‘Playing Sound Waves’, Quality interdisciplinary teaching in middle school classrooms and beyond.

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> It was a sunny Friday afternoon, first period after lunch. About thirty five students were gathered in the library practicing their lines and tuning (if not fixing) their musical instruments. Teachers, other students, the head of the school and a few parents looked on hoping that the open rehearsal would work. Unique about this concert was that the music as well as the African instruments themselves were created by the students. As the show began, a timid strings section alternated with dominating percussion variations, which in turn enlisted the winds in their rhythmic motifs. All, while the budding instrument makers mixed concentration, nervousness and pride in their attentive stares at their conductor and complicity smiles to their peers.

I. Overview

The performance above is the culminating moment in an eighth grade unit entitled ““The Sound of Music”” at the International School of Uganda, in Kampala. In this unit students learned about sound waves in physics and musical instruments and composition in music. The unit went beyond “using music to motivate student learning in physics” it sought to help students appreciate how understanding of sound waves could inform the development of musical instruments, and how their created instruments could help them experiment with new sounds. Taught simultaneously in the music and physics classes, the unit illustrates the kinds of opportunities and challenges that teachers confront when designing interdisciplinary learning experiences for their students.

Calls for quality interdisciplinary education abound among educators and observers concerned with how best to prepare our youth for the work of their generation. Some argue that a changing global labor market requires individuals who are able to frame and address new problems, employ expert thinking flexibly, and communicate effectively with people

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who hold different perspectives on the problems at hand. Others view interdisciplinary education as an opportunity to nourish students' human potential more fully. Some argue that today's knowledge societies where scientific and technological advancements are transforming everyday life demands a public that understands how knowledge is produced by experts in areas such as communication technologies, genetically modified food production, stem cells research and can think critically about the relationship between science and society. For others, the urgency of interdisciplinary education stems from the fact that the most important problems of environmental and cultural survival from mitigating climate change, to legislating immigration, from eradicating poverty to ensuring human rights cannot be satisfactorily be addressed by individual disciplines.

Yet, paired with a renewed interest in interdisciplinary education, is a concern about the lack of rigor or direction observed in certain interdisciplinary teaching practices from elementary schools onward. Experienced educators worry: Is interdisciplinary instruction to be considered at the expense of learning in the disciplines? Or should interdisciplinary teaching build on their disciplinary counterpart? Are "thematic units" in which all teachers in a school are required to address a single theme—"Water" or "Ancient Egypt" –effective? Or do they fail to establish meaningful connections among perspectives? To support quality interdisciplinary learning among their students, interested teachers need to define what constitutes quality interdisciplinary understanding and make informed teaching decisions to nurture it.

To meet this demand, in this paper, I propose a core definition of interdisciplinary understanding and introduce the "Teaching for Interdisciplinary Understanding Framework" [TID framework]. The unit on ""The Sound of Music"" mentioned above serves as an illustrative case. This pedagogical framework was designed to focus teachers' attention on the construction of students' interdisciplinary understanding. The framework stems from a multi-year empirical study of interdisciplinary work in which we analyzed expert interdisciplinary research (e.g. researchers at the MIT media Lab, the center for Bioethics at the University of Pennsylvania) as well as exemplary college and secondary school teaching practices. Most prominently the framework resulted from a close partnership between our research team and experienced secondary Massachusetts school teachers with whom we experimented with novel units of instruction and refined and adjusted principles for instructional design. The framework was further examined in a close partnership with the International Baccalaureate Middle Years Program from which the example stems. The framework serves as a conceptual tool to guide teachers interested in fostering deep interdisciplinary understanding among the young. It addresses five fundamental aspects of quality interdisciplinary instruction: framing topics that are worth teaching in an interdisciplinary way; identifying disciplinary tools that will enable students to understand such topics; integrating disciplines productively; designing a sequence of learning experiences and assessing interdisciplinary student work.

In what follows, I begin by defining interdisciplinary understanding. I then introduce the TID framework illustrating it with the "sound of music" unit developed by teachers in the International Baccalaureate Middle Years Program. I conclude with an account of experienced teachers' views about why they engage in interdisciplinary instruction.

II. What is interdisciplinary understanding?

Put simply **interdisciplinary understanding** refers to

> *the ability to integrate knowledge and modes of thinking from two or more disciplines to generate a new insight.*

That is, students build and demonstrate the interdisciplinary understanding of a particular topic when they can bring together concepts, methods, or languages from two or more disciplines or established areas of expertise in order to explain a phenomenon, solve a problem, create a product, or raise a new question, in ways that would have been unlikely through single disciplinary means.

For example, in "The Sound of Music" unit, students are invited by their physics and music teachers to create an orchestra of traditional instruments and compose and perform a rhythmic piece for their school. To do so, students must study the physics of sound waves, understand how instruments work to make sound and music, and create a compelling musical experience for their audience. The task could not be accomplished through the lenses of music or physics alone—integrating these perspectives productively is of the essence.

Three key qualities of interdisciplinary understanding follow from this definition. These qualities guide the design of interdisciplinary instruction and assessment of student work. Interdisciplinary understanding is (1) purposeful, (2) disciplined and (3) integrative.

