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Jeffrey A. Stone, PENN STATE, stonej@psu.edu
Laura Cruz, PENN STATE, lxc601@psu.edu

The Wicked and the Logical: Facilitating Integrative Learning Among Introductory Computing Students

ABSTRACT

Higher education has embraced integrative learning as a means of enabling students to tackle so-called "wicked" problems, i.e. problems that are sufficiently complex, contested, and ambiguous that conventional, disciplinary specific approaches are inadequate to address. However, challenges remain in defining integrative learning consistently and effectively, especially because the cognitive processes that make up an integrative learning experience are not understood fully. This mixed-methods study was designed to help understand how students perceive, navigate, and resolve challenges that require them to integrate knowledge of one "wicked" subject (sustainability) with the skills of a practice rooted in mathematical logic (computer programming); how they express their integrative learning through reflective writing; and how we gain a stronger understanding of this process through linguistic analysis. The findings suggest that some students demonstrated the ability to integrate computational reasoning skills into socially relevant contexts more successfully, confidently, and in more well-rounded ways than others, though success required ways of thinking that extended beyond programming. The findings also underscore the potential need for reconceptualizing integrative teaching and learning in fields that have problem-solving traditions rooted in less "wicked" solutions.

KEYWORDS

integrative learning, sustainability, computer science, linguistic analysis

INTRODUCTION

Higher education has recently embraced the promise of integrative learning, i.e. cross-disciplinary learning that incorporates knowledge and perspectives acquired from both culture and life experience (Ferren and Anderson 2016; Huber and Hutchings 2004; Klein 2005). The impetus behind recent interest in the subject stems from the growing recognition that many of global challenges are so-called "wicked" problems—problems that are sufficiently complex, contested, and ambiguous that conventional, disciplinary specific approaches are inadequate to address them. Rather, integrated learning emphasizes a form of disciplinary dexterity in which students can bring together knowledge (or skills) from across a variety of sources and apply them to generate new ideas for taming the "wicked" problems of the world (Gallagher 2019; Marback 2009; Yukawa 2015). Part of the appeal of integrative learning in higher education is its inherently civic function, in that "wicked" problem solving is a strategy that enables us to equip our students with the tools needed to be not only informed citizens, but also effective ones (Hanstedt 2018; Huber, Hutchings, and Gale 2005; Noweski et al. 2012; Papanek 2005).

Because of the perceived institutional value of integrative learning, there are now well-developed rubrics that identify benchmarks of integrated learning and facilitate assessment at the institutional level

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(DeZure, Babb, and Waldmann 2005; Huber et al. 2007; Reynolds and Patten 2015). Institutional assessment does not serve the same purpose as classroom assessment, however, and the transition of these high-level tools as the basis of work in the scholarship of teaching and learning remains scattered in practice. A recent compilation of integrative learning practices in public health courses (units), for example, shows evidence being collected in the form of satisfaction surveys, participant counts, student artifact assessment, and focus groups, each tied to different instructional practices (e.g. experiential learning, service learning, study abroad) and conceptual models (e.g. deliberative pedagogy) (Harver, Hein, and Rhodes 2020).

This diversity of practice is also compounded by a number of studies suggesting that integrative learning may be a developmental process that differs over the course of a student's college experience (Kinzie 2013; Lowenstein 2015; Niehaus et al. 2017). For example, Burg, Klages, and Sokolski's study (2013) of student artifacts in a first-year experience unit (writing and mathematics) at a community college suggests the need for developing a set of "basic integrative skills" prior to engaging in integrative learning activities, and that these activities may be more appropriate in upper division units. After interviewing 194 first and second year students, J.P. Barber (2014) proposed a grounded theory of integrated learning as a multi-stage process in which students move from connection (e.g. finding common threads across contexts) to application (e.g. applying something learned in one context to another) and then synthesis (e.g. ideas are brought together to create something new). These scholars note that students frequently do not reach the upper stages of their models, and, as one scholar laments, "it is not clear why some students 'get it' and others do not" (Leonard 2012).

It may be time to consider assessment methods that are themselves integrative. For example, "wicked" problem solving is inherently open-ended, which may be somewhat incompatible with the currently dominant mode of outcomes-based assessment. If integrative learning is a developmental process, as this review of the literature suggests, one-size-fits all rubrics or theories may be ill-suited to capture differentiated learning pathways. And while qualitative studies have proven to be insightful, these insights have been, somewhat by their nature, challenging to generalize or replicate across different contexts. The current study attempts to integrate these approaches and introduce new methodologies for looking deeply into the ways in which two cohorts of computing students engaged in the process of integrated learning, both successfully and unsuccessfully, with the introduction of sustainability into their introductory programming classes. These methodologies are used to gain deeper insight into the process by which computing students engage in integrative learning and how they express that engagement through reflective writing.

