is try to find a pattern that matches a pattern they have already learned. They might find an abstract pattern for which they have tools, such as word problem, division, or poems, and activate appropriate tools to that category. This is called **high road transfer**. By contrast, **low road transfer** is when our brains notice a pattern match between the superficial features of the new information, and some superficial features of previous experiences.[64]

For example, suppose a student is asked to solve this word problem: *"Four children have 16 blocks. Their teacher asks them to share the blocks equally between them. How many blocks will each child receive?"* To solve the problem, the student might use high road transfer and realize that to share the blocks equally, they must use division. Or, if the student uses low road transfer, they might notice that the problem structure or vocabulary are similar to other problems that they have solved in the past and know to follow the same procedure to solve the problem. Assuming the students have seen a similarly worded problem in the past, both types of transfer would successfully solve get the correct answer (4 blocks). However, high road transfer allows the student to organize experiences based on their deeper meaning, and thus will ultimately be more useful for transferring knowledge learned in school to questions and experiences after school.

In terms of potential for transfer, Core Concepts, as described in the previous section, can be said to have a high **return on investment**, in that they are applicable to many contexts, without needing to be learned in each one separately. If the goal of the curriculum is to allow students to construct transferrable knowledge, then these power tools should be important to the construction of the curriculum.

Realms of Meaning

In the 1964 book Realms of Meaning[65], Philip Phenix makes the argument that curriculum design should prioritize opportunities for students making meaning, and that disciplines should thus be grouped by the *ways in which they make meaning*: their typical methods, leaning ideas, and characteristic structures. For example, math and linguistics both make meaning using systems of symbols and agreed upon rules. This way of making meaning has been a successful approach and it is worthwhile for students to understand what it means to make meaning in that particular way. Newer disciplines can be sorted into the same categories (e.g. Computer Science would belong to the Symbolic realm).

This is the most abstract level of meaning, in that it is an entire approach to meaning-making. Someone who is a scientist has internalized the Empiric way of making meaning, and will likely look for evidence and consider alternate explanations even in matters of their personal lives. It is along these lines that interdisciplinary work is often most difficult; when values and methods of inquiry do not align it is hard to find a starting point or see each other's position through their eyes. If a K-12 education is to provide a foundation, that foundation should include an intuition for the different possible ways of making meaning. The Realms

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64 Sometimes this happens cleanly, but often a particular situation will somewhat match several patterns. This accounts for students' inconsistent application of certain concepts that are so puzzling to teachers.

65 Phenix, P. H. (1964). Realms of Meaning a Philosophy of The Curriculum for General Education.

of Meaning are:

- **Symbolic:** Systems of symbolic structures with socially accepted rules of formation and transformation (e.g. Math, Linguistics, Computer Science, etc.)
- **Empiric:** Probable empirical truths framed in accordance with certain rules of evidence and verification, and using certain systems of analytical abstraction (e.g. Physics, Biology, etc.)
- **Aesthetic:** Patterns of the inner lives of humans (e.g. Visual arts, Musical Arts, Arts of Movement, and Literature)
- **Personal[66]:** Knowledge of self and others, learned through experience (e.g. Psychology, Philosophy, Literature, Religion, in their existential aspects)
- **Ethical:** Personal conduct that is based on free, responsible, deliberate decision (Philosophy, Psychology)
- **Integrative[67]:** Synthesized from multiple perspectives into coherent integrated wholes (e.g. Philosophy, History, Religion, etc.)

Some disciplines fit into multiple realms, because there are different traditions within them. For example, Psychology can be a way to make personal meaning, a way to make ethical meaning, or a rigorous empirical practice that makes meaning through experiments and analysis. Even disciplines which seem to fit squarely within one realm can be crucially important to consider in other realms; for example, mathematicians would likely consider Math as not only belonging to the Symbolic realm, but also perhaps the Integrative and even the Aesthetic.[68] Rather than strict delineations, these categories provide a way of discussing higher-level patterns in ways of producing knowledge. This abstract way of thinking about formulating questions or making decisions according to abstract values of a community is the exact kind of thing that computers cannot be trained to grasp.

Problematic Knowledge

The results of learning without meaning, or **problematic knowledge**, have been conceptualized in many different ways: fragile knowledge, rote or recipe knowledge, inert knowledge, and the prevalence of misconceptions. These types of problematic knowledge stem from slightly different ways of losing meaning in the learning process.

Figure 6: A deficiency of either Knowing or Doing results in problematic knowledge (recipe and inert, respectively) **Source**: CCR

Fragile knowledge, the most broad category, describes knowledge based on its behavior: it is not a good foundation, because when there is any stress added to it, it collapses and ceases to be useful. As Figure 6 shows, rote, or **recipe knowledge**, is that which is based too heavily on "doing," and not closely

66 In Realms of Meaning this was called "Synnoetic"

67 In Realms of Meaning this was called "Synoptic"

68 Lockhart, P. (2009). A mathematician's lament: How school cheats us out of our most fascinating and imaginative art form. New York, NY: Bellevue Literary Review

enough connected to conceptual understanding, such that students seem to be able to complete the activity that would require certain knowledge, but do not have a deep understanding that could result in high road transfer. **Inert knowledge** is the reverse; students seem to "know" some information when asked, but fail to apply it when necessary. Only high levels of knowing and doing result in transfer. If students simultaneously do not know about a concept abstractly and cannot execute a solution practically, this is simply a lack of knowledge, as shown in the bottom left corner of the figure. In order for students to adequately transfer knowledge from one situation to another, they need to both have a high understanding and a high ability to make use of their understanding.

There is a multitude of popular pedagogical perspectives, all with the general underlying paradigm of **constructivism**,[69] and the general underlying goal of creating active learning experiences for students. This balancing of top-down traditional learning (in which meaning is explicitly told to the students but may not effectively connect to student conceptions and experiences) with bottom-up progressive pedagogy (in which meaning is constructed by the students but may be limited in complexity) is an important part of the implementation of curriculum; if a particular curriculum focuses too much on the side of the top-down, the result will be inert knowledge, whereas if it focuses too much on the side of the bottom-up, the result will be recipe knowledge, Both of these types of knowledge do not transfer properly to new contexts for different reasons. The key here is to balance the need for both bottom-up approaches and top-down approaches, to create a learning experiences in which children create meaningful, useful, understandings.

Misconceptions are simply understandings in which the meaning is not properly constructed.[70] Often there are counterintuitive understandings that a student must learn, but their original ways of making meaning of the world are more solidly established, and they inadvertently rely on them, instead of the more tenuously established complex ones they recently learned in school. Consider the following example which explores why students seem to drop robust conceptions of force mid-explanation[71]:

> …Thinking about the rising ball, students are likely to activate maintaining agency, the idea that effort must be continued in order to maintain the effect ("if you stop pushing, it'll stop moving"). [The idea of] maintaining agency causes students to think that a continued upward "influence" must act on the ball to keep it moving upward. Asked about forces, students unconsciously map "influence" onto "force," leading to an explanation that's consistent with the motion requires force misconception. Thinking about the motionless peak of the trajectory, however, students' intuitive sense of balancing turns on; an upward something seems to be balancing a downward something. Asked again about forces, students map that "something" onto force and say the forces balance.

Ultimately, how a student will interpret a given problem or situation will depend on how robustly they have constructed various understandings, and how the context triggers or fails to trigger these understandings to be used as tools for approaching the question.

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69 The popular pedagogical paradigm created by Jean Piaget in which students actively construct understanding and cannot simply have it "given" to them.

70 These are often called "alternate conceptions" to preserve the idea that they still have meaning, they just do not match the standard.

71 diSessa 1993 as cited in Hammer, D., Elby, A., Scherr, R. E., & Redish, E. F. (2004). Resources, framing, and transfer. Transfer of Learning: Research and Perspectives. J. Mestre. Greenwich, CT, Information Age Publishing.

PART 2: CORE CONCEPTS

Any piece of information can serve as a tool for understanding any other piece of information. So how do we use the idea of knowledge being a tool as we design curriculum? The key lies in identifying and explicitly focusing on **Core Concepts**, the most powerful tools, both within each discipline and across disciplines.

What is most important?

The most complex aspect of curriculum design is to determine the most essential complex abstractions that should be taught to all students, *within disciplines and across disciplines*.

There have been a number of efforts that have worked to highlight abstract concepts to help students build intuitions, make connections and create more generalized understandings. Although they differ in framing and conceptualization, these frameworks are all pointing to the need for **structuring curriculum to facilitate robust and flexible understandings via deliberate organization of concepts.**

Knowing and Doing

As discussed in the previous section, transfer is really the process of "knowing with" an understanding, or using or leveraging previously learned information as a resource. It is thus no wonder that the distinction between knowing and doing has been of interest in curriculum design; in the context of that dichotomy, knowing on its own is synonymous with having knowledge that one cannot necessarily transfer, or use in a new context, whereas doing involves necessarily mobilizing *some* knowledge to make something happen, even if that knowledge is superficial and procedural rather than deeper and conceptual.

It is not a coincidence, then, that various **literacy**[72] and **fluency**[73] efforts that extend that these ideas beyond language have been increasing in popularity. After all, literacy is the ability to "know with" some set of information,[74] and thus conveys the idea of striving for expert amateurism and preparation for future learning.[75] Mastering the Core Concepts of a given discipline is the equivalent of being literate in that discipline, or "thinking like a [practitioner of that discipline]."[76] Unfortunately, as discussed above, these concepts are so foundational to the thinking that they often go without saying, making them difficult to enumerate.

Key Knowledge Frameworks

The CCR framework is highly informed by those that came before it. Rather than re-inventing the wheel, the goal was to create a framework that was as comprehensive as possible, while remaining as simple as

72 e.g. Financial Literacy, Media Literacy, Scientific Literacy, Graphic Literacy

73 e.g. Math Fluency

74 To be "fluent," a certain level of proficiency must be internalized to the degree of automaticity. Unfortunately

75 It is even evident in our clichés, like when a scientist explaining something to a non-scientist who looks slightly annoyed and says "in English, please" meaning that they are not fluent or literate, in this scientific topic.

76 Wineburg, S., Martin, D., & Monte-Sano, C. (2014). Reading like a historian. Teachers College Press.

possible. Of all frameworks reviewed, the following frameworks were key to our final synthesis.

