Chapter 24
Student-Generated Instructional Materials

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Cognitive Process Instruction

> *We should be teaching students how to think; instead we are primarily teaching them what to think. This misdirection of effort in education is the inevitable consequence of an over-emphasis on objectively measurable outcomes. In brief, we are more concerned with what answers are given than with how they are produced.* (Lochhead and Clement 1979)

In 1979, Jack Lochhead and John Clement published a collection of papers from a remarkable conference organized at the University of Massachusetts the previous year. The book is titled *Cognitive Process Instruction*, a phrase that is both compelling and intuitively meaningful, and it lays out a blueprint for much of the work in higher education that has developed over the last 40 years. As important, relevant, and timely as their quote is, its foundational contribution is not generally recognized or acknowledged. Unfortunately, the higher education community never adopted the titular language of "cognitive process instruction" to describe the transcendent goal for education reform that derives from advances in understanding learning. Rather, the community typically uses "evidence-based practices" as a list of activities, lacking the explicit identification of educational outcomes from "cognitive process instruction."

The contrast between a list of practices (a recipe) and the practice-based outcomes (a delicious meal, improvised by a skilled expert, combining multiple cuisines) is profound. Instead of using such a list, Mintzes' (2019) introductory chapter summarizes concise, generalized, and process-related understandings that come from research on learning: (1) *Prior Knowledge Shapes Learning*; (2) *Learning is a Process of Actively Constructing Knowledge*; (3) *Experts Organize Knowledge and Approach Problems Differently than Students*; (4) *Metacognition can Help Students*

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Learn; (5) *Students Who can Transfer their Knowledge to New Situations Learn More Readily*; and (6) *Interactions with Others can Promote Learning*. These six principles can guide practice, providing the "hills of Rome" (destinations) to which roads can lead, but they do not prescribe or mandate a best path, a favored vehicle, or an ideal terrain.

Laid out as principles, these important findings leave the door open to all of the context-dependent and idiosyncratic features of any given instructional setting. Context can include the background, motivations, and character of any individual learner and particularly the fact that members from a group of autonomous beings cannot and should not be thought of in terms of their average anything when it comes to actions and behaviors. Even more significantly, instructors are as equally identified as learners whose teaching "destinations" (namely, instructional design and implementation) are subject to the same principles: how their own prior knowledge influences their ability to learn about teaching (principles 1 and 2, above); how a more experienced individual's organization and implementation of material may seem both awesome and barely attainable (3); how metacognition about teaching can influence decisions about everything (4); how broad exposure can provide foundational metaphors for transfer and adaptation into their own settings (5); and how their interactions with others can promote their own continued learning (6).

Although we think "cognitive process instruction" is a more sensible label, we embrace Mintzes' definition of "evidence-based practice" that sets out the six principles above. This leaves the decisions of contextual variation and diversity to the sensibility and autonomy of the individual instructor, as well as the ubiquitous challenge of working with the character of every instructional setting and the autonomy and individuality within every group of students. Ignorance of these principles cannot be a statement of individuality or, worse, a misappropriation of academic freedom. Being educated about, aware of, and building a deep understanding of these principles are critical, as is experimentation in one's setting and reflection on those outcomes. We can see rampant, horrid choices made in the name of education that should rightfully be abandoned in nearly all cases: "the preening windbag, the verbatim PowerPoint reader, the poor timekeeper…" (Tokumitsu 2017).

A potentially large fraction of readers might want to dismiss "cognitive process instruction" because of the third word. "Instruction" has become a demonized activity, likely because we have come to a time when so many people have done it so badly that "the lecture" has become a purely pejorative rhetoric. The term "active learning" is used to promote countless instructional activities and contrasted with the fundamentally meaningless term "passive learning" as a way to sell the wholesale rejection of something done badly as an intrinsically bad activity. Unchallenged, Wieman (2014) goes so far as to equate all use of "lecture method" to bloodletting as an antiquated procedure. Sure, there are plenty of ways to do it badly: giving a pedantic seminar is not the same as giving an engaging class lesson that sits in the context of a collection of diverse learning resources. And through this rejection of "lecture," the profession has unfortunately seen the accelerated atrophy of some core skills in recent generations, such as the ability to captivate, inspire, and educate through persuasive and improvisational sermonizing. The lost lesson for students, compellingly argued by Worthen (2015), and predicated on being effective in the classroom rather than ineffective, is "the art of attention, the crucial first step in… critical thinking…requiring students to synthesize, organize and react…." Our socially democratized world has resulted in plenty of social media spaces where an individual can express ideas, but what good is it if no one is listening because they are so eager to interject their own 2-cents worth? This lost lesson of reasoned contemplation is also critical when the text (or time) it takes to string a few actual ideas together gets dismissed with a wave of TL;DR (too long; didn't read). The inattention of students ought to be a challenge to teachers (writers and speakers) to do better at their crafts, not to abandon them.