Interdisciplinary understanding is *purposeful*

In quality interdisciplinary learning the integration of disciplinary perspectives is ***purposeful***. In other words, students are invited to bring perspectives together to deepen their understanding of topics, objects or problems that they and their teachers find compelling. They are taught to integrate multiple disciplines not as a goal in itself, but rather a means of achieving a valued learning outcome. In quality interdisciplinary teaching there is visible *need* for interdisciplinary understanding, where the potential limitations of one discipline's approach to a topic are overcome by drawing on the resources of other disciplines.

For teachers and student in our example, understanding how instruments work and creating music with their hand-made instruments is a valuable learning outcome. It sensitizes students to human capacity to create compelling artistic experiences out of materials in our natural environments, it enables them to appreciate instruments they encounter and the people who make and play them. It also invites them to learn about design and problem solving, and create instruments of their own in the future. With this arguably compelling learning purpose in mind selecting and integrating disciplines becomes a natural next step.

Interdisciplinary understanding is *disciplined.*

A second feature of quality interdisciplinary learning is that it is deeply rooted in the disciplines or established areas of expertise typically emphasized in school (mathematics, biology, history, visual arts, music). Quality interdisciplinary instruction does not replace disciplinary teaching, rather it builds on it, selecting and reorganizing disciplinary learning goals in meaningful and connected ways. Students exhibit quality interdisciplinary understandings when they can use selected concepts, findings, tools, methods or languages that are relevant in disciplines like history, mathematics, biology or the visual arts.

In our example, to understand how musical instruments work students must know, for instance, what constitutes a sound wave, how sound changes depending on wave's longitude and amplitude, how sound waves travel through different media and resonate with different materials. To inquire about how sound works, students may generate hypotheses and devise small scale experiments to test them. In so doing they build the knowledge, understanding, skills and attitudes of the physicist. Students will demonstrate understanding if they can employ these concepts and modes of thinking effectively.

However, understanding of sound waves will not prepare these students to use sound in musically compelling ways. Therefore, in their music class, they will need to learn about composition, the use of pitch to create an appealing melody, the use of volume to create dynamics and mood, the role of motifs and variation in composition, and the power of using different kinds of instruments strategically to express intended qualities in the piece. In other words, essential to student interdisciplinary learning in the example here outlined is their adequate mastery of selected concepts and skills in the disciplines involved.

Interdisciplinary understanding is *integrative*

While mastering selected concepts and skills in two or more disciplines is necessary, it is not sufficient to produce quality interdisciplinary learning. At the heart of students interdisciplinary understanding is their capacity to ***integrate*** disciplinary perspectives. In quality interdisciplinary learning, disciplines are not merely juxtaposed around a "theme." Rather, elements of different disciplines (knowledge, understandings and skills) are put into productive relationship with one another, allowing students to accomplish a new, deeper, more compelling or nuanced understanding of the topic under study. In other words, quality interdisciplinary learning invites students to make good connections across areas of knowledge (i.e., connections that enable a deeper better understanding of the topic under study) and understand these topics in ways that would have been unlikely through single disciplinary lenses.

In our music example, students integrate their understanding of sound waves and elements of music when they apply concepts such as wave longitude, amplitude, resonance to explain exactly how percussion, wind and string instruments produce sound and how such sounds might be used in aesthetically appealing ways. As I will show later, such integrative understanding requires more than simply having information about how sound waves behave.

III. How might teachers approach interdisciplinary instruction?

Perhaps the most striking feature of interdisciplinary teaching practices is the enormous variety of ways in which experienced teachers go about conceiving and conducting their work. Interdisciplinary practices vary in the ages of students taught (from elementary to graduate and professional work), and the disciplinary combinations they employ (history and art or mathematics and biology).

Interestingly, interdisciplinary teaching practices also vary in scope. Most teachers approach interdisciplinary teaching with a genuine and valuable commitment to teaching their own discipline. These teachers find that *small scale extensions* into neighboring disciplines can enrich their students' understanding of the discipline they teach. For example, a biology teacher may "borrow" a few key lessons from the artistic drawing to further students' capacity to observe during fieldwork. A mathematics teacher may invite students to create "fractal computer art" with the intention to build the type of patterned visual thinking necessary to translate functions into two and three dimensional space. These examples illustrate courses that are primarily disciplinary -- with a small scale foray into a neighboring discipline. Contrastingly other teachers may prefer to dedicate a *sizeable unit* to a topic that demands an interdisciplinary approach. For instance, the study of outsourcing or globalization requires that that students learn to think at once like economists, sociologists and anthropologists. A third group of teachers may opt for weaving an *interdisciplinary thread* throughout their disciplinary course. In this case, a history teacher may revisit the question of how monuments, art works and propaganda use symbols to "tell a story about society," preparing student to create informed historical monuments of their own by the end of the year.

Another dimension along which quality interdisciplinary teaching practices vary is the degree to which one or more teachers participate in the teaching itself. In some cases a single teacher finds him or herself to be prepared to teach interdisciplinary topics either by virtue of their formal training or through their own informal studies. Occasionally single teachers stand in front of the classroom, but have been aided by a group of peer advisors to address manageable concepts outside their discipline. Still other times, teachers engage in collaborative planning and co-or linked teaching making the differences and complementarities between disciplinary perspectives visible for students in their class.

Amidst the great variety of fruitful approaches to interdisciplinary teaching three common standards of quality remain unchanged: quality instruction (as does quality understanding) has a clear and meaningful purpose, is well grounded in disciplinary expertise and integrates disciplines effectively.