1) Lynn Erickson's and Lois Lanning's work on **Concept-Based Curriculum**[77] identifies interdisciplinary **macroconcepts** such as "change," "interdependence," and "relationships," and discipline-specific **microconcepts** such as "organism," "civilization," and "number." These concepts act as the grounding force in curriculum that then explores them through specific facts in a given topic, as well as **skills** (defined differently than CCR's[78]) and *strategies* that make up **processes**. **Principles and generalizations** show the relationships between concepts.

2) Grant Wiggins and Jay McTighe outline the importance of **Big Ideas**[79] in their work on Understanding By Design and Authentic Education. They describe a big idea as

> By definition, big ideas are important and enduring. Big ideas are transferable beyond the scope of a particular unit… Big ideas are the building material of understanding. They can be thought of as the meaningful patterns that enable one to connect the dots of otherwise fragmented knowledge.

These may include things like "for every action there is an equal reaction," "allegory," "significant figures," or "blood is thicker than water." They discuss three types of big ideas: 1) Important/Timeless big ideas that are interesting to debate and continue to change (e.g. "What is justice") 2) Elemental/Foundational big ideas which point to frontiers in discipline (e.g. "How many dimensions are there in space-time?") 3) Vital or Necessary big ideas for learning core content which provide deep dives into content (e.g. "In what ways does light act wavelike?").

In line with the cognitive science of transfer discussed above, they discuss the importance of highlighting the abstraction from multiple perspectives and encouraging metacognitive thought about it, and advocate for the use of essential questions to guide students' inquiry.

Other authors also discuss big ideas, but describe them slightly differently. Duschl et al. write, "Each [big idea] is well tested, validated, and absolutely central to the discipline. Each integrates many different findings and has exceptionally broad explanatory scope. Each is the source of coherence for many key concepts, principles and even other theories in the discipline."[80] Niemi and Phelan write "The nature of these concepts [big ideas] differs from domain to domain, but in general they are abstract principles that can be used to organize broad areas of knowledge and make inferences in the domain, as well as determining strategies for solving a wide range of problems."[81]

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77 Erickson, L. H., Lanning, L. A., French, R. (2017). Concept-Based Curriculum and Instruction for the Thinking Classroom. Corwin Press.

78 Bialik, Maya, Fadel, Charles (2015) Skills for the 21st Century: What should students learn? http://curriculumredesign.org/wp-content/uploads/CCR-Skills_FINAL_June2015.pdf

79 Wiggins, G. (2010) What is a Big Idea? Big Ideas: An Authentic Education E-Journal. http://www.authenticeducation.org/ae_bigideas/article.lasso?artid=99

80 Duschl RA, Schweingruber HA, Shouse AW. (editors) Taking Science to School: Learning and Teaching Science in Grades K-8. Washington, DC: National Academies, 2007. As cited in Michael, J., & Mcfarland, J. (2011). The core principles ("big ideas") of physiology: results of faculty surveys, *Advanced Physiology Education*, *35*, 336–341.

81 Niemi D, Phelan J. (2008) Eliciting Big Ideas in Biology. Asilomar, CA: Conceptual Assessment in Biology II Conference.

3) **Threshold Concepts (TCs)**[82] are those that experts (often tacitly) hold to be central to the mastery of their subject, that students find counter-intuitive while learning, and transformative once learned. According to Meyer & Land, who first introduced the term:

> A threshold concept can be considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress. As a consequence of comprehending a threshold concept there may thus be a transformed internal view of subject matter, subject landscape, or even world view. This transformation may be sudden or it may be protracted over a considerable period of time, with the transition to understanding proving troublesome. Such a transformed view or landscape may represent how people 'think' in a particular discipline, or how they perceive, apprehend, or experience particular phenomena within that discipline (or more generally).

Some[83] have suggested that TCs could be structured like an interconnected web. This structure (Figure 7) highlights the interconnectedness of TCs and how acquiring one threshold concept could change the completeness of one's understanding of a related TC. Threshold concepts are typically defined within a particular discipline, but "cross-discipline threshold concepts" that would connect concepts across a variety of disciplines have also been discussed[84]. For example, phase transition is a concept that is fundamental to students having a rich understanding of many science, social science, and humanities disciplines.

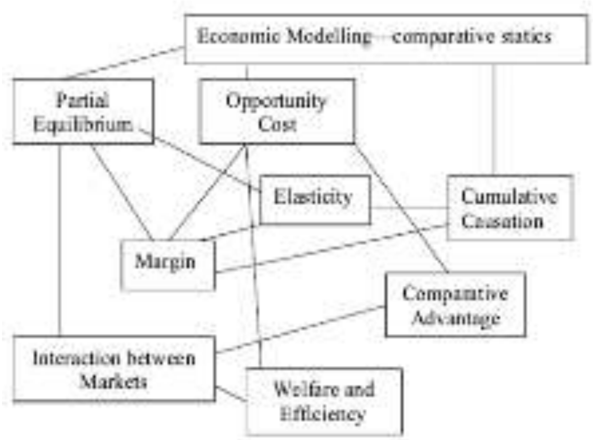

Figure 7: Proposed structure of interconnected Threshold Concepts

4) **Concept maps**[85] grew out of an emphasis on meaningful rather than rote learning, and conceptual structures rather than collections of facts. They are used both as tools for students to create and use to aid learning, and as curriculum tools to drive instruction. Building on concept maps, **cyclic concept maps**[86] showcase the relationships between concepts (Figure 8). The Inquiry Project describes important, empirical relationships among science, math, and epistemology concepts based on how they are best learned.[87]

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82 Meyer, J., & Land, R. (2003). Threshold Concepts and Troublesome Knowledge: Linkages to Ways of Thinking and Practising within the Disciplines. Enhancing Teaching-Learning Environments in Undergraduate Courses Project.

83 Davies, P., & Mangan, J. (2007). Threshold concepts and the integration of understanding in economics. Studies in Higher Education, 32(6), 711-726.

84 Peter, M., Harlow, A., Scott, J. B., McKie, D., Johnson, E. M., Moffat, K., & McKim, A. M. (2014). Threshold concepts: Impacts on teaching and learning at tertiary level. *Teaching & Learning Research Initiative*

85 Novak, J. D., & Gowin, D. B. (1984). Learning how to learn. New York, Cambridge University Press.

86 Safayeni, F., Derbentseva, N., & Cañnas, A. J. (2005). A theoretical note on concepts and the need for Cyclic Concept Maps. Journal of Research in Science Teaching, 42(7), 741–766. http://doi.org/10.1002/tea.20074

87 Wiser, M., Smith, C. L., Doubler, S., & Asbell-Clarke, J. (2009). Learning Progressions as a Tool for Curriculum Development: Lessons from the Inquiry Project.

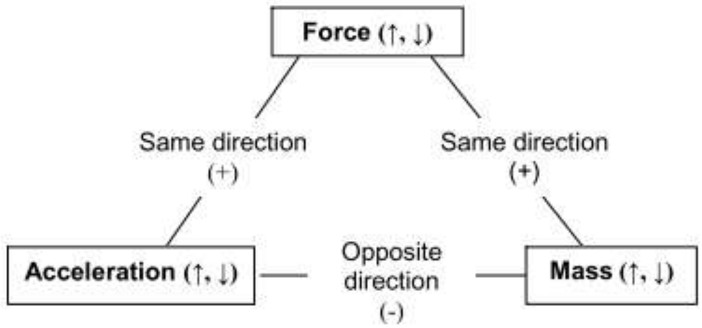

Figure 8: Cyclic Concept Map of F=ma. "+" means change in the same direction, and "-" means change in the opposite direction. I **Source**: Sefayeni, Derbentseva, and Cañnas

5) The Inquiry Project has a view of **learning progressions** for science informed by cognitive science research and centered on concepts, for grades 3-5. They describe learning progressions as a series of *reconceptualizations,* starting with ways of understanding the world that come from directly interacting with it (e.g. weight is reliably assessed by hefting and therefore very small pieces of material weigh nothing) .[88] They propose that learning requires "the reorganization of a large knowledge network that includes many concepts and domain specific beliefs as well as mathematical and epistemological knowledge, in particular about the nature of models, the relation between measurements and visual representations and physical quantities."

After going through a series of empirically determined **stepping stones** which help students move from a **lower anchor,** where student understanding is already solid, to a new state of equilibrium of understanding, called an **upper anchor**. Rather than being pieces of the full expert theory, these stepping stones are conceptualizations that are closer and closer conceptually to the expert theory. As they explain, "our approach is committed to thinking through sequences that work to move the network forward while preserving intelligibility to students."

To help students move from lower anchor to upper anchor via stepping stones, they discuss lever concepts and linchpins. **Lever concepts** are those that are present in the original conceptualization but must be reconceptualized to arrive at the expert understanding. For the subject of matter in physics, weight, size, and material were identified as lever concepts that are important for the development of volume, density, and matter. Lever concepts "are salient in students' everyday thinking, and densely connected to other ideas, so they offer many points of contact with instructional material and therefore multiple sources for conceptual change… In other words, lever concepts provide the 'most bang for the buck[89]'".

What all of these frameworks have in common is a "less is more" approach to content, by placing concepts *first*. Instead of adding yet another element the curriculum must cover, it is consolidating content, structuring

88 Wiser, M., Smith, C. L., Doubler, S., & Asbell-Clarke, J. (2009). Learning Progressions as a Tool for Curriculum Development: Lessons from the Inquiry Project.

89 The authors also mention Linchpins, which are structural representations of concepts that are present in the upper anchor (but not the lower anchor).

it more efficiently, leveraging transfer along the way.[90] As discussed, in order to facilitate transfer, a balance must be struck between doing and knowing. The extreme form of doing results in recipe knowledge, in which one knows *how* to do something, but they are not in fact leveraging deep understanding, rather they are simply remembering the superficial actions necessary to achieve their goal. Therefore, many of these frameworks explicitly try to pair knowing and doing in order to get to the heart of useful knowledge. Similarly, being able to think outside the scope of one discipline entails transfer to a new context, and is therefore also often noted in knowledge frameworks. Table 2 summarizes how the various knowledge frameworks relate to each other within the two dichotomies of Knowing vs. Doing and Disciplinary vs. Non-Disciplinary.