In their criticism of lecture, Wieman, Mazur, and others are still overloading, isolating, and overestimating the significance of a single intervention (the "classroom") in learning. We embrace Feldon's wisdom that there are no magic bullets in educational interventions (2010). One needs to have healthy skepticism when being sold on easy and superficial solutions to complex problems, and to be on the lookout for the law of the instrument (a.k.a. Maslow's hammer), when people who develop a solution go out in search of a problem. Whether it's to support or criticize, overemphasizing a single intervention disdains the importance of building a learning environment that is a diverse, multifaceted ecology of resources promoting the growth of autonomy and self-regulatory behavior (Brown, Doughty et al. 1996; Chen, Chavez et al. 2017; Zimmerman 2008). As Wandersee (1991) did with the endless debates over content versus process, Mascolo (2009) defuses the typical "student-centered" versus "teacher-centered" arguments as a false dichotomy: "it is possible to parse off the active role of the student from the socio-cultural activities of which the student and teacher are a part."

In Mascolo's (2009) cogent argument, much disciplinary knowledge is not written down or preserved in any way other than through the stories we tell. This disciplinary knowledge "is the historical product of socio-cultural processes that have evolved over long periods of time. Such knowledge is preserved and communicated through the cultural vehicle of language. Such knowledge can only be acquired through active participation in language-mediated learning activities that are structured by more expert individuals."

What a tragic error it has been to throw away the metacognitive expertise about a subject that a practitioner-teacher carries alongside the subject matter. Countless critical lessons sit between the lines on a syllabus, and the unwritten rules of any profession live in the mind of an expert and not on the page. We have adopted (Coppola 2013) the wonderful phrase "learning-related attitudes, values, and beliefs," coined by Slavich and Zimbardo (2012), to also capture the ephemeral lessons that come from attending to how an expert "plays the notes." We can no more perform the notes that Yo-Yo Ma uses with the same resonant meaning when he is on the stage, teaching through his performance, than he can perform the notes that we use when teaching (yes, also a performance!). The enduring lessons are not based on what is written down but instead derive wholly from expertise, for example, scientific skepticism and the epistemology of scientific knowledge, neither of which appear on the syllabus but arguably appear when an expert is teaching well.

Much of the emphasis on measurement of learning effectiveness has been driven by the push for accountability, for return on the public investment in education by tuition, state, and federal funding. The accountability push has been largely defined by governments and administrators, as the numbers and graphs of various key performance indicators (KPI). Educational settings with astonishingly high student failure/withdrawal ("DFW") rates are in crisis, and it is immoral if the losses continue unattended. Yet reducing a 40% DFW rate to 30% is a mixed blessing when the best measure of success is the reduction of a hideous mortality rate to a less hideous one. Additionally, the widespread criticism of teaching that it is solely about information delivery is ironic when measures of improved information mastery are the metrics used to warrant change. We hope that the profession can outgrow these bean-counting strategies, but the field seems convinced that the results of a set of targeted, fact-based multiple-choice questions can not only reveal an underlying conceptual understanding but that it can also be used to make value judgments about one's teaching practices. These ideas are particularly promoted by those developing and/or using the so-called concept inventories to answer KPI demands. A nicely balanced view of inventories is given by Smith and Tanner (2010), including future options that might overcome the severe limitations.

The "Evidence-Based Practice" Dilemma

Considering the development in higher education of what is currently called "evidence-based practice," we see two problematic aspects that need resolution.

The QED Problem

> If you take an action that is predicated on anything from a principled belief to a law of nature, you are not questioning its existence. In fact, you are counting on it. For example, starting from the gravitational constant "g," you might take the action of launching a satellite into a geosynchronous orbit around the earth. The data that you obtain about its geosynchronous nature are affirming to your actual experiment; but if what you decide to do is measure "g," you are gathering evidence about one of your fundamental assumptions, and that is nonsense (QED – *quod erat demonstrandum*; thus it has been demonstrated).

Without pointing figures or naming names, take a look at any random paper where one of the "evidence-based practices" is being used. It would make an interesting meta-analysis to determine how many times a study that is built upon the demonstrated and evidence-based value of peer-led instruction (for instance) ends up gathering data whose warrants are used to make claims about the value of peer-led instruction (QED).