IV. The *Teaching for Interdisciplinary Understanding Framework*: a practical thinking tool.

Teaching designs (interdisciplinary or not) involve making thoughtful decisions about what to teach, what exactly students should do to learn, and how one might assess and support students' progress. When our goal is to foster students' deep interdisciplinary understanding (understanding that is purposeful, disciplined and integrative), addressing these fundamental issues entails a unique set of considerations.

The *Teaching for Interdisciplinary Understanding* framework is a tool designed to support teachers in the practice of designing quality interdisciplinary instruction—i.e., deciding what to teach in interdisciplinary ways, identifying the disciplinary tools and connections to be nurtured, and organizing and monitoring students' experience for deep learning over time. To inform quality practice the framework focuses teachers' attention on five aspects of instructional design: the development and use of *multifaceted topics*, *disciplinary understandings*, *integrative understandings*, *performances of understanding*, and *targeted assessment*

For each aspect of design, the framework offers criteria to inform teachers' decisions. In designing units, sets of lessons, or courses, the framework invites us to move among its elements in any way we feel comfortable. We may also emphasize different elements in different moments of a design since, in practice, the framework elements are interrelated and mutually informing. In the end, what matters is that students engage in learning experiences that are *purposeful* (students clearly understand why studying the issue matters and demands an interdisciplinary approach); *disciplined* (understanding that is informed by two or more disciplines) and *integrative* (and understanding that is enriched by the combination of disciplinary perspectives). Appendix one includes a graphic representation of the framework.

What topics are worthy of teaching in an interdisciplinary way?

MULTIFACETED TOPICS

> "With the construction of these simple traditional African instruments students realized what happens when sound is produced, they can <u>see</u> and <u>touch</u>, they are not like a piano" Rita, music teacher.

> "The actual making of the instrument gave a wider scope to their creativity and provided a platform for individual and authentic work and a deeper understanding of the concepts in physics" Marcie, physics teachers

To the question of what topics to teach in interdisciplinary ways the TID Framework proposes: "*Multifaceted topics"*. Multifaceted topics are defined as topics that address aspects of the world that can be productively studied by two or more disciplines. In our example ""The Sound of Music"" unit productively addresses the phenomenon of sound from the physics and musical perspective, involving the understanding of *the physical properties* of how sound is produced and its *musical qualities* and expressive possibilities. Teachers and students are increasingly aware of the topic's complexity and the need to go beyond each disciplines' information to achieve an integrated perspective.

When we define the *multifaceted topic* in our interdisciplinary teaching, we are also conveying the purpose of our inquiry. In "The Sound of Music" unit, a key question captures the multidimensional nature of the topic providing clarity of purpose as the class engages in the unit's investigations:

> **"How do instruments produce sound to create interesting musical experiences?"**

When teachers set out to frame a multifaceted topics that they would like to teach an obvious question emerges. What constitutes a "good" topic? In quality interdisciplinary designs, multifaceted topics are relevant, feasible and clearly framed.

Relevant

First, a good multifaceted topic is *relevant* to students, teachers, and the societies in which we live. Because interdisciplinary work is challenging, it is especially important that the topics be meaningful and engaging to students and teachers while being developmentally appropriate.

For example, in describing "The Sound of Music" unit, the topic was relevant to teachers, society and students alike. Rita, an accomplished musician in her own right, explained how intriguing she found the question of how exactly her instruments produced sound. Physics, once a distant discipline became suddenly a very interesting one. She also valued students' appreciation of traditional African instruments especially as rapid globalization threatens to turn ancient cultural heritage into commodities. Astrid who contributed to teaching music for the unit explained "The students wanted to do something that sounds good. I remember the case of this student who really wanted to know how to make a good drum. 'Look, look!', he shouted, I have made a drum and there is sound in it and there is even a heart in it". Rita added "The nice thing is that they stayed, the bell rang and they stayed, they wanted to know 'what scale is my voice?' 'Why does my instrument not work?'"

Feasible

Second, quality multifaceted topics are feasible with regard to students, context, teacher expertise and resources. Multifaceted topics invite multiple connections sometimes beyond teachers' existing expertise and available resources, which is why considerations

of feasibility matter in how we define a multifaceted topic. An important decision in interdisciplinary teaching is deciding what we will not include in a unit. In our example, Marcie and Rita felt confident that they had the expertise to address the topic even if later in the unit they realized the limits of their capacity to explain why a particular instrument was not making the expected sound or how to create a graphic model of sound waves traveling inside a resonance box. In both cases however, they were able to enlist the help of more knowledgeable individuals. First, Rita brought in a professional native musician and instrument maker who eventually joined the group to help students create their rhythmic composition. Marcie then consulted with the high school physics teacher on viable and age appropriate representations of sound waves for her students.

Clearly framed

Finally, quality multifaceted topics are framed in a way that invites students to purposeful inquiry. A careful framing of the topic for study conveys why students are learning what they are in the unit (e.g., developing knowledge needed to create a product, solve a pressing societal problem, explain a phenomenon). Such a framing goes beyond naming a broad theme being studied such as "musical instruments". Rather it gives students a sense of what about the theme will be examined, why such examination matters and why an interdisciplinary approach is warranted. For example, as framed for "The Sound of Music": *"How do instruments produce sound to create interesting musical experiences?"* the very description of the topic makes both "sound" and "music" as well as the connection between them clear.

What tools will students need to understand this multifaceted topic?