	Know		**Do**	
	Big Picture	Small Picture	Big Picture	Small Picture
Disciplinary	Big Ideas Essential Questions[91] Theories Principles Central Ideas Disciplinary Core Ideas Representative Ideas Threshold Concepts Enduring Understandings	Essential Questions[92] Microconcepts Generalizations	Core Tasks Processes Core Tasks Practices	Strategies Skills
Non-Disciplinary	Lines of Inquiry Essential Questions[93]	Macroconcepts Concepts Cross-Cutting Concepts	Transdisciplinary Skills	Subset Skills © Center for Curriculum Redesign

Table 2: Summary table of types of terms used to describe Knowledge. Understanding by Design (blue), Concepts Based Education (red), International Baccalaureate (orange), Next Generation Science Standards (teal), Realms of Meaning (purple), Meyer and Land (pink), and Rubicon (green)
Source: CCR

Separating knowing and doing into a dichotomy may not actually be productive in the construction of a curriculum. After all, neglecting either one results in fragile knowledge. We therefore do not include this distinction in our framework, and simply focus on designing a process to determine which concepts and content to teach, and how to organize them. Truly learning a concept necessarily entails both the knowing and doing aspects.

Concept Inventories as a Tool

90 An argument has been made that all reasoning/learning is at some level transfer (metaphor, analogy)
91 The type of essential question that deals with what is foundational: these point to big ideas and frontiers in discipline e.g. "How many dimensions are there in space-time?"
92 The type of essential question that is necessary for deep dives into content e.g. "In what ways does light act wavelike?"
93 The type of essential question that deals with what is timeless: these are interesting to debate and continue to change e.g. "What is justice"

Attempts to start collecting, organizing, and assessing the deeper concepts for each discipline have also emerged. At the college level, there have been various efforts to create **concept inventories** for the sciences to assess how well students are learning the key concepts of the discipline. A concept inventory is created by collecting input from experts and educators of a given discipline, and constructing multiple choice tests that diagnose students' particular conceptual structures using "distractor answers" to identify common misconceptions. An example question[94] and its corresponding answer choices is reproduced below:

Imagine that you are an ADP molecule inside a bacterial cell. Which best describes how you would manage to "find" an ATP synthase so that you could become an ATP molecule?
This question is designed to test whether students understand that diffusion is caused by random motion of molecules.

a. I would follow the hydrogen ion flow.
Students who choose this answer think that ADP somehow can identify where a hydrogen ion gradient is.

b. The ATP synthase would grab me.
Students who select this answer think that an ATP synthase senses the presence of ADP and actively grabs it.

c. My electronegativity [is the main factor that] would attract me to the ATP synthase.
Students who select this answer think that charges cause the ADP and ATP synthase to be attracted to each other.

d. I would be actively pumped to the right area.
Students who select this answer think that the ADP is somehow placed in the correct area so that it is close to the ATP synthase.

e. Random movements would bring me to the ATP synthase.
This is the correct answer. In other words, ADP finds ATP synthase by the random motion of ADP molecules.

Through an intensive process of student interviews and iterative question development, these diagnostic tools are developed to be a diagnostic tool of student conceptions on a given topic. The first concept inventory was The Force Concept Inventory (FCI),[95] created in 1992; by 2008, 23 concept inventories had been developed in the Sciences, and had stirred discussion around best teaching practices of Higher Education STEM subjects.

We believe that this effort needs to be expanded in three ways to be effective.

1) it should be used as a curriculum design tool, not just a diagnostic tool,
2) it should include subjects outside of STEM, and
3) it should be adjusted (if necessary) for K-12 students.

This expanded project would likely be most effective if conducted in a digital format, which would allow for continued growth, multiple contributors, interconnected organizational systems, etc.[96]

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94 Garfield, J., & Ooms, A. (2006). Assessment resource tools for assessing students' statistical literacy, reasoning, and thinking. Proceedings of the National STEM Assessment Conference.
95 Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. The Physics Teacher, 30, 141-158.
96 One promising project is Ed's Tools, which offers a computer program to help construct concept inventories for any subject. https://edstools.colorado.edu/

Levels of Organization

As concept-focused knowledge frameworks and concept inventories expand to become the basis for entire curricula, we must consider the hierarchy of concepts and how **content** are paired with **concepts**. Some of the frameworks that we drew from identified concepts that exist at different levels of content (e.g. interdisciplinary, discipline specific, branch specific, or subject specific). We propose explicating this content/concept relationship so that students can most efficiently and effectively make meaning from the **Core Concepts** that exist across and within all K-12 disciplines.

Structuring Content through Concepts

As concept inventories expand to become the basis for entire curricula, they must be organized across different levels of **content**. If a piece of content is not connected to any concept in the curriculum, it will not be connected to a concept in the students' minds, and will therefore not be a useful, transferable, piece of knowledge. Too often, courses are designed to "hit" the main content areas within a discipline to give students exposure to the range of subjects; however, organizing with this goal in mind will almost certainly lead to fragmented, disjointed content.

But how can concepts be organized within disciplines and across them? The seminal Force Concept Inventory refers to a "taxonomy" which groups sets of items into categories such as "Kinematics," "Impetus," and "Action/Reaction pairs".[97] Others have referred to "concept clusters,"[98] use "subtests,"[99] mentioned "macro and micro level"[100] concepts, or explored interdisciplinary concepts such as "maturity."[101] Many frameworks also mention the inter-relationships among concepts. The exact conceptualization depends on the way each framework treats scale, but there is general consensus that concepts are inter-related such that one's understanding of one is affected by and affects one's understanding of the others.

We propose a structure that 1) disentangles content and concepts, and 2) identifies a handful of Core Concepts at *each* level of content organization (with many interdisciplinary connections). Topics are the lowest level of granularity and contain the content itself; they can be taught directly and should be used to exemplify, instantiate, and apply Core Concepts from across the higher levels. One of the advantages of this approach is that specific content (such as "parts of a cell") can inherit higher level Core Concepts (such as "scientific reasoning") and even concepts from other disciplines (such as "division of labor"). This organization helps curriculum designers keep track of the difference between learning objectives and the content used to teach them, facilitating a structure that revisits important concepts from different

97 Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. The physics teacher, 30(3), 141-158.

98 Steif, P. S. (2004). An articulation of the concepts and skills which underlie engineering statics. In Frontiers in Education, 2004. FIE 2004. 34th Annual (pp. F1F-5). IEEE.

99 Evans, D. L., Gray, G. L., Krause, S., Martin, J., Midkiff, C., Notaros, B. M., & Streveler, R. (2003). Progress on concept inventory assessment tools. In Frontiers in Education, 2003. FIE 2003 33rd Annual (Vol. 1, pp. T4G-1). IEEE.

100 Kinchin, I. M. (2010). Solving Cordelia's dilemma: Threshold concepts within a punctuated model of learning. Journal of Biological Education, 44(2), 53-57.

101 Peter, M., Harlow, A., Scott, J. B., McKie, D., Johnson, E. M., Moffat, K., & McKim, A. M. (2014). Threshold concepts: Impacts on teaching and learning at tertiary level, *Teaching & Learning Research Initiative*.

perspectives.[102]

Content Structure

Although there may be useful ways of organizing meaning in each discipline, it is ultimately not crucial to embark on the logistical challenge of reorganizing classes themselves. Rather, the keys to meaning making will be incorporated as Core Concepts at the various levels of organization (Figure 9). For many schools, a massive re-structuring is not possible, and the CCR framework is designed to be as simple to implement as possible.

We therefore identify a set of names that correspond to groupings. Each one is made up of those below it (e.g. Disciplines are made up of branches).

- **Disciplines –** (Mathematics, History, Science etc.)
- **Branches –** (Discrete mathematics, Western civilization, Biology, etc.)
- **Subjects –** (Game Theory, the Russian Revolution, Ecology, etc.)
- **Topics –** (Prisoner's Dilemma, execution of the Romanovs, Foraging etc.)

It should be understood that no ontology and taxonomy can be perfectly coherent all the time and for all uses. At each level, the categories denote a particular grouping of content, and a particular set of defining Core Concepts.

For example, Biology (a **Branch**) as a grouping of content is the study of life and living things; its Core Concepts may be "Structure and function are interrelated," "Natural phenomena tend to take the form of complex systems," and so on. It is part of the scientific approach to knowledge (a **Discipline**), which has its own Core Concepts, which may be something like "Scientific explanations, theories and models are based on collective evidence and always contain a degree of uncertainty," "Applications of science often have ethical, social, economic and political implications," and "Science assumes that for every effect there is one or more causes". This focus on empirical and collective knowledge construction is distinct from, for example, the focus on beauty in the Arts, or the focus on morals or narratives in the Humanities.

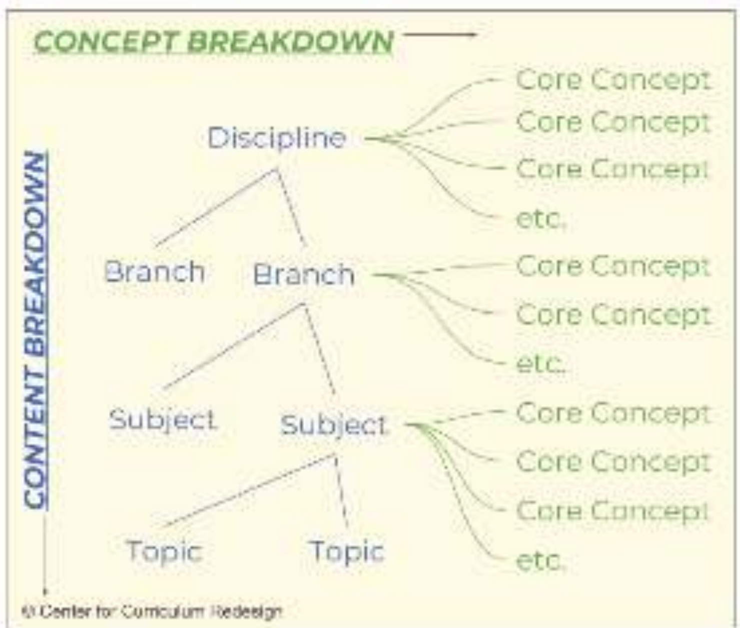

Figure 9: Schematic of Core Concepts at each level of content organization (only Topics can be taught directly, and thus must contain the Core Concepts of the higher level categories). **Source:** CCR

By assigning Core Concepts to each level in the taxonomy, a large and common mode of confusion is avoided. Curricula often choose just a few of these levels and try to encompass all the relevant Core

102 This can be through a "spiral curriculum" a "strand curriculum" "curriculum mapping," etc.

Concepts or Big Ideas within them, resulting in a redundancy, incompleteness, and a confusing mixture of levels. For example, a rigorous study of Core Concepts in Physiology[103] synthesized responses from faculty members to determine the core concepts of their field. Though the list was not initially structured based on how broad or narrow the Core Concept is, we have organized these 15 ideas in three content-based categories: the discipline, the **Branch**, and the **Subject** (Table 3).