And so the first dilemma is either everyone agrees to having generalized knowledge (so that "g" does not need to be measured again), counting on it to operate, and rejecting papers that re-measure "g" over and over or everyone admits that the knowledge about these educational issues is not as generalizable as the advocates of "evidence-based practices" would have us believe. This requires starting to look much more carefully at contextual issues (student population, instructor experience and identity, institutional and social settings, institutional and departmental dynamics, and numerous other contributing factors) and to stop treating an average gain as meaningful without taking into consideration that while the intervention benefitted some, it was detrimental to others.

Our colleagues in medicine do this latter activity as a matter of ethical practice. An intervention cannot be so perfect that everyone benefits. Characteristics are discovered for patients whom it does benefit, what the limits are, and (quite significantly) what the side effects are. For whom is the treatment bad, and why? Similarly, in every study of every one of the "evidence-based practices," there are aggregated data where some student performances under the intervention went down or where there are negative consequences that are, frankly, too often glossed over or ignored. For example, there are serious side effects in one of the recently popular strategies, gamification, that "have been largely ignored by researchers and practitioners alike" (Callan et al. 2015; Hyrynsalmi et al. 2018; Andrade et al. 2016).

What an intriguing question to ask: What is there to learn from the students for whom the effect was negative? Shouldn't an educational intervention, peddled as a universal benefit, come with a warning about the side effects if there are identifiable populations for whom there are academic risks? And how much better to identify the characteristics of those for whom there are benefits, so that they can make better choices. Perhaps, as in medicine, there are compliance issues that lead to the negative outcomes, and so the intervention could be modified or supplemented. And perhaps there are contexts in which the intervention is actually not recommended at all.

We clearly emphasize here our belief that the results from these "evidence-based practices" have been overclaimed and overgeneralized. And if that is true, then the second-generation activities that are predicated on the assumption that these practices are universally beneficial (such as COPUS; Smith et al. 2013) are not nearly as defensible as some have thought.

The Physical Science Problem

> *In their non-probabilistic research domain, chemists, for example, are accustomed to carrying out research with 10^{23} self-equilibrating, cognitively-incapable particles, where the law of large numbers holds and where control of experimental conditions is real and reproducible over a limitless number of trials.* (Coppola and Krajcik 2013)

Regardless of motivation, many of the biomedical and social science areas that adopted quantitative research methods from the physical sciences are in the midst of what is called the reproducibility crisis (Diener and Biswas-Diener 2018; Staddon 2017; Achenbach 2015; Open Science Collaboration 2015; Begley 2013). The underlying assumptions in physical science experiments simply do not operate when you are dealing with truly complex systems. The conditions outlined for chemists, in the quote above, make doing chemistry research much easier than doing psychology research, not harder. People are not only heterogeneous, they are capable, at the level of the individual, of inconsistency and dynamic change that results from both internal and external influences.

Huber and Morreale (2001) noted that when scientists move into education research, they carry their discipline-based biases about research with them, including the cultural expectations and underlying assumptions about quantitative data. The fundamental arguments in the "Scientific Teaching" community (Handelsman et al. 2004; Handelsman et al. 2007) are predicated on the appropriation of physical science sensibilities into the social sciences. They ask (2004): "…why do outstanding scientists who demand rigorous proof for scientific assertions in their research continue to use and, indeed, defend on the basis of their intuition alone, teaching methods that are not the most effective?" Certainly a provocative question, however, no experiment with a teaching method has ever produced data that meet the standard of a physical science experiment. Recent arguments are convincing that even concepts such as validity, reliability, and generalizability need to be defined in their research context and not simply, and likely inappropriately, borrowed from physical science (Cho and Trent 2006; Auerbach and Silverstein 2003).

The Scientific Teaching thesis also asserts that instructors are merely trusting their intuition, which is a straw man argument. There are terrific sources of information about student performance outside of intuition, such as the artifacts they generate, including examination answers and other performance-based assessments. Testing can be designed to match intended learning goals (e.g., using questions that require open-ended, generative explanatory replies, driven by the interpretation of new and unfamiliar data, selected to offer the possibility for multiple interpretations). Combined with a properly scaffolded instructional setting, testing can set a high bar for a course in ways that learning to recognize the right answer from among a list of choices cannot, and the exams themselves provide rich and meaningful information.