SUSTAINABILITY, COMPUTING, AND INTEGRATIVE LEARNING

Sustainability, defined as "the simultaneous pursuit of human health and happiness, environmental quality and economic well-being for current and future generations" (Penn State University 2017), clearly fits the definition of a "wicked" problem. It is characterized by multiple stakeholders, contested meanings, and conflicting outcomes, all with large social and economic impacts. This potential impact was recognized when the United Nations launched its sustainable developments agenda in 2015, focusing on a set of 17 multinational goals to be achieved by 2030 (Huckle and Wals 2015; Moon, Walmsley, and Nikolaos 2018). As a field of academic study, sustainability has emerged in multi-disciplinary, inter-disciplinary, and trans-disciplinary contexts (Felgendreher and Löfgren 2018; Moore 2005; Newell 2010; Rowe 2007). Similarly, as a mode of teaching and learning, practice has ranged from integration into disciplinary based units to the development of stand-alone curricular and co-curricular experiences (Karatzoglou 2013; Rusinko 2010). While early efforts often focused on disciplines with a clear affinity for the study of human interactions with the environment (e.g. biology, sociology, international business), sustainability education has expanded to embrace a wide range of disciplines, including computer science.

This association may seem counter intuitive. Prior studies of the effects of academic discipline on student learning outcomes (Lindblom-Ylänne et al. 2006) suggest that the pedagogical epistemology of the so-called "hard, applied" fields (according to the Biglan classification) is distinctive in that faculty in these disciplines tend to be comparatively resistant to innovation (Quinn 2012; Stoecker 1993) and place greater emphasis on skill building over deep-learning (a characteristic of applied fields) (Laird et al. 2008; Laird and Garver 2010). That being said, a recent set of studies has identified a further distinguishing factor: fields with similar classification also tend to make a stronger differentiation between general education and major units, and they are more apt to build integrative learning into their general education curriculum (Laird and Garver 2010). This latter emphasis may be especially surprising given that similarly classified fields have not produced as much interdisciplinary research as other disciplines (Van Noorden 2015). This has led some scholars to suggest that these areas of study may be less porous than others (Coughlan and Perryman 2011; Jang et al. 2018).

The emergence of sustainable computing appears to belie that conclusion. While at first glance the connection may not be obvious, within the field, sustainability has become codified as an integral value for professional computing organizations such as the Association for Computing Machinery (2018) and the Institute of Electrical and Electronics Engineers (2019). This reflects a growing awareness of the role computing can play in broadening of the social responsibility taken on by businesses (also called corporate social responsibility, or CSR) as well as acting as a broad lever of social and political change in its own right. This latter function is evinced by a growing number of projects, initiatives, and research studies that seek to push the boundaries of what machines can do for us, including processes such as artificial intelligence and machine learning. Computing-based efforts to properly conserve precious resources (e.g. electricity, water) and to combat the spread of so-called "fake news" are examples of these types of initiatives.

The move toward sustainability integration includes a deep rethink of higher education curriculums for some institutions, and a few intrepid pioneers have already started looking at models that deepen the integration both within computer science units (as is the case with this study) (Abernethy and Treu 2014; Cai 2010; Hamilton 2015) and in new units that encompass multiple disciplines. For example, Erkan, Pfaff, Hamilton, and Rogers (2012) integrated sustainability-based problems into a data structures class to expose computing students to the need for multidisciplinary solutions to socioeconomic problems. Similarly, Gross (2013) developed a "green" chemistry unit designed to illustrate the multidisciplinary impact of chemistry on sustainable practices. As has proven to be the case in multiple disciplines, a standard curricular model for integrating sustainability has yet to emerge.

It could be argued further that computer science education may constitute a particularly conducive environment for expanding the study of integrative learning as a process. At roughly the same time as higher education has shifted its focus to "wicked" problems, K-12 educators have been faced with a "wicked" problem of their own, i.e. the looming science, technology, engineering, and mathematics (STEM) labor shortage (NCEE 1983; Ketenci, Leroux, and Renken 2020). Researchers in this field have studied the nature of learning in math-related areas such as computer science and have articulated the existence of a process deemed "computational thinking." While definitions of the term vary by source, the gist is that it defines the various steps learners take as they successfully work through quantitative problems (Shute, Sun, and Asbell-Clarke 2017; Yaşar 2017). By breaking the process down into component steps, educators believe it may be possible to direct instruction toward the distinctive challenges presented at each phase. This approach allows educators to scaffold that instruction so that students receive the foundations of computational thinking as early as elementary school and grow that knowledge through post-secondary levels (Bower et al. 2017; Lye and Koh 2014). This research into the nature of computational thinking has paved the way for researchers to ask new questions about other types of complex learning processes. The leap toward framing integrative thinking, especially integrative thinking that includes computational thinking, as both a multi-stage and developmental process seems a small one.

Pedagogically speaking, computer science has moved from a STEM-based, problem-solving approach focused on a sequenced order of skill acquisition toward an emphasis on real-world—and often ill-defined—applications (Bers 2019). In the classroom, much emphasis is placed on problem-based learning in which students are provided with challenges from which they must render varied and/or novel solutions. What this means is that computer science instructors are accustomed to navigating the kind of open-ended problem solving that is associated with integrative thinking. And furthermore, computer science is highly sensitive to rapid changes in technology and the marketplace. Consequently, instructors must place a great deal of emphasis on highly transferable processes, particularly when most skill development is tied to hardware, software, or business practices that are likely to be pushing obsolescence in fewer than five years. In other words, while the computer science tools (languages, frameworks, etc.) may change, students also benefit from learning adaptability and skills to integrate what they know how to do into new contexts.