Science (Discipline)

Causality: [Living organisms] are causal mechanisms (machines) whose functions are explainable by a description of the cause-and-effect relationships that are present.

Scientific Reasoning: [Physiology is a science.] Our understanding of [the functions of the body] arises from the application of the scientific method; thus, our understanding is always tentative.

Levels of Organization: Understanding [physiological functions] requires understanding the behavior at every level of organization from the molecular to the social.

Mass Balance: The contents of any system or compartment in a system is determined by the inputs to and the outputs from that system or compartment.

Biology (Branch)

Physics/Chemistry: The functions of living organisms are explainable by the application of the laws of physics and chemistry.

Energy: The life of the organism requires the constant expenditure of energy. The acquisition, transformation, and transportation of energy is a crucial function of the body.

Evolution: The mechanisms of evolution act at many levels of organization and result in adaptive changes that have produced the extant relationships between structure and function.

Homeostasis: The internal environment of the organism is actively maintained constant by the function of cells, tissues, and organs organized in negative feedback systems.

Interdependence: Cells, tissues, organs, and organ systems interact with one another (are dependent on the function of one another) to sustain life.

Structure/Function: The function of a cell, tissue, or organ is determined by its form. Structure and function (from the molecular level to the organ system level) are intrinsically related to each other.

Physiology (Subject)

Cell-to-Cell Communication: The function of the organism requires that cells pass information to one another to coordinate their activities. These processes include endocrine and neural signaling.

Cell Membrane: Plasma membranes are complex structures that determine what substances enter or leave the cell. They are essential for cell signaling, transport, and other processes.

Cell Theory: All cells making up the organism have the same DNA. Cells have many common functions but also many specialized functions that are required by the organism.

Genes to Proteins: The genes (DNA) of every organism code for the synthesis of proteins (including enzymes). The functions of every cell are determined by the genes that are expressed.

Flow Down Gradients[104]: The transport of "stuff" (ions, molecules, blood, and air) is a central process at all levels of organization in the organism, and this transport can be described by a simple model.

Table 3: Categorizing Physiology Core Concepts into three layers of abstraction of content
Source: CCR adapted from Michael & Mcfarland

By organizing Core Concepts according to levels, their number for each topic becomes manageable, as higher level concepts apply to all of their lower level elements. In this case, while the subject is Physiology, there is no need to choose between "Scientific Reasoning" and "Flow Down Gradients," because they are organized by scale. The other concept-focused frameworks each only partially divided concepts based on the taxonomy of concepts. Table 4 shows a crosswalk that summarizes the way that CCR's approach

103 Michael, J., & Mcfarland, J. (2011). The core principles ("big ideas") of physiology: results of faculty surveys. *Advanced Physiology Education*, *35*, 336–341.

104 Flow Down Gradients may even be a lower level Core Concept than Physiology.

compares to similar concept-focused frameworks.

<table>
<tr><th></th><th>Concept-Based Education</th><th>Big Ideas</th><th>Threshold Concepts (TCs)</th><th>Concept Inventories (Cis)</th><th>Inquiry Project</th><th>CCR[105]</th></tr>
<tr><td>Interdisciplinary</td><td>Macroconcepts</td><td>Some Essential Questions: Important/Timeless - Interesting to debate; Continue to change e.g. "What is justice"</td><td>Cross- disciplinary threshold concepts (e.g. “Phase transition”)

TCs can be integrated vertically or horizontally in the curriculum</td><td>None</td><td>There are interrelationships among concepts e.g. math is closely related to science

Some important concepts e.g. epistemological concepts are naturally interdisciplinary</td><td>Core Concepts (of Theme)</td></tr>
<tr><td>Discipline</td><td rowspan="3">Theories Principles Generalizations Microconcepts</td><td>Some Essential Questions: Elemental/Foundational - Point to big ideas and frontiers in discipline e.g. "How many dimensions are there in space-time?"</td><td>TCs are generally defined within disciplines: Concepts that are transformative integrative, irreversible, bounded, and potentially troublesome to students.</td><td>CIs are developed within discipline, but the concepts tested may or may not be broadly applicable to the whole discipline.</td><td rowspan="3">Learning progressions are determined empirically and cover concepts at different scales systematically</td><td>Core Concepts (of Discipline)</td></tr>
<tr><td>Branch</td><td rowspan="2">Some Essential Questions: Vital or necessary for learning core content - For deep dives into content e.g. "In what ways does light act wavelike?"</td><td rowspan="2">Little differentiation is made between branch and subject TCs – these are collectively referred to as ‘micro’-TCs</td><td rowspan="2">Most concept inventories are at the branch or subject level (i.e. the Electrical Engineering CI has 3 sub-assessments in Fields, Waves, and Fields and Waves)</td><td>Core Concepts (of Branch)</td></tr>
<tr><td>Subject</td><td>Core Concepts (of Subject)</td></tr>
</table>

Table 4: Crosswalk of Curricula that place Concepts first, and how CCR compares I **Source**: CCR

105 A Note on Terminology: The confusion with multiple names (Core Ideas, Big Ideas, Macroconcepts, Microconcepts, Threshold Concepts, etc.) becomes redundant; at each level, these things refer to those most transformative, essential, core concepts. We therefore concluded that simply using the term “Core Concepts” (in contrast to “Essential Content”), is the best way to clarify our meaning of the term#. (For more information on the decision process, See Appendix 2).

PART 3: ESSENTIAL CONTENT

When asked what teachers hope their students take away from their class, attendees at CCR keynotes around the world as well as teachers in CCR seminars rarely mention specifics of content. In the real world, any particular piece of content is available for search instantaneously. This leads to the question, what content is *essential* to include in a curriculum? To answer this, we must first look at the purposes of content.

If you can search anything, why learn anything?

Learning Happens in Context

Learning happens in a context, and over time it is generalized and abstracted, but isolated information found online cannot fully capture the context in many cases. Daniel Willingham[106] compares this to studying vocabulary words. Students are asked to use new words in sentences when they are learning them, in order to learn not just a definition, but how the word is used in context. When students simply look up synonyms online, they often end up using them incorrectly, such as saying "he meticulously balanced on the edge" (using the definition of "meticulous" to mean "careful"). The same reasoning, he argues, should be applied to all content learning. Just having the ability to look up a fact may not be enough to use and apply that fact properly.

Avoiding the Dunning-Kruger Effect[107]

One important use of knowledge is to guide us to what we don't know, and should learn more about. As adults, there is a critical mass of knowledge that we use to create a rough map of our understanding and its gaps. Actor John Cleese humorously explains the **Dunning-Kruger effect** as "if you're very very stupid, how can you possibly realize that you're very very stupid? You'd have to be relatively intelligent to realize how stupid you are." Without a minimum understanding of a subject area, the trap one is likely to fall into is not just ignorance (which can be cured with an internet search), but "meta-ignorance," ignorance about one's ignorance,[108] which can be far more pernicious.

For example, when reasoning about economic policies, citizens must implicitly estimate various economic realities in order to compare them to an ideal and consider possible changes. In a 2014 Gallup survey, 63% of Americans said that they believed crime rate had been on the rise, despite the crime rate being at a 20-year low. Those who thought crime rates were rising were 8 percentage points less likely to support stricter

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106 Willingham, D. (2017) "You Still Need Your Brain" Grey Matter http://nyti.ms/2rKoSPt

107 Kruger, Justin; Dunning, David (1999). "Unskilled and unaware of it: How difficulties in recognizing one's own incompetence lead to inflated self-assessments.". *Journal of Personality and Social Psychology*. 77 (6): 1121–1134.

108 Poundstone, W. (2016) Head in the Cloud: Why Knowing Things Still Matters When Facts Are So Easy to Look Up. Little, Brown

gun control laws.[109] [110]

If one doesn't know that their estimates are not representative of reality, they may not think to look up the true numbers. In fact, in this study, participants who identified with both major US political parties misrepresented the inequality in the same way and agreed on the ideal distribution. Factual information, therefore, serves a crucial role in one's ability to think critically and creatively.

In fact, having the ability to look things up may exacerbate the effect. In one study, [111] participants who were allowed to use Google to answer trivia questions perceived themselves as smarter than did those who were not allowed to use Google (even when the percent of questions answered correctly was artificially equalized).

Speed, Fluency, and Automaticity

Used in daily life

There is a basic level of each discipline that is necessary for day-to-day living. For example, there is a level of understanding that is necessary for basic math fluency with constructs such as weight, temperature, and money.[112] In neurotypical children this level is achieved without any concerted effort, but it is important to keep in mind which parts of the curriculum will be truly useful for all students' lives.

Part of a shared social background

Consider giving directions to a local compared to a tourist. When speaking to a tourist, we naturally understand that we cannot rely on any shared information or assumptions, and take much more time to explain things that we otherwise would take for granted.[113] Similarly, news and media are not written in a way that explains every single idea; there is a collection of background information that is assumed and relied upon. E.D. Hirsch has worked to identify what content falls into this category for the U.S. (e.g. cholesterol, absolute zero) in his work on Cultural Literacy,[114] although this list would be adjusted for people from various sub-communities and other cultures around the world.

Necessary for more complex concepts

Every complex concept can be said to be made up of smaller pieces of information, which require automaticity to reach the more complex understandings. While anyone can look up anything at any time,

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109 Interestingly, 20 years prior, in 1994, people who thought crime rates were increasing were 9 percentage points more likely to support stricter gun laws, so there is some interaction with rhetoric

110 Kohut, Andrew (2015) Despite lower crime rates, support for gun rights increases. Pew Research Center. http://www.pewresearch.org/fact-tank/2015/04/17/despite-lower-crime-rates-support-for-gun-rights-increases/

111 Wegner, D. M., & Ward, A, F. (2013) "The internet has become the external hard drive for our memories." Scientific American 309.6: 58-61.

112 Patton, J. R., Cronin, M. E., Bassett, D. S., & Koppel, A. E. (1997). A life skills approach to mathematics instruction: Preparing students with learning disabilities for the real-life math demands of adulthood. *Journal of Learning Disabilities*, 30, 178-187.