DISCIPLINARY UNDERSTANDINGS

"Let me give disciplinary teaching a chance too". (Marcie)

"This was a good excuse for me to introduce the elements of music." (Rita)

Because interdisciplinary work is deeply rooted in disciplines or established areas of expertise, "tooling" students to produce quality work requires that we ensure a selective mastery of disciplinary concepts and modes of thinking that are relevant to understand the topic under study. In other words, quality interdisciplinary teaching requires the identification and support of key *disciplinary understandings*. Students may need to become acquainted with basic knowledge base in a discipline. They may need to learn methods for generating knowledge or with the ways in which uses and applications such disciplinary knowledge can help us understand the world. Occasionally student might need to grasp the prototypical ways in which knowledge is communicated in the discipline (scientific reports, critical essays).

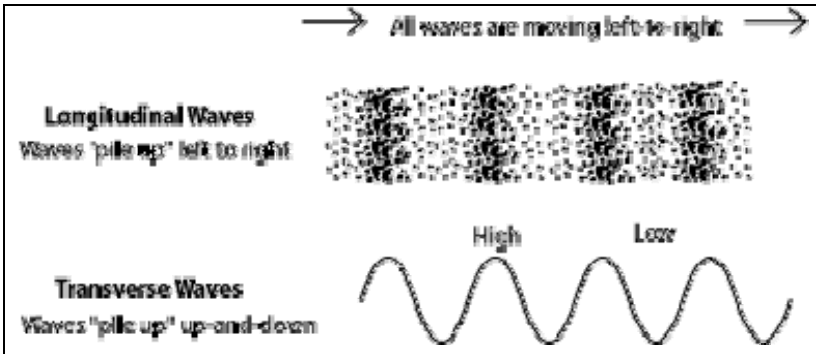
What constitutes quality *disciplinary understandings* in an interdisciplinary unit or project? The disciplinary understandings are "robust" and "selective".

Robust

In quality interdisciplinary designs disciplinary understandings are robust in the sense that they echo the work of experts in each discipline involved. Teachers seek to make sure that no disciplinary misconceptions or undesirable oversimplifications are included in the design.

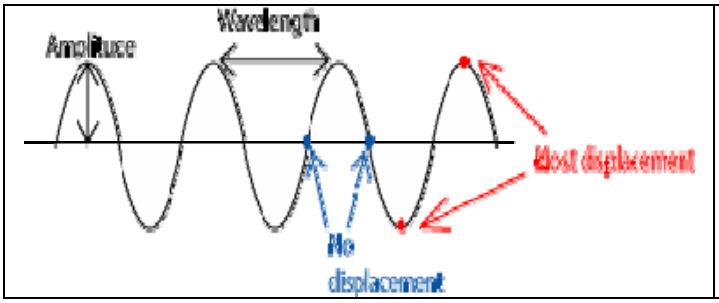
Consider, for example, the disciplinary understandings in physics required in our "Sound of Music" unit. Understanding of sound from a physics perspective implies a close examination of intrinsic elements of sound waves (propagation medium, amplitude and length), the extrinsic manifestation of the sound wave (rarefaction and compression), and the incidence that a sound wave has on materials and how these materials qualify the sound wave (vibration, resonance, echo). Echoing the work of experts, students will need to understand for instance:

Types of waves[2]



In longitudinal waves like sound, the waves have a forward movement where they become more and less dense (compression and rarefaction). In transverse waves like water compression and rarefaction is translated into the highs and lows of the wave. Note that the multiple representations of waves are the sources of serious misconceptions on the topic for children in schools.

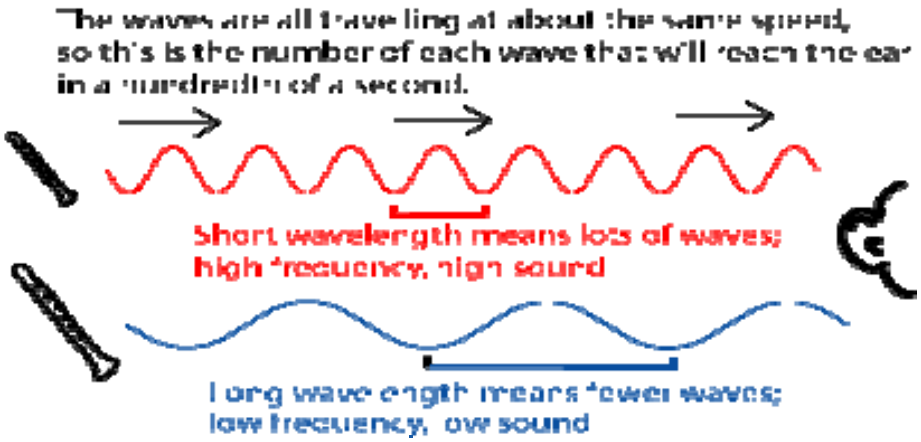
Loudness and Amplitude



The amplitude of the wave is a measure of the displacement: Are the air molecules bunched very tightly together, with very empty spaces between the waves, or are they barely more organized than they would be in their normal course of bouncing off of each other? Scientists measure the amplitude of sound waves in decibels. Leaves rustling in the wind are about 10 decibels; a jet engine is about 120 decibels.

[2] The following schemes and comments are extracted from http://cnx.org/content/m13246/latest/

Wave length, frequency and pitch



Since the sounds are traveling at about the same speed, the one with the shorter wavelength "waves" more frequently; it has a higher frequency, or pitch. In other words, it sounds higher.