> *The long-range goal is to improve the level of reasoning typically used by students; some even predict that it will raise the level of human intelligence in general. At the very least, research on human thought processes should be able to help us eliminate some of the more stultifying aspects of education and bring thinking back into the classroom without sacrificing content or substance.* (Lochhead and Clement 1979)

The Role of Teaching in Learning

There may be no more familiar aphorism in an educator's experience than "I never really learned it until I taught it." In other sections of this book, peer-based instruction is featured, and one of the things it creates, regardless of its form, is the opportunity for one individual to express his or her emergent understanding to another person, in other words, to teach. If only by instinct, educators recognize the value of these interactions, which at least in part explains why they are a staple in formal education. Wagner (1982) reports a long-term perspective on peer-based instruction that goes back nearly 2000 years. In higher education, the most recent uptick of interest in peer-to-peer instruction began in the 1960s (Boud et al. 2001; Whitman 1988; Freeman 1995; Topping 1998), which likely derives (Goldschmid and Goldschmid 1976) from the postwar boom in universities and the concomitant toll that took on the faculty-to-student ratio. Peer instructors become an extension of the main instructor (Topping 1996), and upper-level undergraduates can be as effective as new faculty members (Falchikov and Goldfinch 2000), or as ineffective when they exhibit "didactic telling" behaviors (Roscoe and Chi 2007).

Taking on the teacher's role provides unique benefits to learning that complement other strategies. First, as a peer instructor, you have an audience who actually wants and needs your help, assistance, or input (Wagner 1982), as opposed to explaining something to your teacher, whose expertise you are pretty sure is higher than yours. Second, you open up strong and positive interpersonal relationships where the roles of power and authority are at least more equal (Goldschmid and Goldschmid 1976) and alternate during periods of reciprocal instruction (Palincsar and Brown 1984; Brown and Palincsar 1989). Third, learners benefit from their near-peers who most recently learned something. Medical education relies strongly on intergenerational instruction for this reason (Dandavino et al. 2007). Schwenk and Whitman (1984) identified what they called a greater "conscious competence" in new residents, relative to their experienced senior colleagues. The new residents, who are more likely to be thinking deliberately about each step in a medical treatment, are also more likely to share critical information with their younger peers (Rashid et al. 2011; Leeper et al. 2007; Piscotty et al. 2011; Peluso and Hafler 2011; Busari and Scherpbier 2004).

Because learning is not a smooth and linear process, it is more easily characterized as the series of errors you make as you develop your understanding and expertise. As you practice your way to Carnegie Hall, your practice is characterized, at least in part, by the errors that you learn from (Metcalfe 2017; Institute of Medicine 1999; Ohlsson 1996; Fischer et al. 2006). The analogy with proofreading writing is spectacular. At some point, the errors you commit in writing are so idiosyncratically personal that you cannot see past them no matter how hard you try; you are sure the text is perfectly written. And then you hand it off to a fresh pair of eyes. Teaching writing relies on peer review, feedback, and editing, with the friendly and helpful improvement of a writer's understanding tied explicitly to how that understanding is expressed (Rabkin and Smith 1990). We are compelled by the idea that one critical role for interpersonal interaction during learning is the need to "proofread" ideas, to uncover the flaws that you simply own so deeply that you cannot see past them.

Proofreading ideas is a system familiar to the academic life that stretches from the cradle to the grave. Metcalfe (2017), among others, reports how, within the American education system, the most talented student tends to be brought "to the board" to provide an answer or explanation for the class. In contrast, in Japanese classrooms, the weaker students come forward, and they are in an environment where peer instruction walks them through the trouble they are having with the topic at hand. In our own university programs, we have observed the same thing as others: students report that peer instruction settings create a safe and supportive environment in which to make errors (Coppola et al. 2001). As professional authors, we continue to rely on "proofreading our ideas" (writ large), through collaboration, peer review, editorial oversight, and public disclosure to help clarify and refine our thinking, the origin of Shulman's notion of "teaching as community property" (1993), and the "end of pedagogical solitude," both of which represent time-honored traditions of sharing what we know openly as a path to improvement.

From a purely practical perspective, students need to realize that providing explanations to others is at the core of assessment about their learning. Whether it is a paper, a poster, an oral report, or a well-structured exam, they are going to be in the position of explaining something to someone. Because learning cannot occur without making errors, students must be thoughtful about controlling the setting in which they make them (Metcalfe 2017). And they cannot learn without making errors, so what they have control over is the setting in which they make them. The obvious goal is to make (and correct) errors in a low-stakes setting, in front of an attentive other (the indispensable proofreader), rather than at the high-stakes event, in front of the person responsible for the assessment.

Explanatory knowledge (Coleman 1998) is an underappreciated area of understanding about learning. Starting from the premise that "I never really learned it until I taught it," researchers have uncovered a significant effect: if you are aware of the need to explain something that you are tasked with learning, you will learn it better than if you were only learning it for yourself. And if it is true that "…providing explanations to others is at the core of assessment…," then developing explanatory knowledge should have a profound effect on designing learning environments.