113 Poundstone, W. (2016). Head in the cloud: The power of knowledge in the age of Google. Oneworld Publications. Chicago

114 Hirsch Jr, E. D., Kett, J. F. and Trefil, J.S. (1988) Cultural literacy: What every American needs to know.

having to look up *everything* would slow down future learning and problem solving. For example, although one could look up any unfamiliar words, this process is distracting from reading. Generally, the more vocabulary one knows, the greater their reading comprehension.[115] This problem is exacerbated in settings where students have to process information in real-time, such as lectures or group work, and do not have the option to look things up whenever they need to.

In such cases, a lack of fluency or automaticity (the combination of accuracy and speed) in lower level components can serve as a bottleneck to learning higher-level concepts.[116] More broadly, research has shown that fluency "increases retention and maintenance of skills and knowledge, endurance or resistance to distraction and application or transfer of training."[117]

But learning a concept is usually not simply the process of amassing the smaller pieces of information that comprise it. This is the thinking behind the research exploring learning progressions: "curricula should be designed to provide students with a systematic exposure to increasingly complex meanings... and grounding them in experiences with particular content and topics".[118] It may be that learning topics in a certain order or through a certain pathway will lead to the knowledge being represented and stored differently, and to serve as preparation for different types of future learning. Therefore, another reason some knowledge may be included in curriculum is that it is part of a particularly effective learning progression.

Content as Substrate for Core Concepts

If the majority of what teachers want students to take away takes the form of concepts that can be applied to new situations, there is still a decision to be made about what content best illustrates the concepts, such that students learn them and are able to transfer that understanding. The context in which a particular concept is learned deeply affects the way it is structured in the learner's mind.[119]

Therefore, when a concept is first introduced, it should be through an **exemplar**[120] – content that naturally demonstrates the concept, such that the student can internalize a set of intuitions. This means it is not merely an example, but it *exemplifies*[121]: it makes salient the features that are relevant to the concept. The exemplar content should be stable, accessible, and have minimal distracting properties.[122] Since each topic is full of information and what is signal for one concept is noise for another, this step often involves some amount of setting the stage and orienting students to the relevant features. By seeing the same concept through different content, the elements which are part of the deeper structure and the elements which are

115 Schmitt, N, Xiangying J, and Grabe. W. (2011) "The percentage of words known in a text and reading comprehension." The Modern Language Journal 95.1: 26-43.
116 Binder, C. (1993). Behavioural fluency: a new paradigm. Educational Technology.
117 *ibid*.
118 Mosher, F. (2017). A Hitchhiker's Guide to Thinking about Literacy, Learning Progressions, and Instruction A Hitchhiker's Guide to Thinking about Literacy, Learning Progressions
119 https://en.wikipedia.org/wiki/Situated_cognition
120 This aligns with the use of the term in Psychology: https://en.wikipedia.org/wiki/Exemplar_theory
121 Elgin, C. Z. (2017). True Enough. MIT Press.
122 *Ibid*.

incidental to the context become apparent.[123]

After that, however, the concept should be explored in less straightforward contexts, with less scaffolding from the teacher. At this stage, the particular topic might be an exemplar of a different set of concepts, but still be an **Instantiation** of a concept that has already been introduced. As the name suggests, the topic is an *instance of the concept,* but being just one instance of many, it also has many other features. In other words, the topic is an example of the concept, but not an exemplar. If the color red has been covered in the context of the color wheel as an exemplar, it may be useful to point out all of the things on the street that are red, (even though this topic – the reason you are on the street – may be the exemplar for learning cardinal directions). That the concept may be not salient (camouflaged, occluded, overshadowed, or a borderline case[124]) allows students to practice generalizing the concept and to fine-tune their understanding.

Finally, the concept can be an **application** to a conceptually distant topic. The challenge may be that the teacher does not explicitly prompt the application of the concept, more closely simulating real life scenarios, and/or that the concept is not salient in the context. In the example of teaching the concept of the color red, the application topic may not include anything that is red, but the student can learn to see that red is part of what makes orange, purple, which are in the application topic. By interweaving contexts which make salient different concepts, a scaffold for *conceptual* understanding can be constructed that enables complex concepts to be built up simultaneously and systematically, in a way that is likely to transfer to real life contexts. While this is the same process by which experts eventually gain this conceptual understanding, there is no reason that it can't also be explicitly used as a curriculum design guideline for students.

This idea is discussed in The Inquiry Project in the context of always teaching more than one concept at a time: "one always is considering portions of several concepts (foregrounding some, backgrounding others), working on successive **subconcepts**, such as scale weight, each of which involves relations among parts of concepts, revisiting concepts and amplifying the subconcepts and contexts considered."[125]

Knowledge as Substrate for Competencies

Although we have not discussed **competencies** in in detail in this paper (please see "Four-dimensional education: The competencies learners need to succeed"[126] for further details), knowledge cannot be

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123 e.g. Quilici, J. L., & Mayer, R. E. (1996). Role of examples in how students learn to categorize statistics word problems. Journal of Educational Psychology, 88(1), 144–161. http://doi.org/10.1037//0022-0663.88.1.144 Tenenbaum, J. B., Kemp, C., Griffiths, T. L., & Goodman, N. D. (2011). How to grow a mind: statistics, structure, and abstraction. Science (New York, N.Y.), 331(6022), 1279–85. http://doi.org/10.1126/science.1192788

124 "Camouflaged: a tiger who blends into the surrounding jungle instantiates being striped but would in that circumstance be unlikely to exemplify stripedness. (It might, however, exemplify how stripes – even orange stripes – can camouflage in a jungle of green.)" "Occluded: a bald man wearing a hat is ill positioned to exemplify his baldness." "Overshadowed: the fearsome timbre of a lion's roar may block its effectively exemplifying its pitch." "Borderline case: even though a chartreuse fire hydrant is a vivid instance of greenness, its color is too close to yellow to be a good exemplar."(Elgin, C. Z. (2017). True Enough. MIT Press. p.191)

125 Wiser, M., Smith, C. L., Doubler, S., & Asbell-Clarke, J. (2009). Learning Progressions as a Tool for Curriculum Development: Lessons from the Inquiry Project.

126 Fadel, C., Bialik, M., and Trilling, B. (2015) Four-dimensional education: The competencies learners need to succeed. Center for Curriculum Redesign.

discussed completely in a vacuum. The perceived importance of teaching students how to think, how to learn, and how to apply socio-emotional skills, often overshadows discussions about *which* content should be taught in the first place. However, it is important to note that learning is highly situated and context-dependent, and competencies are thus best taught *through* some fitting content substrate, or medium.[127] And there is reason to believe that some content may be better aligned for teaching some competencies than others.[128]

For example, it is unclear whether mathematics is a good vehicle for teaching critical thinking (as is often supposed) since the same features that make it very rigorous when mastered, make it difficult to grasp and thus practice for novices;[129] it may be that a more concrete domain, such as social studies, and a more accessible learning mechanism, such as debate, would be more effective. This points to the need for further research into proving/disproving the claims of various disciplines in the development of cognitive competencies.

Modernized Knowledge

When choosing content to include in a curriculum, it is important to make sure that it is not outdated. This is challenging for a few reasons.

First, consensus on facts changes as more information is gathered, and observing the aggregate scale, there can be said to be a predictable rate of decay of facts within a given discipline[130]. Therefore, even if one could learn all of the most relevant facts, as their life continues, a growing fraction of that knowledge will become incorrect. Learning is never finished; it is always setting up a foundation for future learning.

Second, the types of jobs available are changing. Forecasting new professions has always been a difficult endeavor since the tendency to think linearly prevails, and discontinuities in progress, and thus needs, cannot be forecast. Some accounts conclude that automation is fundamentally changing the workforce by eliminating jobs, while others conclude that automation creates almost as many jobs as it replaces. Regardless, the types of jobs available to workers worldwide look different today than they did 20 years ago.[131] Looking at the change in the types of jobs held by workers from 1995-2015 in the figure below, the polarization of jobs is apparent. The number of high-skill jobs (i.e. managerial and professional) and to a lesser extent low-skill jobs (i.e. service and retail) is increasing while middle-skill jobs (i.e. trade work, machine operation, and assembly) are disappearing. Given these trends, there is ever greater urgency to help students to build a strong foundation for complex content areas, and to prepare them for the likelihood that they will likely need upskilling during their lifetimes.

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127 Garner, Ruth. (1990) "When children and adults do not use learning strategies: Toward a theory of settings." Review of educational research 60.4: 517-529.

128 Lehman, D. R., Lempert, R. O., & Nisbett, R. E. (1988). The effects of graduate training on reasoning: Formal discipline and thinking about everyday-life events. American Psychologist, 43(6), 431–442.

129 Bialik, M., & Kabbach, A. (2014) “Mathematics for the 21st Century: What Should Students Learn? Paper 4: Does mathematics education enhance higher-order thinking skills?” Center for Curriculum Redesign

130 https://en.wikipedia.org/wiki/Half-life_of_knowledge and in particular Thierry Poynard’s article in Annals of Internal Medicine, vol 136, p 888 and Rong Tang’s http://crl.acrl.org/content/69/4/356.full.pdf