Selective

Disciplinary understandings included in a design must also be *strategically selected* — both in terms of *which disciplines* are included in a unit or course as well as *which specific insights* from each discipline are borrowed. In quality designs teachers select which disciplines will be included weighing the particular ways in which disciplines might contribute to student understanding of the topic. Furthermore, teachers must, for feasibility, select which particular concepts, theories, examples, methods or techniques they will borrow from each discipline.

For instance, to understand how instruments make sound and how to use sound to create aesthetic experiences, students in Marcie and Rita's classrooms were expected to master the a few key concepts. As stated above, in physics, they were to learn propagation medium, amplitude and length; rarefaction and compression; as well as vibration and resonance. In turn, in music Rita focused her instruction on helping students understand: the basic elements of music (Rhythm, melody and harmony); the different qualities of musical sound (pitch, color, timbre and texture), the classification of instruments (Wind, percussion and string); how to manipulate their instruments to evoke desired emotions; variation as an element of composition, and how to behave according to performance etiquette.

Other disciplines and perspectives, such us traditional decorative visual arts or the history of African musical instruments were considered, but not included in this unit to ensure enough time could be spent gaining a deep understanding of music and physics within the available timeframe.

How will disciplines come together to address this topic?

INTEGRATIVE UNDERSTANDINGS

> "With the instruments the students created we bring those elements [of science and music] to life" (Rita)
>
> [We experiment] "With the voice different pitches […] they suddenly understood, they suddenly realized 'I am a woman but I have a low voice'. They learnt how to manipulate the voice and the guitar to create a lower pitch" (Astrid)

Integrative understandings are insights that deeply and meaningfully connect elements from different disciplines. That is, a student has an integrative understanding when he or she can act upon, generate, or describe a productive relationship of ideas across disciplines. There are multiple ways in which concepts and modes of thinking in different disciplines connect, and one unit or course may draw on multiple forms of integration. Appendix 2 includes a list of productive integrative understandings. The list is not meant to be exhaustive.

In quality interdisciplinary designs, integrative understandings are more than superficial links among disciplinary ideas. Rather, they deepen students' understanding. Two considerations should inform teachers' attention to integrative understandings. Integrations must be *tied to the purpose* of the unit, and they must *advance understanding.*

Tied to unit purpose

In quality units, *integrative understandin*gs are aligned with the purpose behind the unit's multifaceted topic. In "The Sound of Music", for instance teachers expect students to become able to use what they know about the physics of "sound" to produce an informed explanation of how their instruments work. For students, the instrument themselves became the points of integration. Conversely, exploring new kinds of sound produced by their instruments could inspire students to push the boundaries of what counts as music in more traditional terms. Both connections are key to the overall purpose of the unit.

Clearly described

In quality interdisciplinary teaching the sought after types of integrative understanding are clear and shared with students so that they will know what they are striving for. Ideally, multiple strategies for representing the nature of the integration—verbal descriptions, visual models, reference to exemplars (examples of experts doing similar interdisciplinary work), etc.—are available. As Rita and Marcie put them forth, integrative understandings for the unit included:

1. Students will be able to explain how musical instruments work by understanding the science of sound. Indeed, they will use their understanding of physics to build their own instruments and demonstrate elements of acoustics, resonance, pitch and vibration.

2. Students will expand, transform, and create "new" music. Through the use of new (unfamiliar) sounds they will expand their sensibilities about what is possible outside of canonical music.

What will students do to learn?

PERFORMANCES OF UNDERSTANDING

To the question of how students will learn, the framework responds "by engaging in *performances of understanding*." Performances of understanding are opportunities for *flexible thinking with knowledge in novel situations*. Such experiences allow students both to build and demonstrate their understanding. They are based on the theory that understanding is not something we *have*—like a set of facts we possess—but rather is something we *do*. Note that by using the term *performances*, the framework does not emphasize "stage performances", like plays or concerts. Rather, we refer to the fact that understanding is performed or enacted, whether it results in a group presentation, an essay, or a mental computation to respond to a question.

In a quality interdisciplinary designs, performances of understanding may take several different forms. In particular, *integrative performances* are not left t the end of the unit but supported at different points in a unit or course. Typically, quality designs exhibit:

Introductory performances give students a preview of the larger topic in its potential complexity. In "The Sound of Music", students attended a local concert that employed traditional African instruments. They identified sounds they liked and attempted to explain how they are produced.

Midway syntheses offer structured support on a manageable integration. For example, Rita and Marcie wanted their students to "translate" physical features of sound into music creating a table similar the one below:

Science	Music
Wave amplitude	Volume
The elements that determine the speed of sound: 1. Elasticity 2. Density 3. Temperature of medium.	The elements that determine the speed of sound in a music context: 1. (Elasticity) Dryness and softness of the instrument's material 2. Density of the instrument's material. 3. Temperature of instrument[3].
Wave longitude (Frequency, for example 440 vibrations per second)	Pitch (Musical note, for example the central A [LA] in the traditional keyboard)

Also midway in the unit students' assignment in the physics class required them to manipulate sound waves to see their impact on sound produced by musical materials. They placed a tuning fork in water and watched the waves it generated. They also placed dry grains of rice on a drum and watched pattern formations when it vibrated, capturing the relationship between sound and sound waves rarefaction and compression. They placed a ruler half way over the edge of the table and tapped it. The further out the ruler was placed, the lower pitch; the closer the highest. In building first spontaneous- and later informed explanations for the difference in sound students began to grasp the role of waves' length with regards to the sound qualities of a given material. Conversely in the music class Rita posed the question: "What does it mean for you to try to convey different musical qualities through your instrument now that you are beginning to understand the physical implications of sound in music?"