PURPOSE

Taken as a whole, this review of the relevant scholarly literature provides a compelling case for the potential benefits, relevance, appeal, and timeliness of integrated learning as the subject of both practice and research, both inside and outside of computer science. The key word in the previous sentence is potential. While this works in theory, there is much to be learned about how integrated learning works in practice. For our study, we wanted to know more about how students perceive, navigate, and resolve challenges that require them to integrate knowledge of one "wicked" subject (sustainability) with the skills of another (computer programming). We also wanted to learn more about how students express that integrative learning through reflective writing. Our study was guided by two research questions:

RQ1: How do students perceive their own integration of knowledge from one discipline (sustainability) with tools from another discipline (computer programming) in problem solving?

RQ2: How do students articulate their integrative learning process through reflective writing?

THE STUDY

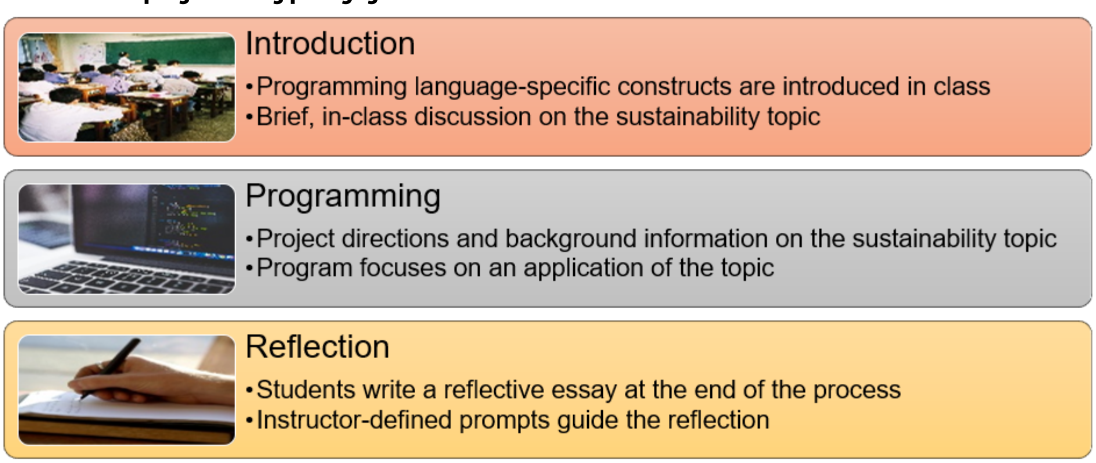
The unit setting

Two distinct unit sections were used for this study in order to provide a sufficient number of student participants. Both sections were distinct introductory programming units with significant overlap of disciplinary content. Both sections were taught by the same instructor. The primary differences between the two unit sections were the programming language utilized (C++ vs. Java) and the intended audience (engineering students vs. information science and technology students). Both had been taught previously in a traditional manner—students were exposed to a series of core programming skills, building on relatively narrowly framed problem sets from related disciplines (e.g. mathematics, engineering). The impetus for change came from several sources. On one hand, the provost (of a large, research-intensive public university located in the northeastern United States) had indicated a strong interest in capturing the perceived institutional benefits of sustainability within curricula. Those benefits accrued, at least in part, from the assumption that traditionally college-aged students found sustainability issues to be highly relevant and engaging. Given that assumption, too, the instructor believed that the introduction of sustainability issues might also serve to attract new majors to the field, especially those in under-served populations (such as women) for whom the integration of social context has been demonstrated to enhance interest and persistence (Goldweber et al. 2013; Rader et al. 2011). That insight, coupled with the recognition of a growing market for sustainable computing skills mentioned previously, served as the basis for an intensive and extensive redesign process.

The pedagogical approach

The cornerstone of the unit redesign was the introduction of a series of programming projects, each of which involved the application of knowledge about a sustainability topic (e.g. air pollution, clean water) to a particular programming challenge. Each of the projects was based on a specific United Nations sustainable development goal and included a small set of curated information in various forms (tables, videos, text) to provide context related to that goal. The general pedagogical process for each project is shown in figure 1.

Figure 1. Sustainable programming pedagogical model



For each project, students were first provided with requisite programming construct knowledge and skills, both through online readings and at least one period of in-class lecture and active learning exercises. Students were also given a brief introduction to the sustainability topic through a short lecture and active discussion (10-15 minutes). Next, students were given a project containing a relevant programming problem to solve. Depending on the project, students had one to two weeks to submit their project solution. These projects were small in scope, given the unit level (introductory) and the time allotment. Finally, students were prompted to write a short reflective essay about their experience. Previously, reflection has been shown to be a valuable tool for assessing student learning and is well-suited for assessing integrative learning (e.g. Burrows et al. 2001; Cowan 2014; Fekete et al. 2000; Whalen and Paez 2019).

An example may be illustrative here. For an early project in the unit, students were introduced in class to the computer programming concept of conditional selection (i.e. if-then statements—"if it is raining, then I will use an umbrella.") A brief lecture and out-of-class reading assignment was followed by in-class exercises designed to build skill with the associated programming constructs. Next, a short lecture/discussion was used to explore the idea of air pollution, its negative impacts, and common metrics. This was followed by the introduction of a programming project involving input of air pollution data (e.g. location and ozone levels) and output of a corresponding assessment of severity. Students would complete the project outside of class over the course of the next week. Once the project was completed, a reflective essay assignment was provided for students to complete within 48 hours.