131 OECD (2017), OECD Digital Economy Outlook 2017, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264276284-en

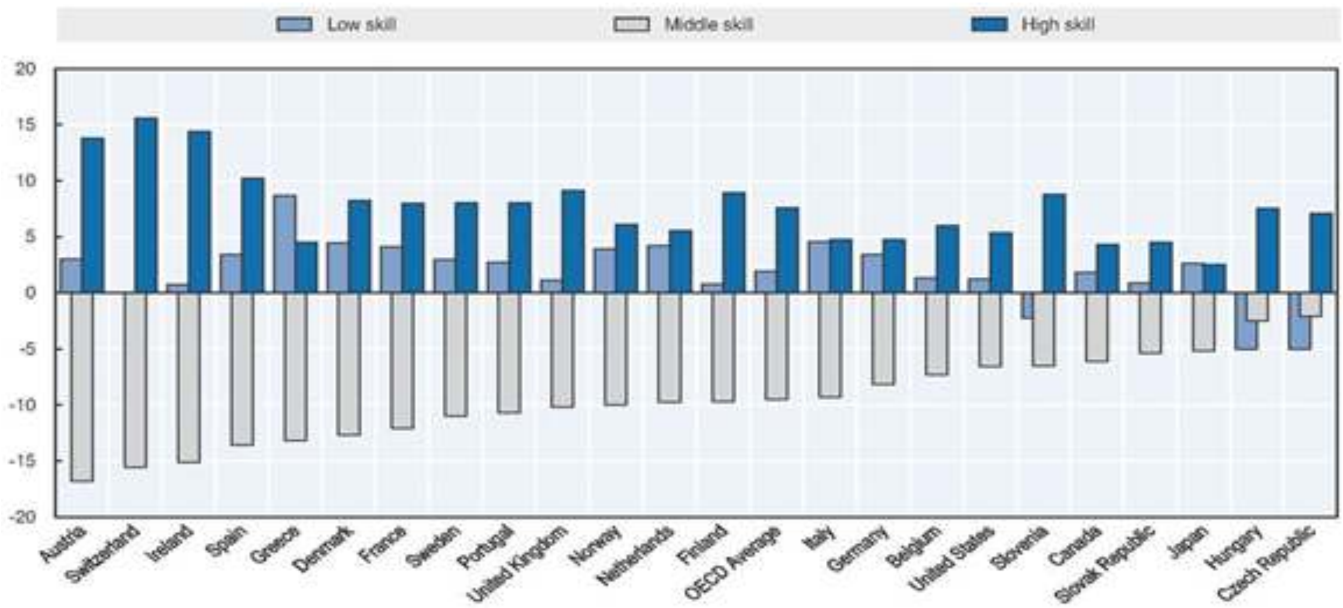

Figure 10: Job polarization by country: Percentage point change in share of total employment, 1995 to 2015. Across all countries, the number of middle skill jobs (gray) decreased by an average of about 10%. high skill jobs (dark blue) increased by about 8% and low skill jobs (light blue) increased by about 2% on average
Source: OECD

Specifically, tasks that involve predictable physical work, data processing, and data collection are the most susceptible to being automated, while also accounting for ~50% of all work activity in the US (see Figure 11).[132] The jobs least likely to be automated are those that require expertise, interacting with other people, and in particular, management skills. This makes intuitive sense, since algorithms will take over the most rote tasks first, people will need to manage these computers just as they managed those tasks when they were being performed by humans.

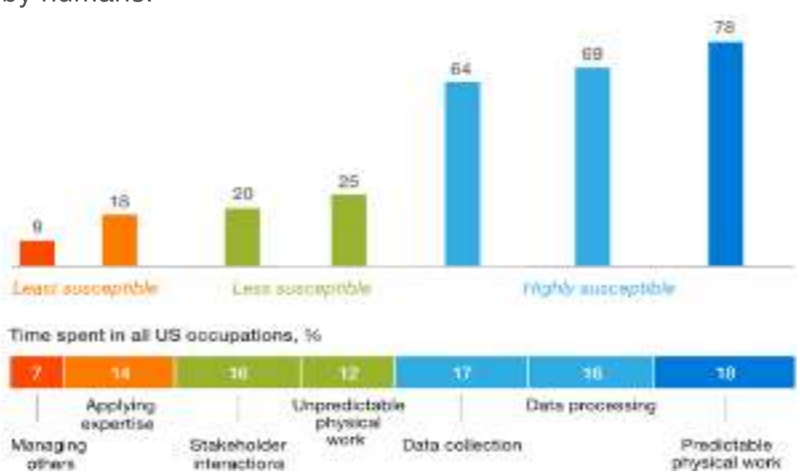

Figure 11: Top: Percent of time spent on activities that can be automated by adapting currently demonstrated technology. Bottom: Percent time spent in all US occupations I **Source**: McKinsey

132 Michael Chui, James Manyika, and Mehdi Miremadi (2016) Where machines could replace humans—and where they can't (yet). McKinsey Quarterly https://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/where-machines-could-replace-humans-and-where-they-cant-yet

Third, it is important to consider the larger trends taking place. The world is changing at an increasing rate along multiple fronts: technology, environment, globalization, and advances in our understanding, which ought to change the content that should be included in the curriculum. Ideally, education reform would minimize the lag between human progress and preparation for people to enter the changing landscape of the workforce, society, and life. Each of these will require different content areas to be added to the now outdated curriculum, and various updates to be made to the focus of what students ought to take away from those content areas.

These trends will affect what is important in the entire range of ways of making meaning and can be summarized into the following major changes:

1. **Technology:** trends that are forecast[133] to be particularly transformative are:
    a. the rise of smart machines and systems (robotics etc.)
    b. massive data and new media ("big data", social networks/media, etc.)
    c. "amplified humans" (artificial intelligence, robotics, gene editing, etc.).
2. **Environment:** Climate change is a new and large-scale challenge, whose stresses and demands must be addressed[134]
3. **Globalization:** People and organizations are increasingly interconnected, and creating previously unforeseen emergent patterns.[135]
4. **Social Unrest:** With greater inequality, polarization, distrust and large-scale changes, there is global social unrest that must be addressed.
5. **Advances in the Fields:** Curriculum often fails to include new findings due to already being full; it should be updated to include the important recent discoveries

One way to capture these changes is through the six Realms of Meaning mentioned earlier. Each of these roughly encapsulates a set of disciplines, making it a simple way to make sure that the full range of content is considered. Cross-referencing these two sets of categories produces a table that illustrates the types of topics or disciplines that need to be emphasized or added wholesale. The table below illustrates some examples at their appropriate intersections.

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133 Davies, A., Fidler, D., Gorbis, M. (2011) "Future Work Skills 2020" Institute for the Future
134 ibid.
135 ibid.

Major Change → Realm of Meaning ↓	Technology	Environment	Globalization	Social Unrest	Advances in the Fields
Symbolic:	Statistics, Big Data, Programming	Data Analysis, Modeling	Natural Language Processing for Translation, international law (the UN?), International economics	Political Science, social justice theory, philosophy, law	Game Theory, Logic
Empiric:	Robotics, Engineering, Household electronics	Solar Panels, Wind turbines, climate change	Natural language processing for different languages	Information Literacy for Social Science	Quantum Physics
Aesthetic:	Private vs. Public Self Image	Appreciation of nature's beauty, landscape art	Developing taste for different cultures (food, art, music, way of life, etc.)	Exposure to inner life of humans different from ourselves	New Media; New Art Movements
Personal:	Social media/communication, marketing	Awareness of ecological footprint, citizenship and activism	Entrepreneurship, Cultural sensitivity	Practice proper debate, based on understanding, community organizing	Wellness
Ethical:	Autonomy and accountability as we become more merged with machines; Distributed Trust[136]	Leaving the earth better than we found it for future generations	Cultural sensitivity	Clear ethical framework regardless of tribe;	Moral Psychology
Integrative:	Triangulating sources	Interconnected systems (economics, ecological, psychological etc.) work together to create the large scale trends we find ourselves in	Multiple perspectives, e.g. international view on the history of intellectual discovery	Integrating different perspectives on social issues	Postmodernism and reactions to it

Table 5: Examples of content to add based on cross referencing Realms of Meaning with the major changes facing society
Source: CCR

What Content Should be Added

In order to reflect the changes that are occurring in society, it is important to add modern disciplines, branches, subjects, and topics where appropriate, and not be constrained by inertia. Currently, these disciplines have been crowded out by the traditional disciplines, and yet they are becoming increasingly useful and deserving of space in the curriculum. Below is a (non-exhaustive) list of modern content areas

136 e.g. Botsman, Rachel (2017) Who Can You Trust: How Technology Brought Us Together and Why It Might Drive Us Apart https://www.amazon.com/Who-Can-You-Trust-Technology/dp/1541773675

that should be integrated into curriculum as they are now widespread in use and in importance:

Technology & Engineering:

This includes Computer science, in particular: Coding, Robotics & Artificial Intelligence; Bioengineering, in particular: Genome editing and Synthetic Biology; as well as advanced manufacturing including CAD, 3-D printing.

Media:

The changes that the internet has made to society have just begun, and already they have been transformative. Everyone constantly consumes and creates media, and this has become inextricable from the social world. And yet, no one is taught how to properly and healthily use this media. Curricula must change to keep up. This includes journalism, including the different forms it is now beginning to take, and audio/video. If everyone can make a video about anything, what does this mean to interact with this world in a productive way? How can one discover their voice?

Entrepreneurship & Business:

As jobs continue to become more polarized in the skill levels they require, as the landscape of what is needed in the workforce continues to change, and as the economy nevertheless continues to grow, students will need to be prepared to take advantage of opportunities that present themselves throughout their lives. It is often no longer enough to find a job out of college and work there until retirement. Students must be prepared to approach their careers from a business perspective.

Personal finance:

As jobs become less stable and opportunities become more varied, while the laws are becoming more complex, and personal debt continues to grow, those entering the workforce need to have some preparation on how to organize their financial lives. This is perhaps the most applicable knowledge students will learn, and is relevant to all students.

Wellness:

Rather than only treating problems when they become a serious issue, students should be taught how to proactively take care of themselves mentally and physically. This has come to be known as “Wellness” and is a very broad category, and often spanning some sort of space from physical education and health education. In a society in which problems like depression, anxiety, obesity and back pain are common problems, students should be informed and empowered to keep themselves well. They should also be taught about interpersonal wellness: what constitutes emotional or psychological abuse, and be given practice developing their own foundation of emotional awareness.

Social Sciences:

The social sciences study humans as their topic, but use systematic methods to do so. This may include Sociology, Anthropology, Psychology, Political science, Future Studies, Civics etc. This area of research has not only made great advances and become very important in many professions that deal with humans, but it also entails an important and unique way of making meaning of the social world. The world students need to be prepared for is increasingly interpersonal, and Social Sciences addresses these topics.

Naming the disciplines, branches, subjects, and topics that may become more relevant due to the trends in progress is only the first step. As this material gets integrated it will be necessary to identify the core concepts and an effective scope and sequence through them. It is also important to note that while modern disciplines need to be added, this does not mean that traditional disciplines must be abandoned. Adding modern disciplines can be an act of consolidation, as the important concepts from previously separate subjects may unite new and old material, while strengthening and deepening the potential for understanding.

What Content Should be Removed

The method of consolidating does mean that some content must be removed. The redesigned curriculum should be more efficient, doing more with less, as discussed above. In many ways, the curriculum has been extremely stagnant, even since ancient times (See Appendix 3). It is an important part of the redesign process to comb through the content of the curriculum and remove anything that is obsolete, or redundant and not an efficient use of time. This is often the hardest part, since it may feel risky to remove something that has been present for so long and is present in so many other curricula (and when done well, may be useful as an instantiation of a concept). According to Perkins, "Curriculum suffers from something of a crowded garage effect; it generally seems safer and easier to keep the old bicycle around than to throw it out."[137] But the point of the curriculum, as discussed, is not to cover as much content as possible. Without this process of removal, change cannot happen.

