Promoting the Dispositional Dimension of Competency in Undergraduate Computing Programs

Abstract

The Computing Curricula 2020 (CC2020) report, issued by the ACM and IEEE Computer Society, identified knowledge, skills, and dispositions as the three main components of competency for undergraduate programs in computer engineering, computer science, cybersecurity, information systems, information technology, and software engineering, as well as data science. As earlier generations of curricular guidelines in computing have described knowledge and skills to some extent, the notion of dispositions is relatively new to computing.

Dispositions are cultivable behaviors, such as adaptability, meticulousness, and self-directedness, that are desirable in the workplace. Multiple employer surveys and interviews confirm that dispositions are as crucial for success in the workplace as the knowledge and skills students develop in their academic programs of study. As such, the CC2020 report describes eleven dispositions that are expected of competent computing graduates. These are distinct and separate from the technical knowledge and disciplinary skills of computing and engineering. Dispositions are also distinct from baseline or cross-disciplinary skills, such as critical thinking, problem-solving, teamwork, and communication. In contrast, dispositions are inherently human characteristics that describe individual qualities and behavioral patterns that lead to professional success. Dispositions are learnable, not necessarily teachable.

This work-in-progress paper motivates dispositions within computing disciplines and presents the background of this approach. It also discusses the use of reflection exercises and vignettes in understanding, promoting, and fostering behavioral patterns that undergraduate computing students identify as related to dispositions they experience in the course. Preliminary data and results from the study are also presented.

1 Introduction

A major concern in higher education is to ensure that graduates are "career-ready", that is, they not only have learned knowledge and skills that are needed by employers but have also developed the professional traits and attitudes necessary for a successful career. This is especially important in fields such as engineering and computing, where students are expected to perform in the workplace from day one, without any additional training. Employers are known to value employees and potential employees who demonstrate what are often referred to as professional or soft skills, such as persistence, self-direction, and adaptability [1, 2, 3]. As a typical undergraduate program is three or four years, we have a short time to take young people straight out of high schools and turn them into nascent professionals. This means that we must find the space and time in our programs to develop these "professional skills".

Terms such as "soft skills", "human skills", and "noncognitive skills" [4, 5, 6] are frequently used in the popular press but have varying definitions and connotations. Therefore, we use the term "professional disposition" to refer to these traits that are valued in the workplace. The term professional disposition has been defined as "the tendency to behave in certain ways when certain conditions are realized" [7], and as "as patterns of behaviors that are exhibited frequently and intentionally in the absence of coercion, representing a habit of mind" [8]. In keeping with these prior definitions we use an operational definition of professional dispositions as cultivable behaviors desirable in the workplace, to emphasize their tie to career readiness. In our view, professional dispositions are limited to personal characteristics and behavioral patterns that are malleable, learnable, and observable.

Recent curricular recommendations [9, 10, 11] and accreditation criteria [12] have emphasized the role of competencies for computing graduates. Competency is defined as consisting of three components: knowledge, skills, and professional dispositions. Knowledge is the content that we normally teach in higher education and skill is the ability to apply knowledge to a task. A disposition is distinct from knowledge or skills, representing the intent and willingness to apply the knowledge and skill in a given context [13, 14, 15]. According to Frezza [16], dispositions are learnable in the sense that they can be translated into habits that result in desired behaviors. For example, the disposition "meticulous" can be cultivated by practicing habits such as double-checking work, or in the context of computing, carefully testing software. While the development of knowledge and skills has been a primary focus of research in computing education, the development of curricula that promote the cultivation of professional dispositions has not been as well studied [17, 18].

This multi-institutional project, funded by the National Science Foundation aims to study how professional dispositions can be fostered across undergraduate computing programs. The project tries to understand and promote students' awareness of dispositions. The eventual goal is to foster dispositions among computing students through two hands-on activities: reflection exercises and vignettes. Four different institutions are participating in this project. Reflection exercises and vignettes are being integrated into the coursework taken by students majoring in various areas of computing, including computer science, cybersecurity, and information technology. To study students' understanding of dispositions, and promote and foster them, the researchers used a mixed-methods quasi-experimental research design, including pre- and post-surveys, reflection exercises, and vignettes. The authors have conducted experiments over several semesters to gain insights into what dispositions mean for students and how students understand them. In this paper, the project design is described and motivated along with the research and study protocol. In addition, preliminary results and the current project status are presented.