Multiple instructor-provided reflective prompts were provided for each project, but this study analyzes responses to one specific prompt intended to gather student input on how (if) such information was applied toward solving the given programming problem. The prompt followed this general format:

> *How did the information provided on <sustainability topic> help you to solve the programming problem? Why do you think this is?*

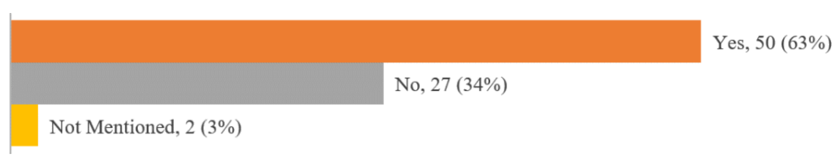
This summative reflection was intended to allow students to consider their process and how/if the diverse knowledge acquired was integrated towards the project solution—i.e. whether and how integrative learning took place. The decision to use a single, summative reflection (rather than, for example, a reflective journal) was made to limit the burden on the student while providing them with an opportunity to assess their own learning over the past week.

This study is based on a systematic evaluation of these reflective writing submissions collected from the two introductory programming units offered during the 2018-2019 academic year. Altogether, 16 of 20 enrolled students participated in the study (80 percent) though none were involved in the planning or conduct of the study. The 16 participating students were asked to complete reflective writing assignments for five specific projects, resulting in 79 distinct reflective writing submissions. All study procedures were approved by the Penn State University Office of Research Protections. A mixed-methods analysis approach was used, combining both qualitative (content) analysis and automated linguistic analysis of the student reflections. This mixed-methods approach was seen as preferable given the open-ended problem solving associated with integrative thinking and the research questions being investigated.

Stage 1: Qualitative coding

For the purposes of investigating RQ1, we first conducted an emergent coding process from which we identified four persistent themes that are consistent with prior studies of integrative learning (table 1 below). In a second round of coding, both researchers independently rated each of the student artifacts along the four themes, indicating whether the theme was supported, not supported, or not present for each (1=*Yes*, 0=*No*, 3=*Not Mentioned*). Finally, the two sets of ratings were reviewed together, discrepancies resolved, and themes adjusted accordingly (see table 1).[1]

Table 1. Emergent integrative learning themes with description and distribution (1=Yes, 0=No, 3=Not Mentioned)

Theme	Description	
Knowledge	Artifact reflects evidence that the student gained knowledge about the sustainability topic	
Problem solving	Artifact reflects evidence that the student applied knowledge of the sustainability topic into their problem-solving process	
Visualization	Artifact reflects evidence that the student utilized knowledge of the sustainability topic to enable them to better visualize the problem to be solved	

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Goal orientation	Artifact reflects evidence that the student integrated knowledge of the sustainability topic into their understanding of the purpose or goal of the programming project	

The results indicate that the work of a majority of students reflected these themes, which are listed in order of the development process or continuum of integrative learning with the exception of visualization, which was mentioned in only 20.25 percent of the student reflections. These indicate stronger gains for lower order integrative thinking skills, such as knowledge acquisition and application, and wider differentiation at the level of synthesis (e.g. goal orientation) and contextualization (e.g. visualization) (Burg, Klages, and Sokolski 2013; Leonard 2012; Niehaus et al. 2017). Goal orientation, which maps most closely to the highest stage identified in previous studies (synthesis), was indicated by a slender majority of the student artifacts, a finding that belies several previous studies suggesting that such an outcome was more rarely achieved, especially in lower division, non-major units.

That being said, after several readings we began to sense that there might be further distinctive factors embedded in the language the students used (or did not use) to frame their reflections. Computing students are not often called upon to engage in reflective writing, so we began to wonder if we were not so much analyzing their ability to engage in integrative thinking, but rather their ability to *express* that engagement in meaningful ways, a working hypothesis that was supported by the increasing percentages of students who simply did not address key aspects of their problem-solving process (see column 3).

Stage 2: Linguistic analysis

Other studies of integrative learning have reviewed student artifacts, including reflective essays, and student narratives (often in the form of interviews) using emergent coding, but such qualitative methods, while illuminating, are not intended to examine underlying rhetorical structures. Because the instructor is himself a skilled computer programmer, we chose to explore the potential of emerging computational tools to provide additional insight into the language students used to articulate their integrative learning process. Sentiment analysis has recently made headlines, for example, in mining large bodies of text-based data, both inside and outside of education (Balahadia, Fernando, and Juanatas 2016; Mäntylä, Graziotin, and Kuutila 2018; Munezero et al. 2013; Rani and Kumar 2017; Troisi et al. 2018; Wen, Yang, and Rose 2014). While full-on sentiment analysis is frequently used with much larger data sets, our study utilizes Linguistic Inquiry and Word Count (LIWC), a program designed to serve a similar purpose, i.e. automated analysis of text-based data (in this case, the student reflective essays) for persistent themes, including pre-defined affective, cognitive, structural, and behavioral constructs. This software was used to investigate RQ2.