Non-Disciplinary Structures

So far the discussion of curriculum structure has been under the assumption that disciplines are relatively distinct, as is their teaching. However, this does not have to be the case.

Disciplines have been a convenient way of organizing knowledge, but if change is to happen and deep, relevant, transferrable concepts are to be learned it is likely that a more **interdisciplinary approach** will be needed. After all, if the most important things about knowledge are its relational qualities–mapping ideas and activating resources–more relationships across more disciplines will be a powerful way to bolster mental models of concepts (as well as consolidate content). For instance, "exponentials" (from mathematics) can be taught alongside "compound interest" (from finance) and "financial bubbles" (history, sociology), as well as "bacterial growth" (biology) and "resource exhaustion" (environmental literacy).

Additionally, interdisciplinary approaches can be a powerful motivational tool, as students may explore different contexts, meanings, and applications of concepts, and find angles they are personally curious about. This allows students to be guided by **intrinsic motivation**, or interest, rather than **extrinsic motivation** like grades or performance.

A report issued by the National Academy of Sciences[138] in the United States identifies four primary drivers

137 Perkins, D. (2014). Future wise: Educating our children for a changing world. John Wiley & Sons.

138 National Academy of Sciences (2004). Facilitating interdisciplinary research. Washington, DC: National Academies Press. pp. 2, 40

of interdisciplinarity today:

- the inherent complexity of nature and society,
- the desire to explore problems and questions that are not confined to a single discipline,
- the need to solve societal problems,
- the power of new technologies.

Accordingly, the interest in interdisciplinarity and its analogues has rapidly emerged since the 1960's.

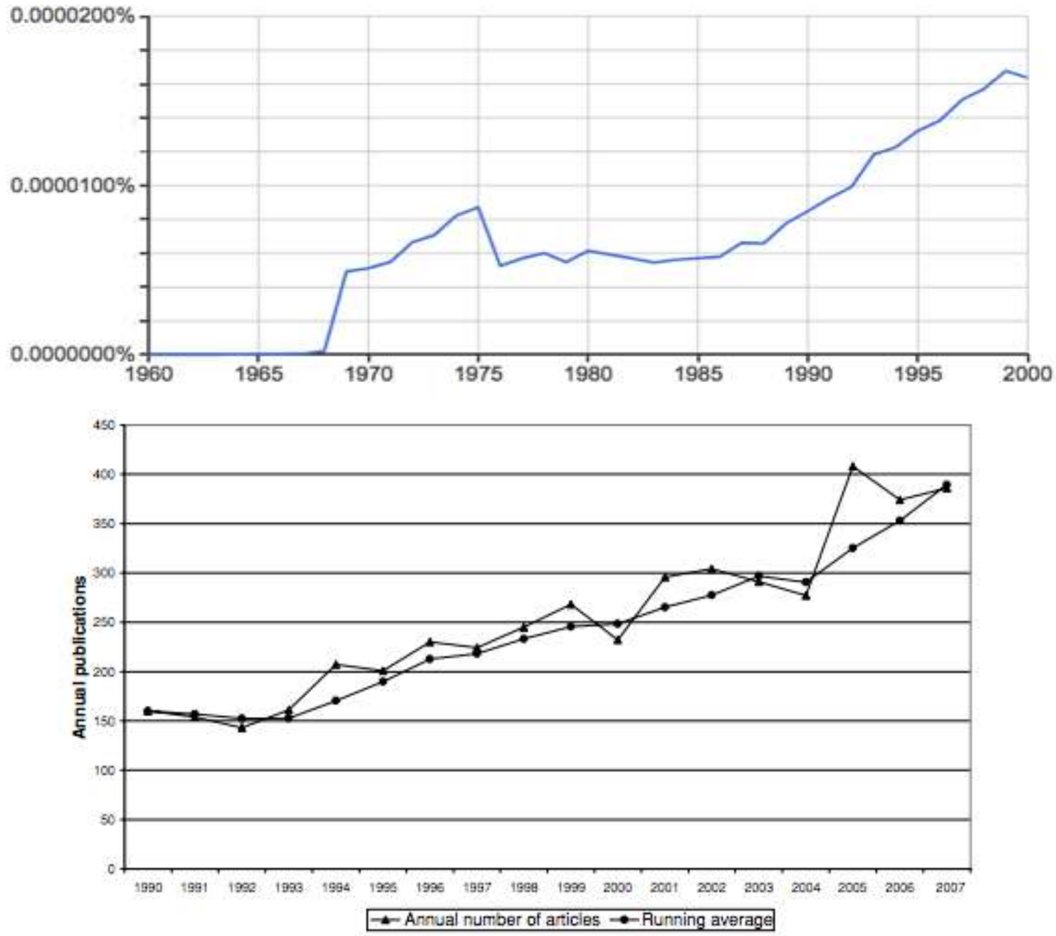

Figure 12: (Top) Google n-gram visualization of frequency of the word "interdisciplinarity" over time. (Bottom) Trends in articles with the term "interdisciplinary" in the title 1990-2007.
Source: (Top) Google N-grams (Bottom) Jacobs, Jerry, and Frickel

Interdisciplinary studies is now a major area of study, and interest in it continues to grow (See Figure 12). In order to get a more clear sense of the entire landscape of knowledge and how disciplines relate to one another fluidly, it may be possible to make use of new analysis and imaging tools (See Appendix 4).

Embedding Interdisciplinary Themes in Curriculum Design

Running through disciplines are cross-cutting **Themes**, which can be drawn from as a source of examples for any disciplinary content. These can be applied to any other body of knowledge, as a way of seeing it in a particular perspective with its particular focal points.

As discussed above, these are often thought of as different types of **literacies**, which naturally convey the idea of "knowing with" and "preparation for future learning". In this sense, they are at the same scale as disciplines, but inherently transdisciplinary. Like disciplines, they each have their own set of threshold concepts, which encapsulate the habits of mind that each **Theme** comprises. CCR has identified the following as fruitful Themes (See Appendix 5 for a deeper discussion of each):

- Environmental Literacy
- Global Literacy
- Civic Literacy
- Information Literacy
- Digital Literacy
- Systems Thinking
- Design Thinking
- Computational Thinking

These are simply important categories to consider when designing curriculum to develop knowledge that will be useful across disciplines. Like disciplines, each lens would have its own set of Core Concepts that students would be expected to internalize, through a range of different sources of content.

Changes in Disciplines

The exact connections and lines between Disciplines are always shifting, if slowly. Over time, disciplines branch to create subfields and merge to create interdisciplinary fields. For example, in the image below[139], the field of Neuroscience emerges as a synthesis of Molecular & Cellular Biology, Psychology, and Neurology, whereas Urology emerges as a subfield that splintered off of Medicine.

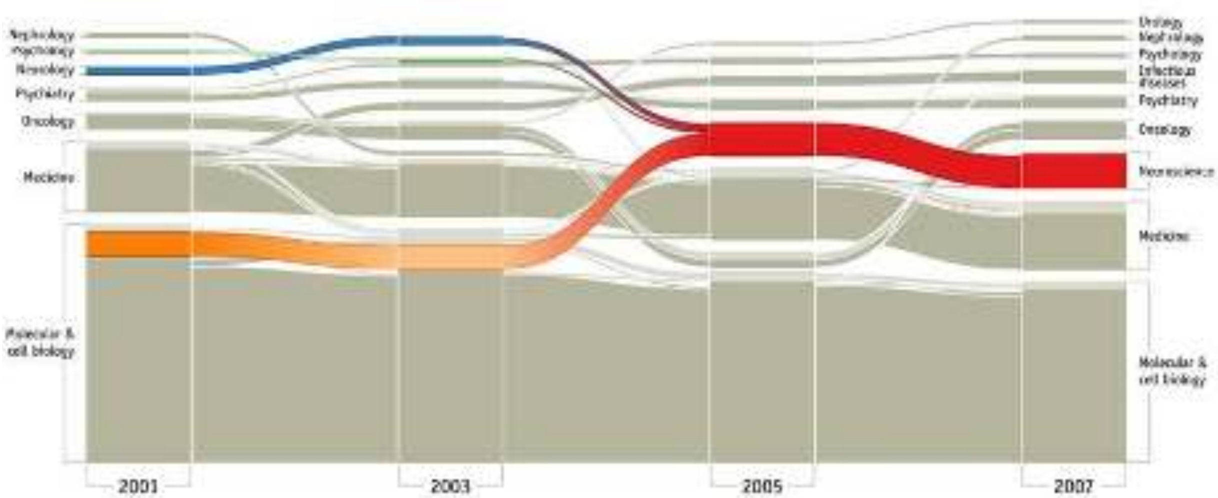

Figure 13: The emergence of Neuroscience as a discipline
Source: Roswall, Martin, and Bergstrom

By disregarding the directionality of time, all disciplines are interdisciplinary, either because they are at the root and thus contribute to other disciplines,[140] or because they are composites of other disciplines. Newer disciplines tend to be in some ways composite of older disciplines (for example, Optogenetics comprises optics, neuroscience, and genetics) or they may be sub-disciplines, splintering off from existing ones (such

139 Rosvall, Martin, and Carl T. Bergstrom. (2010) "Mapping change in large networks."PloS one 5.1
140 Crease, Robert P (2010) "Physical Sciences" The Oxford handbook of interdisciplinarity

as Civil Engineering).

Curricula tend to focus on root disciplines (especially under pressure such as assessments that test root disciplines in isolation). The goal then becomes to teach more of the newer interdisciplinary subjects, and to highlight the interdisciplinarity in the root disciplines.