In some key experiments, Coleman et al. (1997) gave college students short lessons to learn new and unfamiliar topics in biochemistry. The two experimental conditions only differed in the instructions: one group was tasked with preparing to teach others, for which there would be a brief test on their learning of the topics, and the other group was to be only tested on their learning. The researchers used three types of questions that they categorized as recall, near transfer, and far transfer. The learning-with-teaching group outperformed the learning-only group, and the performance gap increased as the need for knowledge transfer to answer the questions increased. In attributing explanatory knowledge as the reason for this observed difference, the researchers concluded that "preparation to teach the contents of a text versus to understand it personally may influence the mental representations that are created from text." A range of benefits from explanatory knowledge can be attributed to observations of school children through university students, covering exam scores, retention of knowledge, and conceptual understanding (Nestojko et al. 2014; Allen and Feldman 1973; Bargh and Schul 1980; Benware and Deci 1984; Repice et al. 2016; Wilson and Varma-Nelson 2019). These benefits extend to creating and using prompts for students to explain things to themselves (Bisra et al. 2018; Chi et al. 1994).

Real Work

In a recent chapter entitled “Do Real Work, Not Homework” (Coppola 2015), we synthesized a set of six practical design attributes, derived from the frameworks of McLellan’s situated learning (1996), Herrington’s authentic learning (2000) and authentic tasks (2004), and Rabkin and Smith’s real work (1990). These had all been important in our own teaching, and we hoped they would be useful to instructors who were looking to align their own ideas with the recommendations from these frameworks.

Taken together, these six attributes are complementary dimensions of designing work that draws from a learning-through-teaching perspective. They are (from Table 18.3, Coppola 2015):

1. *Balance convergent and divergent tasks*: Convergent tasks are evaluated against a given standard (or “the right answer”), and so learners can assess how successful a given pathway is in achieving the prescribed goal. Divergent tasks focus on the construction of individual outcomes within a set of common guidelines, and so individual learners come to a defensible position.
2. *Peer presentation, review, and critique*: Developing explanatory knowledge allows learners to deepen their understanding and to anticipate arguments, revealing strengths and weaknesses in understanding.
3. *Balance teamwork and individual work*: Successful communities of practice rely on individual members with a diverse base of knowledge and experiences and additionally where, in the aggregate, a common understanding encompasses more than any individual might have achieved.
4. *Students use the instructional technologies*: As a matter of principle, learners should be trained in at least the instructional technologies deemed useful by a teacher. It is often more informative to see what learners construct in representing their understanding using multiple modes, rather than for the learners to see only the practiced, expert view.
5. *Use authentic texts and evidence*: Understanding and interpreting empirical evidence can be accomplished by direct experimentation and also by using the original primary literature. Parts of these resources will be inaccessible to new learners, but other parts will not be (alternatively, significant historical papers can be used).
6. *As important to the class as the teacher’s work*: The work generated by students, resulting from divergent tasks, in particular, can be returned to the class as Student-Generated Instructional Materials. Subsequent assignments and/or testing based on student-generated materials intentionally and explicitly distributes the role of “teacher” in the instructional setting.

These first five attributes are familiar, well represented, and featured throughout this and comparable volumes. The last one, however, is not typically mentioned on “the usual suspects” list. In writing the “Real Work” chapter, we found regular occurrences in the literature describing work students generate being then used in class as instructional materials; still this body of compelling, high-level activities has yet to be commonly defined. Here and elsewhere, we have chosen the term "Student-Generated Instructional Materials" to describe this area of work (Zurcher et al. 2016). Different authors have used different terms; computer scientists have called it the inside-outside method, Education 2.0, and the Contributing Student method (Ramirez-Velarde et al. 2014; Lau et al. 2014; Hamer et al. 2012), while some biochemists call it participatory learning (Bottomley and Denny 2011).

Student-generated work is common and an expected outcome, particularly in the visual arts, music, theater, architecture, fabrication engineering, dance, writing, and in any area with original research activity. So although "student-generated materials" are not at all unusual to encounter, implementation of the materials for instructional purposes opens a whole new area of exploration. Instructors can, and do, use the student-generated work as object lessons and as the basis of discussion. The specific application of student-generated work as instructional materials may be overlooked (Snowball and McKenna 2017) simply because it lacks a unique label and ends up subsumed under the immense category of student-generated work: "using student-generated video as a teaching tool" (Jordan et al. 2016) or learning with "student-generated multiple choice questions" (Kay et al. 2018).

This chapter enables us to delve into the rich breadth represented by these activities. As described above, Student-Generated Instructional Materials hit all of the marks for evidence-based practice as outlined by Mintzes. Student-Generated Instructional Materials quite readily qualifies as an excellent example of cognitive process instruction. It elevates the students in a course to be co-instructors, asking them to learn, to anticipate teaching others, and to design and evaluate such work. Importantly, learners then follow through by actually using the student-generated work as part of the canonical instructional materials associated with the course.