LIWC generates a numeric measure for over 80 linguistic categories (for a full description of the categories, see Pennebaker et al. 2015). Most of these measures reflect the percentage of words matching predefined dictionaries. Prior research has shown the validity and reliability of LIWC measures across different contexts and languages (e.g. Alpers et al. 2005; Bantum and Owen 2009; Tausczik and Pennebaker 2010) and for correlating linguistic style with psychological, emotional, and other factors such as depression, confidence, analytical thinking, narcissism, gender, and age (e.g. Wang et al. 2016; Guntuku et al. 2019). For this study, analysis of the linguistic style of the reflections focused on four summary measures provided by the LIWC software. These summary variables—*Analytical Thinking, Emotional Tone, Clout, and Authenticity*—are not based on the percentage of total words for each reflection. These variables represent composites on a 0-100 scale, where lower values represent "low" scores for the variable and higher values represent "high" scores (Pennebaker et al. 2015).

Analysis of the linguistic style of the reflections show a high mean and median for the *Analytical Thinking* variable (see table 2). According to Pennebaker, Booth, Boyd, and Francis (2015), a high number for this variable indicates formal, logical, and hierarchical thinking, as opposed to the more informal, personal, present, and narrative thinking indicated by lower numbers. This finding is consistent with the emphasis on formal and verifiable problem-solving approaches commonly found in mathematics-based fields such as computer science and engineering.

Table 2. Descriptive statistics for linguistic style summary variables (n=79 reflective writing submissions)

LIWC variable	N	Mean	Median	SD
Analytical thinking	79	77.71	81.89	20.40
Clout	79	36.47	32.66	24.79
Authenticity	79	49.67	45.61	29.89
Emotional tone	79	46.15	46.73	36.18

The remaining variables are indicative of affective factors. The *Clout* variable has a relatively low mean and median value in comparison to the other three summary measures. The lower *Clout* value is indicative of a more tentative, humble, and/or anxious style (Pennebaker et al. 2015). The final two variables (*Emotional Tone* and *authenticity*) have means and medians near the middle percentile. *Emotional Tone* measures the relative positive or negative style of the communication, though a midrange value suggests ambivalence (Peslak 2017). *Authenticity* measures the relative honesty or reserved style (Pennebaker et al. 2015). Additional correlational analysis found that *Clout* is highly correlated with both *emotional Tone* ($r = 0.407$, $p < 0.01$) and *Authenticity* ($r = -0.508$, $p < 0.01$), which suggests that more positive reflections also tend to exhibit a more confident style, whereas reflections with a less authentic or "honest" style tend to exhibit a less confident style. Taken collectively, these affective findings suggest that the students may have been anxious, or under-confident about the integrative learning process, but not to the point where it appears the process was perceived as sensitive or threatening. Nor did they appear to constitute a social desirability bias (e.g. responding positively because of the perceived social value of sustainability and/or sustainability education), which has occurred in other studies with similar subject matter (Rader et al. 2011).

Stage 3: Integrating qualitative and linguistic coding

After conducting both coding procedures (qualitative and linguistic), the researchers looked for possible points of integration between the two. A series of Kruskal-Wallis H procedures were conducted to determine if there were significant differences in coding for any of the four "impact" measures—*Knowledge, Problem-Solving, Visualization*, and *Goal Orientation*—and the linguistic style (from the LIWC measures) of the reflective essays. This process resulted in three additional findings.

First, the analysis indicated significant differences in *Analytical Thinking* values based on whether students indicated the sustainability information helped them visualize the programming problem. Students who did not mention the visualization aspect (mean = 75.13, SD = 21.30) used significantly less analytical language than those who indicated the sustainability information helped in their problem visualization (mean = 89.87, SD = 10.01).[2] This suggests that students who successfully used the sustainability information to visualize the problem used a more formal, logical, and hierarchical writing style, indicating greater recognition of the impact the sustainability information had on their ability to "see" the problem solution.

Secondly, the results showed there were significant differences in *Clout* values based on whether students indicated the sustainability information was helpful to their problem solving and/or their understanding of the purpose of the assignment.[3] Students who indicated that the provided information assisted in their problem solving were significantly more confident (mean = 44.23, SD = 23.63) than those who indicated the information was not helpful (mean = 21.28, SD = 20.64). Similarly, students who indicated that the provided information assisted in understanding the purpose (mean = 43.35, SD = 24.34) were significantly more confident than those who did not indicate whether the information was helpful (mean = 29.40, SD = 24.00). Taken together, these two findings suggest that students who found the sustainability information helpful were generally more confident, which may indicate a deeper level of recognition of the connection between the background material and program solution. In contrast, a less successful outcome—not recognizing the connection between the background material and program solution—resulted in student reflections with a more anxious or humble rhetorical style.

Stage 4: Cognitive orientation

In the second to last stage of the analysis, the linguistic codings were analyzed through the lens of cognitive-oriented language. Prior research has shown that the use of language related to two subcategories of cognitive processes—the use of insight words (e.g. think, know) and causal words (e.g. because, effect)—can indicate a move toward the active processing of events (Tausczik and Pennebaker 2010). In the context of this study, these measures may indicate that the process of responding to the instructor's prompt is encouraging active processing of the problem-solving procedure. To assess this possibility, a series of Kruskal-Wallis H tests were conducted to determine if there were significant differences in coding for any of the four "impact" measures and the use of insight words, causal words, and words indicating cognitive processes.