Synthetic final performances allow students to bring disciplines together in a way that shows mastery and greater independence. Moving beyond initial analogies and connections Marcie and Rita aspired at preparing students to actually explain how instruments make sound. Visual representations of the sound waves produced by the vibration of a string or a drum skin were of the essence as was an effective performance that would illustrate richness in rhythms and qualities of sound made by various instruments.

Disciplinary tooling performances. Naturally, throughout a well-designed unit, students alternate between the three kinds of synthetic performances described above and *disciplinary tooling performances* that help them build adequate foundations. These activities focus more narrowly on grounding students in a particular discipline. They enable teachers and students to turn their focus toward deepening particular *disciplinary understandings*. In music class students were invited to consider questions such as: "How to hold your instrument and what fingering/blowing techniques are appropriate? They realized the complexity of music technique and the effort and practice that come with it. They also had opportunities to reflect about performance etiquette—

[3] Within the features that determine that speed of sound in a music context, temperature is decisive inasmuch musicians need to warm up theirs brass and wood instruments to accomplish a quality sound; and the that humid and hot climates un-tune string instruments.

e.g., do you take a bow after the audience has stopped clapping or immediately after you finish playing?

In quality interdisciplinary designs, understanding performances are:

Carefully sequenced

In other words, performances are sequenced to advance interdisciplinary understanding of the topic. Whether teachers begin their planning with a very clear articulation of desired interdisciplinary learning outcomes or with a good definition of an area for open exploration, quality interdisciplinary units and courses sequence performances in ways that move toward progressively deeper interdisciplinary understanding, from early intuitive introductions to a problem of study, to guided examinations to more independent work as illustrated above.

Well-supported

In quality units, performances are also well-supported by rich experiences and resources. Not all experiences in the classroom are undertaken as performances in their own right. Presentations, films, readings, visits, discussions, and other activities and resources inform students' performances and provide added opportunities for students to advance understanding. In "The Sound of Music", students had master classes with local musicians, listened carefully to performers, examined a variety of real instruments and used simple materials in their science experiments.

How do we know students are learning?

TARGETED ASSESSMENT

Targeted assessment refers to assessment practices that focus particularly on core dimensions of interdisciplinary understanding. It will come as no surprise to readers that targeted assessment focuses on (a) the degree to which students' work exhibits clarity of purpose (b) the degree to which the work is well- grounded in the disciplines, (c) the degree to which it integrates disciplines productively, and (d) the degree to which students show a reflective stance about their work.

For example, in examining students analysis of their instruments, Marcie and Rita may need to probe asking students to explain in some detail how they view sound waves being produced with the vibration of a string, a drum top, or a mouthpiece. They visual models will reveal acquired understandings as well as misconceptions that may still be present in students' views. For example, in response to the question of why a an African guitar needed a resonance box, one student (mistakenly though understandably explained) "Because the box makes echo and they you hear the music better"

In quality interdisciplinary teaching targeted assessment is

Valid

Assessment builds on a representative selection of student work (e.g., a disciplinary paper, an integrative presentation, and a series of journal entries). Representativeness is less about evaluative "fairness" of assessment than about considering all relevant aspects and indicators of student understanding. In "The Sound of Music", these would include, students' journal reflections, their experiments on sound, their instruments and explanations, their thoughts during the collective composition, their performance in the end and the graphic illustrations of how their instruments work.

Ongoing.

Assessment may begin with a diagnostic assessment of student baseline understanding, beliefs and dispositions early in the unit or course (even if very informal). An example of this Rita's students are invited to notice sounds they enjoy in a performance and *try* to explain what made them different from one another. Assessment is not limited to grading a final project but seeks to support students (and inform instruction) along the way,

Informative

Assessment offers explicit and productive feedback to students as they progress through the unit or course—feedback that will allow students to modify and refine successive performances. For example, when working with a student whose guitar did not produce sound, Rita and Marcie probed to see if this student understood the role or resonance boxes to augment and enrich sound. Recognizing that the student had not grasped that yet, they took the moment of assessment as a moment for teaching. They suggested that she tried different sized resonance boxes in her instrument and came back to discuss what she had found.

In sum, the Teaching for Interdisciplinary Understanding framework presents teachers with a series of concepts designed to guide their decisions about what and how to teach. It does not tell educators what exactly to teach but how to think about their options in quality interdisciplinary designs. The framework pays serious attention to disciplinary expertise as central to interdisciplinary understanding. It outlines specific cognitive forms of disciplinary integration – e.g., aesthetic synthesis, complex explanation, crossover tool (see appendix 2). It provides a common language to discuss a broad variety of disciplinary combinations at multiple instructional levels (primary, secondary and higher education). Perhaps most interestingly, the framework offers a common conceptual point of reference for teachers whose interests and expertise and motivations for interdisciplinary is broadly varied.