Student-Generated Instructional Materials

Criteria and Benefits

We called the sixth real work attribute "as important to the class as the teacher's work" to draw attention to the authentic purpose of Student-Generated Instructional Materials. Students explicitly share the teacher's role by creating instructional materials and then returning those materials to other students as part of the class. van Dijck (2009) calls such students "prosumers" (producers and consumers of content), and Wheeler et al. (2008) posit these materials create "a fertile terrain" that cuts across and catalyzes communication between people in multiple subject area domains. Student-generated materials can be used for other audiences, including the public, and for other purposes, such as public service (Wyatt and Oswalt 2011).

New technologies play a large role in Student-Generated Instructional Materials. As these technologies have widened the scope that students can use for generative work, so too do they enable students to create instructional materials. New technologies enable students to create multi-representational explanations (Johnson and Reynolds 2005), and when returned to the class as a whole, students can access numerous and diverse versions of learning objects consisting of drawings, text, videos, oral narration, and animations. These objects promote understanding of underlying ideas and also help in the development of interpretation skills (Larkin and Simon 1987; Lowe 1989, 1993; Bowen and Roth 2002; Roth and Bowen 1999; Paas et al. 2003; Mayer et al. 1996; Michalchik et al. 2008; Kozma and Russell 2005; Russell and Kozma 2005; Kozma 2003).

Direct comparisons between gains with teacher-generated instructional materials prepared on the same subjects as student-generated materials consistently favor the student-generated ones (Mayo 2001; Spier-Dance et al. 2005; Haglund 2013), consistent with better learning resulting from the anticipatory need to teach (Ramirez-Velarde et al. 2014). Normal instructional design features apply to Student-Generated Instructional Materials, including scaffolding the assignments against benchmarks for progress (van Dijk and Lazonder 2016) and careful collaboration with teachers who have reservations about, if not resistance to, such materials (Croft et al. 2013).

Students who develop instructional materials gain a strong sense of ownership (Hudd 2003) and empowerment (Hains and Smith 2012) and improve their communication and collaborative skills along with subject matter understanding (Brown et al. 2013). One important issue addressed by Student-Generated Instructional Materials is the clash between disciplinary knowledge and the very different home contexts of many nontraditional students. Using student-generated content allows teachers to bring student experiences and voices into the community of practice and acknowledges the importance of their prior experiences in knowledge production. Increased motivation and positive emotional affect (Pirhonen and Rasi 2017) have also been observed along with an increased sense of inclusivity (Taylor and Robinson 2009; Robinson and Taylor 2007).

I Cannot Compose the Final Exam Until the Students Finish Writing the Book

In 1989, the University of Michigan's chemistry department reformed its undergraduate chemistry curriculum, using mechanistic organic chemistry as the foundational course (Ege et al. 1997; Coppola et al. 2001). In 1994, a peer-led, small group supplemental instructional program (SSG, Structured Study Groups) was introduced into the courses for students interested in adding the Honors designation to their grade (Varma-Nelson and Coppola 2005). This option is elected by about 160–180 students each term. Students in the SSGs are assigned to one of eight peer leaders who previously excelled in the course, who showed promise for their teaching skills, and who were recommended by their own leaders to apply for the positions. Weekly tasks are similar to the studio instruction in the writing, visual, and performance arts, where in-session time is devoted to peer review, discussion, and critique of artifacts created outside of the class meeting (Coppola et al. 2001).

During the second semester, a term-long SSG project is required in which small teams of students transform the content of a recent scientific publication into written and web-based teaching materials. In so doing, the class collectively creates a multimedia text and traditional 250-page book that present a fine-grained look at numerous chemical transformations (Coppola and Kiste 2004; Hayward and Coppola 2005). This book, written by students, is duplicated and distributed to the class, and this is the text on which the final examination is based. So, as an instructor, "I Cannot Compose the Final Exam until the Students Finish Writing the Book." In an interesting twist, the final exam questions are based on uncorrected errors from the student-generated text, which students are allowed to bring with them to the exam. Studying for that exam means our students face what is perhaps the key question that ought to underlie any course to encounter new content, and ask yourself "do I believe this?" *Do the information and its explanation make sense?* Quite spontaneously, each year, the students decide they need to meet as a group, to tear through the text and ask questions of one another; after all, they are the authors.

We have used performance-based assessments to look at the differences between students in the SSG program and their peers in the same course who did not elect the SSG option (Coppola et al. 2001; Coppola 2010). Although SSG students are self-selected, we have strong and well- controlled evidence that there is a performance boost that accompanies enrollment in the SSG option. We think that this is due to structured time-on-task in an environment where errors can be made and corrected and where the level of the tasks is slightly higher than the typical demand on examinations. More significantly, in other studies, we have observed that the expertise the SSG students develop more closely aligns with that of senior graduate students, in their ability to analyze a laboratory task or to think their way out of a counterintuitive experimental observation (Coppola 2010).