The results indicated significant differences in only two cases: whether students found the sustainability information useful in visualizing the problem[4] or solving the problem[5]. In both cases, students who did not mention whether the sustainability information was helpful (*Visualization*: mean = 20.09, SD = 4.12; Problem-Solving: mean = 23.46, SD = 6.58) used significantly more cognitive process-oriented language than those students who indicated the information was helpful (visualization: mean =

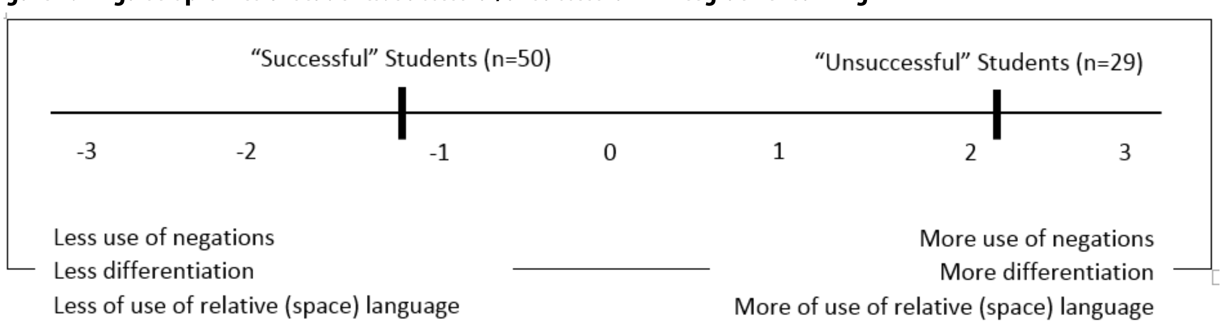
15.74, SD = 5.45; problem solving: mean = 17.32, SD = 5.27) ($p < 0.01$). The cognitive processes measure was also found to have significant inverse correlations with *Analytical Thinking* ($r = -0.47$, $p < 0.01$), *Clout* ($r = -0.39$, $p < 0.01$), and *Emotional Tone* ($r = -0.41$, $p < 0.01$). This finding, along with the finding that students who did not find the sustainability information helpful used significantly more cognitive process-oriented language, suggests that those students who reported the provided sustainability information as not helpful used less analytical, less confident, and more negative emotional language. These results align with prior findings that suggest that people use more cognitive, process-oriented language in describing so-called "negative" events, such as deaths, natural disasters, or unsuccessful efforts (Tausczik and Pennebaker 2010).

Stage 5: Linguistic profiles

Taken collectively, the patterns that emerged from the integration of qualitative and linguistic coding suggest that there are linguistic profiles for students whose reflective essays communicated that they successfully or unsuccessfully engaged in integrative thinking. We define success as positively coded (yes) and lack of success as negatively coded (no) for the primary integrative thinking attributes (see table 1 above). It should be emphasized that this is an indication of how successful the students perceived themselves to be as communicated through their reflections, rather than a direct assessment of their work in completing the projects. A stepwise discriminant analysis was conducted to uncover any linguistic profiles. This discriminant analysis was used to determine the ability of 77 LIWC factors to predict successful integration of the sustainability information.[6]

These results indicate that the use of more negative language (e.g. no, not, never), more differentiating language (e.g. but, else), and more spatial relativity references (e.g. in, around, under) is predictive of "unsuccessful" students. A higher use of negative terms would make sense for "unsuccessful" students as they are describing a negative event (i.e. failure). The other two distinctions, differentiation and spatial references, are more puzzling as both have been linked to higher-order thinking. The higher use of differentiation—i.e. exclusion words, serving to make distinctions between items—has been shown previously as an indicator of greater cognitive complexity (Tausczik and Pennebaker 2010). See figure 2 below.

Figure 2. Linguistic profiles of students: Successful/unsuccessful in integrative learning



DISCUSSION AND IMPLICATIONS

This study has implications for both research and practice, but these implications should be considered largely suggestive. In addition to the relatively small sample size, the pool of potential participants was limited to two units on one campus over the span of two academic semesters, all factors that may limit the replicability of the results. That being said, the primary intention of the research was not to generate replicable teaching practice, but rather to gain deeper insight into how computing students engage in integrative learning as expressed through reflective writing. The latter is especially relevant as our findings suggest that the reliance on self-recorded student reflections as a source of evidence for student learning presents several layers of interpretative challenges. These interpretative challenges may require the use of new methodologies or tools to further gain insight into integrative learning as both a learning and developmental process.

In this study, we proposed the use of computationally generated linguistic analysis as a means not only for mining student rhetoric for indicators of successful integration, but also for generating common benchmarks. Because the process of linguistic analysis relies on established cognitive, affective, and behavioral constructs, these can potentially be compared across different student groups, disciplinary populations, and/or learning processes—including integrative thinking. It is possible, too, that as our knowledge base grows, we might consider modifying, refining, or extending those constructs to encompass the depth and breadth of insights gained into how students navigate the pathways between and among disciplinary ways of thinking. In other words, it is possible that we could develop a larger lexicon or data dictionary of a wide range of teaching and learning constructs that could be used to expand not only both the methodological range of the scholarship of teaching and learning, but also its scope. The ability to use these constructs as benchmarks would permit researchers to link multiple classroom-based studies together (Draeger and Scharf 2019; Friberg and McKinney 2019).