V. To conclude. Beyond "forced" connections: Why do teachers pursue interdisciplinary teaching?

An important source of concern about interdisciplinary teaching is what teachers and students experience as "forced" or "contrived" efforts to make connections across domains. Oftentimes forced disciplinary connections stem from lack of clarity about the purpose of interdisciplinary instruction. In "forced" units, teachers explained, disciplines (like the arts) are used merely as motivators to engage students in another discipline's thinking and are not considered as genuinely contributing to a deeper understanding. In forced units others argued, interdisciplinary work becomes a goal in itself as opposed to a means to further understanding of a topic or problem. Experiences interdisciplinary teachers exhibit multiple genuine motivations for interdisciplinary work. They include: building on a holistic view of students; preparing students as lifelong learners and adaptable problem solvers; preparing students to understand and address global issues; highlighting an intellectually rigorous view of knowledge; and viewing themselves as dynamic members of professional learning partnerships and communities. Teachers motivations or reasons for doing interdisciplinary work are not mutually exclusive. Rather multiple and complementary motivations and reasons (e.g., attention to students' interest, rigorous knowledge and personal learning) offer a robust grounding for quality teaching designs.

A Holistic view of students

Interdisciplinary learning recognizes students as whole individuals and members of society, rather than exclusively in their role of aspiring masters of academic content knowledge. Teachers who embrace interdisciplinary teaching often view their students as individuals with unique interests and diverse intellectual profiles, able to engage relevant topics and problems as agents in their own learning.

For example, it its formulation "The Sound of Music" engages students with different interests (e.g. social, technical, musical, artistic) meaningfully. It also engages distinct human capacities (e.g. aesthetic, logical-qualitative, experiential, practical and interpersonal) offering powerful entry points to students with varied intellectual profiles to engage with the topic in depth. A holistic view of students recognizes children's diverse interests and talents, some of which might have remained unseen in single disciplinary courses. Interdisciplinary learning harnesses such interests and capabilities to nurture deep understanding of relevant topics.

Preparing students as lifelong learners and adaptable problem solvers

Some teachers note that in quality interdisciplinary classrooms, students are not merely expected to record and repeat information given by a teacher, rather they are invited to identify what they know and what they need to know about the topic under study, finding

new sources of relevant information often outside of the primary discipline considered with their teachers' support. In so doing, students strengthen their growing role as agents in their own learning and find opportunities to reflect about their own approaches to learning.

When well designed, interdisciplinary instruction helps students understand their strengths and challenges as learners. They gain confidence in their capacity to investigate areas of knowledge about which they know little and develop relevant expertise, in doing so, interdisciplinary teaching strives to nurture students' long-term attitudes toward life long learning.

In our musical instruments example, students may address the failure of their instruments to make sound by enlisting the expertise of the schools high school physics teacher who can explain for instance the role of resonance boxes in augmenting sound. Framing questions or problems, identifying available sources of expertise and ensuring their own understanding prepares students as adaptable actors in our rapidly changing information societies.

An intellectually rigorous view of knowledge

Interdisciplinary learning invites students to appreciate the nature of knowledge in particular disciplines and see the cohesion and the complementarity of various fields of study. For many teachers the central motivation for interdisciplinary work is the rigorous teaching of their own discipline. Arts teachers may invite students to examine humanities topics such as migration or globalization in depth to inform students' understanding of the arts as a tool for cultural critique. Biology teachers may incorporate a few lessons on still life drawing in their class in order to help students become more careful observers of nature during fieldwork. Physics teachers may draw on the history of the Manhattan project and the creation of the atomic bomb primarily to shed a human light experimentation in physics and on ethical considerations in scientific research.

In some cases, teachers engage in interdisciplinary work because they expect students to appreciate similarities and differences in the ways particular disciplines shed light on the world. Teachers motivated by this possibility value students' capacity to reflect about the nature of knowledge in ways that prepare them as knowledge managers. For example, students may compare what constitutes evidence in art, history and biology as a way to enrich their understanding of the nature of evidence. Other teachers may examine the role of symbolisms in theatre, music and visual arts seeking to inspire students' original artistic productions.

Preparing students to understand and address complex global issues

For some teachers the motivation for interdisciplinary work stems directly from their engagement with a complex and relevant topic. Issues such as the effect of global trade in

developing societies, the role of the media in the construction of body images among adolescent girls, or the impact of climate change on health cannot be satisfactorily approached through single disciplinary means. Interdisciplinary instruction becomes a necessary means to address problems or relevance in their full complexity –problems that would have resulted intractable in disciplinary courses alone.

Complex topics or problems such as the impact of climate change on health are typically multifaceted. Particular dimensions (e.g. carbon heat trapping, greenhouse gas emissions, and tropical diseases and prevention) are typically studied by different disciplines (chemistry, atmospheric sciences, and public health). For teachers who seek to support students' comprehensive understanding of the problem, drawing on these various perspectives becomes a necessity.

Opportunity for teachers' mutual learning and professional development

Finally, some teachers find interdisciplinary teaching rewarding because it offers learning opportunities the enable them to find novelty and interest in their work. They find opportunities for new and creative professional life as they consider using materials stemming from multiple disciplines, (as opposed to a single textbook). It enables them to learn about topics of their interest, enrich their own view of their disciplines and of themselves as learners ready to guide students in interpret relevant aspects of the world. Teachers view themselves as ongoing learners, ready to stretch beyond their comfort zone to increase the richness of what they teach.