The previously described second semester SSG project involves production of a student-generated web site. In this work, students incorporate explanatory features such as animations to represent the details of the chemistry, as well as other useful HTML-coding features such as mouse-overs. We additionally have students produce a traditional printed book, in part because it is a genre with its own unique demands but also because the students need a portable format on which to make notations and to bring to the examination.

Several published examples of student-generated texts exist. Hoban et al. (2015) have written a review of this general area, particularly on the use of student-generated wiki-texts as instructional supplements. Others have pointed to the benefits of text-writing for pre-service teachers (Kidd et al. 2008; O'Shea et al. 2007), as well as the benefits of online peer review (Gehringer et al. 2010). Wheeler et al. (2008) emphasize the value of communally accessible student-generated texts as a vehicle for developing pride in ownership through the explicit recognition that others will see the work. Student-generated texts have been shown to enhance reading and writing in technical vocabulary and in second language acquisition (Rees et al. 2013). Vázquez et al. (2012) developed a supplemental, student-generated wiki-text in our introductory physical chemistry program, and Pazicni has further expanded the idea of "write-to-teach" in the broad area of student literacy (Pyburn et al. 2013).

Video and Other Media-Based Explanations

Podcasts and other media-based explanations are types of student-generated work that have been used as instructional materials (Forbes et al. 2012; Lee et al. 2008; Lee 2007). In our own work, for example, we have used student-generated tutorials created by 2–3 student teams (Coppola et al. 2001) and then made the tutorials available to the whole class of 1500 students. The student- generated tutorials integrate into the diverse ecology of examination and practice resources used in our program. During a 5-year period, the SSG students created a set of 400 useful videos that were attached to questions covering the academic year. Our students have rarely created pedantic tutorials and instead opt for creative formats, such as songs, plays, newscasts, etc. (Lee et al. 2008). Most recently, we have changed the assignment to standardize the presentation by using narrated slide shows which more explicitly address the detailed background knowledge needed to answer the question. This change is a genre switch to provide greater diversity in our available suite of learning resources.

Student-generated tutorials used for teaching laboratory techniques and procedures in chemistry have been used with success (Box et al. 2017; Benedict and Pence 2012), benefiting from the same feature cited in medical education, the "conscious competence" of a new learner to transmit the most critical information to other new learners (Schwenk and Whitman 1984). In the University of Michigan chemistry department, one faculty member has created a "Compute-to-Learn" program, in which students create unique, interactive demonstrations that are not only made available to the class but are also deposited in a reviewed and indexed repository maintained by the commercial software developer (Jafari et al. 2017).

Drawing strongly on constructivist epistemology (Falkner and Falkner 2012), several individuals have proposed an array of contributing factors to explain why these student-generated instructional materials have value. In large part, the explanations rest on creating an authentic audience for both presentation and peer review (Cajander et al. 2012; Sondergaard and Mulder 2010; Luxton-Reilly and Denny 2010; Kearney and Schuck 2005) and promoting intrinsic motivation (Herman 2010).

Canonical Responsibilities (Instruction, Assignments, Homework, and Exam Questions)

Numerous examples of all the canonical responsibilities of teachers (providing direct instruction, creating assignments and homework activities, constructing and evaluating assessments, particularly examinations) can be found in student-generated work. In their inside-outside (Education 2.0) strategy, Ramirez-Velarde et al. (2014) describe how "students … generate most of their learning materials as well as a significant part of their evaluation exams. … [they create] questionnaires, discussion topics and questions, schemas and synoptic tables, relation trees and other visualization aids. They also develop specific problems and exercises that are included in their exam evaluations…. [and] the learning material is ready to be used by future generations."

The overwhelming weight of evidence suggests that when students generate instructional materials, it positively affects their own learning. Reflecting on the need to teach others, students develop explanatory knowledge, which in turn accounts for their increased engagement (Collis and Moonen 2006) and improved performance on assessments including formats such as wiki (Ellis and Folley 2010), video (Jordan et al. 2016), direct instruction of others (Alaimo et al. 2010; Hickey and Pontrello 2016), storyboards (Colbran and Gilding 2014), and flash cards (Colbran et al. 2017).

In our first-year organic chemistry program, the second half of the Honors laboratory course syllabus is blank. Through a set of weekly milestones, the students propose, review, and ultimately establish the agenda for the set of experiments, including cost and safety considerations. The chemical materials are ordered just ahead of the midterm break, and then these first-year undergraduate students return to complete the course they have defined (Coppola 2006). Gehringer and Miller (2009) have reported a comparable course design in their two-term computer science course, integrating student-generated activities for some of the difficult concepts into the course syllabus.