For this study, the pathways between and among disciplines include the integration of computational reasoning skills into socially relevant (e.g. sustainable) contexts. Our findings suggest that some students perceived themselves to be able to accomplish this task more successfully (stage 5), confidently (stage 3 and 4), and in more well-rounded ways (stage 1) than others. To do so successfully, however, required ways of thinking that extended beyond programming. At the other end of the spectrum, a few students questioned, and even in some cases resisted, the nudge toward integration, suggesting that they saw sustainability not as an enabler, but rather as a distraction or even an inhibitor of their achievement of the formal logic of programming. This latter perspective reflects the conventional emphasis placed on formal problem solving prevalent in many computing units; indeed that is embedded deeply in computer science as a discipline.

That problem-solving mindset was intended primarily to handle problems that lead to clear solutions (over time). Growing recognition of the "wicked" nature of modern scientific and social problems, on the other hand, suggests that students will also need to be equipped with skills to handle not only ill-defined, but often largely insoluble challenges characterized by multiple perspectives, competing stakeholders, and shifting priorities. This means that topics such as sustainability do not serve as simply window dressing or colorful containers for programming exercises, but rather they constitute a fundamental challenge to reconsider what it means to be an effective and ethical computer scientist in this current historical age. This re-conceptualization of the porosity of the field is already playing out in the professional world, and so computing education, too, will require a collective shift in mindset about what it means to teach, and to learn, programming. Our society is increasingly dependent on information technology and, thus, the creators of that technology will need to be sufficiently dexterous across multiple problem-solving approaches so that they can be ready to tame whatever challenges the future may hold.

Indeed, scholars and academic leaders alike have argued that similar forms of dexterity apply across multiple disciplines, so that integrative thinking has risen to become a leading framework for higher education in the United States. That said, as interest in integrative learning has spread so has recognition that it is a complex, multi-stage process (Kinzie 2013; Lowenstein 2015; Niehaus et al. 2017). As a researcher, this complexity presents challenges as to what vantage point from which to view it. The conventional approach has been to assess the outcomes of the process, as evidence of its (hopefully) successful completion. As discussed in the prior literature review, though, many learners struggle to reach synthesis, often identified as the end stage of the integrative thinking process (Barber 2014; Burg, Klages, and Sokolski 2013).

This further suggests that if we shift the focus of research to a particular stage or step in the process, it may result in gains in our understanding of why (or why not) students are able to reach the desired outcomes, whether that takes the form of a theory of difficulty, a targeted intervention, or new integrations (Shopkow and Middendorf 2019). Similar approaches applied in computational thinking, scientific problem solving, and metacognitive development, for example, have proven illuminating (Boustedt et al. 2007; Domin and Bodner 2012; Price et al. 2020; Woolley et al. 2018), so we consider this study only the first step in a larger research agenda seeking to understand how each stage of the integrative thinking process works, where bottlenecks may be eased, and how we pool knowledge to think across disciplinary divides (Lewis 2017; Werder 2013). Additionally, there may be other complex learning processes to which this framing approach could be constructively applied. Consider the possibilities of what we could learn, for example, by breaking down the components of creative problem solving or inquiry guided learning.

It may be tempting to add reflection to that list of possibilities. In this study, we situate reflection as both evidence for and part of the larger integrative learning process. Indeed, as previously noted, the two go hand-in-hand, with one component playing an integral role in the other (Aguila 2016; Rust and Korstange 2018). For the purposes of this study, too, we have treated reflection as primarily a linguistic construct, and our analysis of it as an act of interpreting the latent structures that underlay that construct. That being said, reflection serves a much greater purpose than simply a stage of a process; indeed, it is a form of learning in its own rite, and scholars have noted that it can take on many different forms, not all of them expressed in ways that are easily captured (Chaffey, de Leeuw, and Finnigan 2012; Fessl et al. 2017; Lindroth 2015; Wong 2016). These elusive qualities may contribute to the frustration or bewilderment that instructors can express regarding the assessment of reflective work, but it also underscores how important it is that we cultivate reflective practice, both for ourselves as educators, as well as for our students (Rossing and Lavitt 2016; Schön 1983). Machine analysis still requires thoughtful humans to interpret the results and ponder its implications.

Previous studies of reflection and learning have affirmed the act of reflection as a personal and often private experience (Aguila 2016; Fessl et al. 2017). These attributes can make it very challenging to study as a learning process, with researchers often emphasizing either the analysis of reflective artifacts or the use of qualitative methods, such as interviews or focus groups. Our linguistic analysis of student reflective essays did suggest some previously unexpressed aspects of the interior worlds of our students' minds, which may also serve as a reminder of what more lies beneath the surface that we cannot see/hear/read. It bears reminding that these measures, ours included, are all proxies for the act of reflection and, by extension, integrative learning. We should be wary of making the rhetorical, even conceptual, errors of treating reflection as either a metonymy, i.e. using a loose term (e.g. reflection) to stand in for a more specific meaning, in research; as a synecdoche, i.e. mistaking the container, or in this case, the artifact, for the thing contained, in teaching.