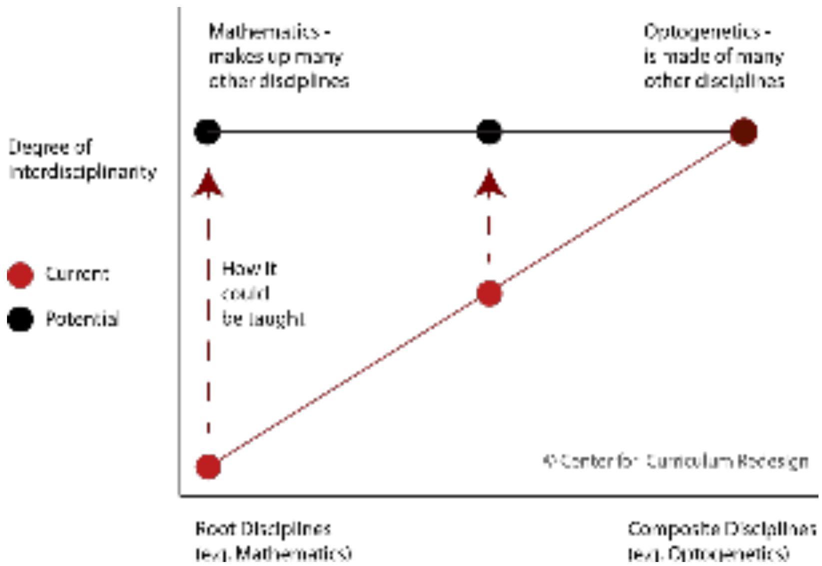

Figure 14: Interdisciplinarity in all disciplines, root and composite
Source: CCR

Interdisciplinarity is likely to become more viable as curricula place concepts at the center, and content is designed to serve those more abstract elements, to achieve transfer. In that case, examples can be chosen deliberately, preparing students for learning across disciplinary lines.

PART 4: PRACTICAL CONSIDERATIONS

There are several options for how to redesign the curriculum's treatment of disciplines:

1. **Traditional**: Disciplines are organized into departments directly, and modern disciplines are simply added either as units to their related discipline, or as an elective.

2. **Hybrid**: Disciplines are intact, but the departments are novel categorizations. These can be lenses as discussed above, or Realms of Meaning as discussed earlier in the document.

3. **Redesigned**: Disciplines are no longer the organizational backbone of the curriculum and classes are mostly on hybrid topics, such as "Systems Thinking". This makes adding new disciplines natural.

The route each school chooses to go will be a result of their goals, capabilities, buy-in, pressures, and so on. Even a traditional organizational structure can go quite a long way toward teaching interdisciplinarity through projects and the interconnectedness of Core Concepts (See Appendix 6). However, the exact organizational structure is not as important as aiming for a robust and flexible understanding of the fundamentals, by identifying the Essential Content and Core Concepts and structuring learning experiences around them.

Scope and Sequence

When content is organized in a curriculum, it is constructed as a progression with a scope and sequence. Based on this sequence, later elements can leverage understanding built earlier, and the curriculum can build to cover greater complexity over time efficiently. It is within the context of a curriculum that content elements take on a relative scope, in terms of what elements they tie together. As discussed above, "curricula should be designed to provide students with a systematic exposure to increasingly complex meanings… and grounding them in experiences with particular content and topics". The same paper says, "no particular order of instruction is necessary, but we argue that picking a reasonable order across a school or school system (and even more widely if possible) is wise, and likely to be more effective than leaving the choice solely to individual teachers".

In the CCR framework, as discussed above, this means that Core Concepts should be introduced first through an **exemplar** topic that *exemplifies*[141] the features important to the concept, then in slightly more distant topic which serves as an **instantiation** of the concept and requires the students to practice generalize and fine-tune their understanding, and finally in the context of distant topics that require **application** of the concept. Since each level of the content structure has a handful of Core Concepts, one can imagine multiple ways to order topics in order to simultaneously introduce new concepts and practice familiar concepts, all through the same topics, as long as the levels on which each concept has been covered (exemplar, instantiation, application) are kept track of. The figure below illustrates the Core Concepts across the content hierarchy as they apply to the topic selected at the bottom. Ideally students have been exposed to those in the instantiation category before – in the exemplar category, and those in the application category more than once before – in the other two categories. If not, it should be noted that they should not be the

141 Elgin, C. Z. (2017). True Enough. MIT Press.

focus of this topic, and will not “count” as exposure to the Core Concepts for future lesson planning.

In the example below, Topic 1 could be used an exemplar of Discipline 2 Core Concept 3 (D2CC3) or of Subject 2 Core Concept 1 (S2CC1), as an instantiation of D2CC2, B2CC1, or S2CC2, or as an application of B2CC2. Topic 2 will have the same discipline, branch, and subject Core Concepts, but the use of Topic 2 as an exemplar, instantiation, or application of those concepts may differ.

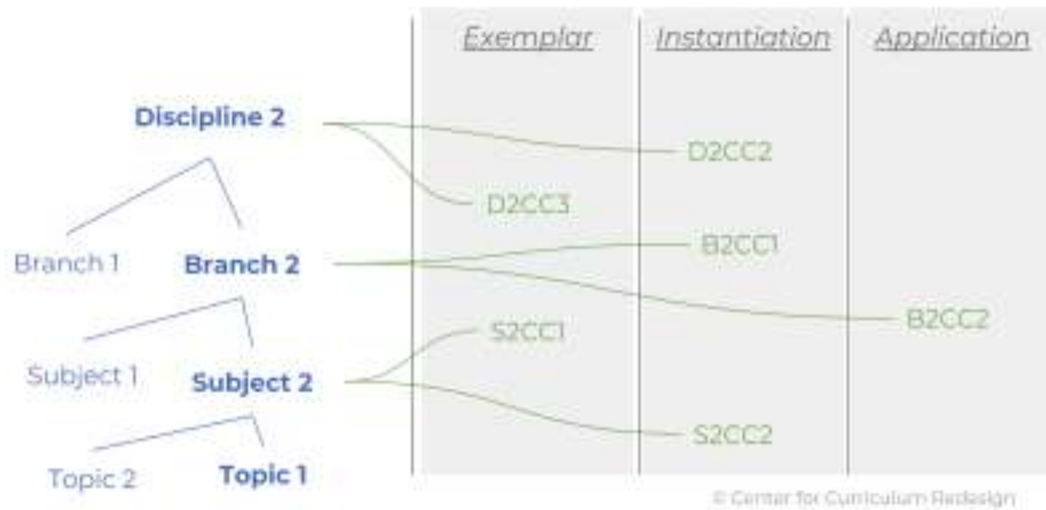

Figure 15: Discipline Core Concepts (DCCs), Branch Core Concepts (BCCs), and so on, and whether they fall in the exemplar, instantiation, or application categories relative to Topics 1 and 2.
Source: CCR

This structure naturally makes use of one of the most robust findings of the learning sciences: interleaving information that should ultimately be integrated leads to more long-term learning than studying the information sorted into its natural categories.[142] Normally, this is applied to content, but in this case the explicit untangling of content and concepts leads to the inevitable grouping by content and thus interleaving of concepts.[143]

Decision Making

One of the main tensions with organizing curriculum is the level at which the various decisions are made. At the highest level are disciplinary experts and policymakers, followed by curriculum designers, then teachers, and finally students. It is possible to completely prescribe all elements, or to leave all elements completely up to the students, and of course, most organizations fall somewhere in between. The particular configuration of responsibility depends on the constraints and preferences of a given jurisdiction, but they should be made explicit and used as a guideline for appropriate division of labor and corresponding expectations and communication channels.

142 Rohrer, D. (2012). Interleaving helps students distinguish among similar concepts. *Educational Psychology Review*, 24(3), 355-367.

143 Those who have had experience working with Spiral Curricula may recognize that this framework would fit well with the notion of revisiting concepts, but that is just one way of conceptualizing this underlying structure.

CONCLUSION

Once the levels of Core Concepts have been established, the particular pieces of content must be considered for inclusion or exclusion, one by one.[144] There should be no content that does not serve concepts. **Most content will exemplify a specific concept that has a high potential for being leveraged to understand many aspects of the world**. It should also serve as a good instantiation or application of concepts that are exemplified elsewhere.

In addition to serving concepts, content across all levels of primary and secondary education should be:

1. **Modernized** with the addition of new disciplines and new approaches to old disciplines, including interdisciplinarity

2. **Systematically increasing in complexity** so that as students learn more they are asked to make more and broader connections to increasingly abstract (but relevant) concepts.

3. **A Substrate for teaching competencies** which include Skills, Character, and Meta-Learning

The goal is to rid the curriculum of obsolete, irrelevant information, while simultaneously modernizing, systematically sequencing, and infusing the content with competencies. Students should learn the useful ways of seeing the world developed by different disciplines, as well as particularly important topics and discoveries within and across the disciplines. In other words, the goal is to maximize the potential for **making meaning** in the curriculum. This is not just so that students find school more enjoyable, but also to make their learning more useful to them later in life. Without meaning, a structure of understanding is not built, and learning does not get internalized in a way that applicable outside of its original context.

This idea can be exemplified through an analogy to learning to play an instrument. There is nothing wrong with beginning with drilling scales, as long as more meaningful learning takes place not long afterwards. It is possible to get sucked into the minutiae of music and never get to the meaning of it, just as it is possible to get sucked into any other minutiae. In this excerpt from “A Mathematician’s Lament,”[145] a dystopian world is described where music is taught the way math is taught now:

> Since musicians are known to set down their ideas in the form of sheet music, these curious black dots and lines must constitute the “language of music.” It is imperative that students become fluent in this language if they are to attain any degree of musical competence; indeed, it would be ludicrous to expect a child to sing a song or play an instrument without having a thorough grounding in music notation and theory. Playing and listening to music, let alone composing an original piece, are considered very advanced topics and are generally put off until college, and more often graduate school. As for the primary and secondary schools, their mission is to train students to use this language— to jiggle symbols around according to a fixed set of rules: “Music class is where we take out our staff paper, our teacher puts some notes on the board, and we copy them or

144 In practice, this process will likely be more iterative than we suggest here.

145 Lockhart, P. (2009). A mathematician’s lament: How school cheats us out of our most fascinating and imaginative art form. New York, NY: Bellevue Literary Review

transpose them into a different key. We have to make sure to get the clefs and key signatures right, and our teacher is very picky about making sure we fill in our quarter-notes completely…"

To avoid mistreating other subjects like this, it is important that each piece of curriculum is there for a reason, and that meaning is never too far away. Students can continue to practice scales and notation, even as they begin to play solo pieces, play pieces as part of an orchestra, compose their own pieces, and even learn to improvise. Ultimately, they are never going to need to play a perfect scale (or the equivalent in another subject) but they are going to rely on the automaticity of their scales in order to do higher level processes such as composition and improvisation. It is therefore crucial that meaning is the primary concern, and all else is in service of that, as that is what will effectively get internalized and prepare students for the future, whatever it may hold.

Supplementary Materials:

http://www.curriculumredesign.org/our-work/papers/knowledgesuppmat

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