Case studies are commonly used in a variety of disciplines, and implementing student-generated case studies (Yurco 2014) has been reported in business (Ashamalla and Crocitto 2001), medicine (Philip et al. 2008), and scientific ethics (Coppola 2000). Improvements in general reasoning, problem-solving skills, and subject matter understanding have been reported to result when students create such materials (Cliff and Curtin 2000; Gallucci 2009; Herreid 1994).

Electronic homework systems have enabled hundreds of students to generate questions that are then made available to their peers. The PeerWise platform (http://peerwise.cs.auckland.ac.nz/) has been used and studied extensively (Kay et al. 2018; Devon et al. 2012; Hardy et al. 2014; Bottomley and Denny 2011), with student ownership and control underlying the development of independence, engagement, and motivation (Fergus and Kirton 2013; Kelly 2012; Collis and Moonen 2006; Yu and Liu 2005; Fellenz 2004; Luxton-Reilly and Denny 2010). In our organic chemistry program, we collaborated with a commercial platform provider, called Sapling Learning (http://www2.saplinglearning.com/), to train about 400 students to author in this open-ended environment. This endeavor resulted in nearly 1000 usable examination questions tied directly to our own course (Zurcher et al. 2016). In our experience, a deeper reflection on the subject matter takes place when students need to construct meaningful questions, give and get feedback on them, and even think about fair and rational scoring rubrics (Corrigan and Craciun 2013; Ahn and Class 2011).

Summary

In this essay, we sought to bring greater visibility to the overlooked area of Student-Generated Instructional Materials. We think that the artifacts and cognitive processes that result from this method can provide a rich evidence base for studying student learning. As illustrated here, the area is well represented but suffers from the lack of a single identifiable label or snappy acronym (SGIM?). The area has never been the targeted subject of a national funding initiative, and it has flown below the radar when the usual suspects of "active learning methods" are gathered.

Student-Generated Instructional Materials are also a powerful example of how the responsibility for teaching can be distributed while maintaining the critically important role of the teacher's expertise in pedagogy and instruction. The teacher assumes the role of reviewing and evaluating the pedagogical choices made by students, perhaps as a peer reviewer of teaching, rather than only serving as an arbiter of what is right or wrong in subject matter learning. The fact that many instructors feel uneasy, or even fearful, about sharing the power and responsibility for teaching (Ahn and Class 2011) is likely a positive indicator about the importance of this method.

Student-Generated Instructional Materials could arguably be categorized under the larger area of user-generated content (Stone et al. 2014) where motivation to be an active participant derives from "social status, social relations, and social identity" (Schaedel and Clement 2010) in what Paulin and Haythornthwaite (2016) call "crowdsourcing the curriculum." van Dijck's notion (2009) of students as "prosumers" (producers and consumers) of knowledge across media platforms such as YouTube, Facebook, and Wikipedia is centered on their development of a sense of agency (Lazzari 2009).

Recommendations

In identifying this complex, fruitful, yet under-recognized area of work with cognitive process instruction, we return to the first part of this essay. It is an error, by our reckoning, to persist in championing the so-called evidence-based methods as do-or-die criteria for instructional effectiveness or excellence.

The overemphasis that reform-minded (cheer)leaders make about the finite theater of the classroom, rather than the entire learning ecosystem, is problematic. The lack of recognition of a rich area such as Student-Generated Instructional Materials is also problematic. What else is being missed, particularly in the scholarly lives of learners who do have agency and diverse choices?

The "QED Problem" (continuing to reaffirm the principle that was used to design an intervention) is easy to address within the editorial boards of journals and in the hands of reviewers. Recasting "evidence-based" to mean the research-based principles about learning, as listed by Mintzes, is a good way to start. We can take these as axiomatic and move forward.

We have also raised questions about the generalizability of results when instructional contexts are inherently unique, the misappropriation of physical science to social science questions, and the lack of attention to those for whom an intervention is harmful. Context and culture matter, and the makeup of a class and its prior history and experiences, of a departmental faculty, of an institution, all matter. In 1997, we wrote about the changes in our undergraduate chemistry program, and our comments are as relevant to this discussion as they were then (Ege et al. 1997):

> In describing the path that we have taken to address these issues, we intend to inform rather than to prescribe. We will describe an evolving culture within a large academic department and university. We will also describe an evolving curricular program, but do not suggest a one-time "fix" intended or recommended for export. We hope that sharing our experiences and organizing principles will enable other science educators to create useful curricular analogies that draw from their own experiences, strengths, and academic culture.

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