Much of the literature on so-called "wicked" problems in education has focused on how we teach students to become adept at addressing complex problems that exist in an uncertain, and unknown, perhaps even unknowable, future. The primary weapon that we have identified to equip them with is integrative learning, or the ability to marshal knowledge and skills across multiple sources in new and interesting ways. That said, it can be argued that educating students to become these nimble thinkers requires an equally dexterous approach to how we approach teaching, learning, and related scholarship. Our study focused on how students perceived their ability to integrate knowledge across different domains of knowledge, but the challenge of developing a robust, shared body of evidence based practice related to integrative learning enjoins us, as faculty and scholars, to also marshal knowledge and skills across multiple sources in new and interesting ways. In this case, a computer scientist has endeavored to bring an innovative way of thinking about both integrative learning and reflective practice to the table, and we invite others to pull up their chairs and join us.

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Jeffrey A. Stone (PhD, 2010, Penn State) is an Assistant Professor of Information Sciences and Technology (IST) at Penn State (USA). His research focuses on the use of information technology and social media in the public sector; computer and information science pedagogy; and gaming identity. https://orcid.org/0000-0002-8417-0431.

Laura Cruz (PhD, 2001, University of California at Berkeley) is an Associate Research Professor with the Schreyer Institute for Teaching Excellence at Penn State (USA). Her research focuses on innovative teaching, educational development, and emerging forms of scholarship.

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ETHICS

This research was deemed exempt by the Penn State Institutional Review Board (IRB). Participation was voluntary, and all students consented to participate.

NOTES

1. Inter-rater reliability scores for the initial coding indicated high levels of observer agreement for all measures; Cohen's Kappa values ranged from 0.93 to 1.00 and percent agreement ranged from 96.02 to 100. Once the initial coding was complete, the authors resolved any disparate ratings in order to achieve a 100 percent inter-rater agreement; this resolution was performed to facilitate further statistical analysis.

2. ($\chi^2 = 7.520$, df = 2, $p < 0.05$, n=79). Dunn's pairwise tests with Bonferroni correction showed significant differences between responses coded as "Yes" and "Not Mentioned" ($p < 0.01$).
3. Problem solving: ($\chi^2 = 18.884$, df = 2, $p < 0.01$, n=79). Dunn's pairwise tests with Bonferroni correction showed significant differences between responses coded as "Yes" and "No" ($p < 0.01$). Goal orientation: ($\chi^2 = 7.605$, df = 2, $p < 0.05$, n=79). Dunn's pairwise tests with Bonferroni correction showed significant differences between responses coded as "Yes" and "Not Mentioned" ($p < 0.01$).
4. ($\chi^2 = 6.027$, df = 2, $p < 0.05$, n=79). Dunn's pairwise tests with Bonferroni correction showed significant differences between responses coded as "Yes" and "Not Mentioned" ($p < 0.05$).
5. ($\chi^2 = 14.230$, df = 2, $p < 0.01$, n=79). Dunn's pairwise tests with Bonferroni correction showed significant differences between responses coded as "Yes" and "No" ($p < 0.01$).
6. For a detailed description of this method, see appendix A.

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APPENDIX: DISCRIMINANT ANALYSIS

To assess the linguistic profile of those students who were successful in utilizing the provided sustainability information to solve the programming problem, a stepwise discriminant analysis was conducted. This discriminant analysis was used to determine the ability of 77 LIWC factors to predict successful integration of the sustainability information. For purposes of this analysis, coding for the *Solving the Problem* measure was collapsed into two categories (1=*Yes*, 0=*No/Not Mentioned*), with *Yes* codings representing "successful" integration and all others classified as "unsuccessful."

Preliminary analysis led to the removal of 33 LIWC variables whose mean value was less than 1.0, resulting in a set of 44 potential predictors. The analysis generated one significant function, Λ=0.264, $\chi^2(4)$=97.17, n=79, $p < 0.001$, with 73.62 percent of the function variability explained by *Solving the Problem* codings. Eight LIWC factors were entered into the equation – *Negations*; *Relativity* (*Space*); *Relativity* (*Motion*); *Differentiation*; *Comparisons*; *Sexual*; *Power*; and *Prepositions*. All other LIWC variables were excluded by the stepwise analysis. See table 3 for the standardized function coefficients and correlation coefficients. Predictors with an absolute value correlation coefficient less than 0.200 were excluded from function interpretation.

Table 3. Descriptive statistics for linguistic style summary variables

	Correlation coefficients w/discriminant function	Standardized function coefficients
Negations	0.567	1.003
Differentiation	0.281	0.595
Relativity (Space)	-0.264	-0.639
Comparisons*	-0.168	-0.543
Power*	0.149	-0.440
Relativity (Motion)*	0.098	0.591
Prepositions*	-0.086	0.313
Sexual*	-0.074	-0.514

* Variable was excluded from interpretation.

Classification results show that the grouped cases were classified with 97.3 percent overall accuracy. Accuracy for "successful" integration cases was 94.0 percent, while "unsuccessful" cases were found to have 86.2 percent accuracy. The cross-validated accuracy results indicated that 91.1 percent of grouped cases were correctly classified. Group means for the function showed that "successful" cases had a mean value of -1.255 and "unsuccessful" cases had a mean of 2.164 (see figure 2).

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