For many teachers interdisciplinary learning is rewarding because it involves breaking traditional isolations. They enjoy the collaborative nature of interdisciplinary work and healthy relationship among adults in their school communities. A social studies teacher may approach the math teacher primarily because they would like to work together and eventually find that math can offer important predictive tools in her unit on voting patterns. When co-teaching, partners can model effective collaboration, intent listening, challenging arguments and offering meta- disciplinary views.

Finally we have heard from teachers that an important motivation for their interdisciplinary experimentations is the views they hold of themselves as thinkers, citizens, and professionals. As one teacher put it:

> My goal is to transform them [the students]; to challenge them to think deeply; to become human beings in the fullest sense of the term. I want them to be weary of simple solutions. I am relentless. I ask them questions to move their thinking one further step. I view ideas in the disciplines as arrows in a quiver, which I use selectively and with precision to transform thoughts at each time. That makes teaching meaningful to me as a person.

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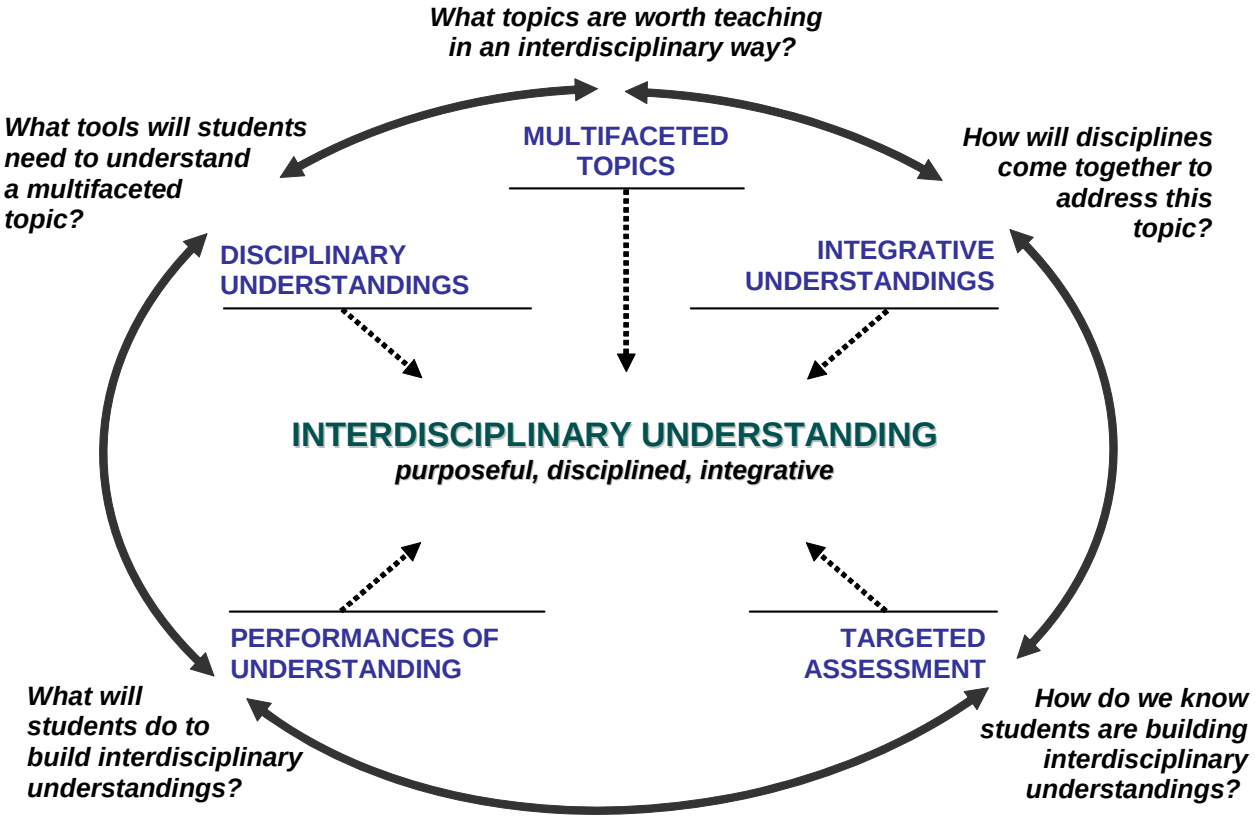
INTERDISCIPLINARY TEACHING FRAMEWORK



Appendix 2 A taxonomy of integrations

Analogy-based connections — when elements across disciplines are *analogous,* and students see that similar concerns, tools, and concepts can operate across or be translated across multiple domains:

Aesthetic synthesis.

Students examine a scientific, historical, or social problem in depth and distill its meaning or significance in a work of art.

Crossover tool.

A concept, instrument, or skill (e.g., observational drawing technique, designing experiments) is used in a variety of disciplinary contexts, resulting in a deeper understanding of the tool itself and its broad applications.

Resonance.

Similarly, an idea (e.g., the experience of immigration) is explored in multiple disciplinary contexts seeking resonances that will deepen one's understanding of the idea at hand.

Complementary connections — when elements from different disciplines *complete or augment* one another. Disciplinary elements are not analogous. Instead, they are different complementary pieces of a larger puzzle:

Complex explanation.

An explanation of a phenomenon in which multiple factors (such as those represented by economic, physical-science, and psychological concepts) interact causally e.g., the study of how economic incentives may lead to reductions greenhouse-gas emissions and thereby slow climate change).

Contextualization.

When elements in one discipline are placed in their broader historical, social, philosophical, or cultural contexts.