2 Related Work

The field of teacher education has recognized for quite some time that the development of dispositions necessary for teacher success is an important part of teacher preparation [19]. Dispositions are an important component of the Council for the Accreditation of Educator Preparation [20] standards for teacher education programs in the United States, and scales to assess dispositions of teacher candidates are actively developed [19, 21]. In the field of pharmacy, APCE [22] accreditation in the United States contains a standard for Personal and Professional Development which consists of the following: self-awareness, leadership, innovation and entrepreneurship, and professionalism.

In the context of engineering education and accreditation, it does not appear that dispositions are explicitly considered in the learning outcomes. In the US and several other countries, ABET [23] accredits engineering programs using several criteria. One of them is student outcomes, i.e., "what students should know and be able to do by the time of graduation" [24]. The outcomes are thus related to a mix of the skills, knowledge, and behaviors that students acquire in their program, for example, "Student Outcome 7: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies".

In the UK, the Engineering Council accredits engineering programs based on learning outcomes that are specified by the Accreditation of Higher Educations Programmes (AHEP) Standard [25]. Their focus is primarily on skills. An example of the Engineering Analysis field is "C3. Select and apply appropriate computational and analytical techniques to model complex problems, recognizing the limitations of the methods employed." [25] Nonetheless, AHEP expects study programs to prepare graduates for successful registration as "Incorporated Engineer" (IEng) or a "Chartered Engineer" (CEng). Both IEng and CEng are regulated by the UK Standard For Professional Engineering Competence (UK-SPEC) [26]. In contrast to AHEP, the UK-SPEC addresses competency and commitment, which reflects on the triad of knowledge, skills, and disposition, as discussed in this paper.

Another example of competency-based education and accreditation is the Japan Accreditation Board for Engineering Education (JABEE) [27]. JABEE also tends to specify learning outcomes with regard to knowledge, rather than skills, or dispositions, as they expect, for example: "(c) Knowledge of mathematics, natural science and information technology, and ability to apply, and (d) Knowledge of the related professional fields, and ability to apply" [27].

Dispositions have received less attention in the computing fields than in other disciplines. However, in the field of software engineering, there have been many studies that have looked at personality traits, which are similar in many respects to dispositions, to determine their effect on issues such as predicting performance in pair programming, forming optimal teams, and finding the best fit for work roles [28, 29, 30, 31, 32, 33]. Most of these studies have used assessments based on personality trait models [34], which have a number of limitations, including reliance on self-reporting. A few studies have tried to overcome this by relying on text mining of project artifacts [30, 35, 36]. Another study on programming competencies expected of novices identified the willingness to collaborate, communicate, and persist despite frustration as dispositions of successful computer science students [37, 38, 39].

In general, these studies have focused on identifying and associating dispositions with performance metrics, rather than looking at ways to promote dispositions. As noted in the introduction, the competency model introduced in the ACM Information Technology curriculum report [11] and further expanded in the Computing Curriculum 2020 report [9] includes dispositions as a fundamental component of competency. A competency is characterized by three interrelated dimensions: knowledge, skills and dispositions. Knowledge is the *know-what* dimension, skills are the *know-how* dimension, and dispositions are the *know-why* dimension. In this model, dispositions are the human dimension of competency expressed through individual behaviors. They allow a professional to bring together their knowledge and skills and successfully apply them. Therefore, in order to produce successful professionals, it is important that computing programs include the cultivation of dispositions in the curriculum.

3 Project Approach

The goal of the project is to study how professional dispositions can be understood, promoted and eventually fostered across undergraduate computing education in a way that integrates into a wide variety of courses without impacting existing learning objectives related to computing skills, or requiring large amounts of instructor time to set up. A challenge is the nature of dispositions, which are not teachable in the traditional sense. Dispositions may be best fostered by example and by developing greater student awareness of behaviors associated with them. Hence we need to understand dispositions and student perspectives of dispositions, before they can be promoted and fostered among students. We are focusing on two evidence-based approaches which can easily be combined with current projects and assignments in a course:

- **Reflection Exercises** in which students rate the extent to which they have applied dispositions while carrying out course assignments and describe how they have done so. These exercises are meant to help students focus closely on their own dispositions in the context of computing coursework. The reflections allow insight into students' perspective on dispositions and their role in completing assignments;
- **Vignettes** in which students study how others have applied dispositions in real-life scenarios and describe how they have themselves applied those dispositions in their own life.

The dispositions being studied are drawn from the ACM CC 2020 curriculum report [9]: persistent, adaptable, self-directed, collaborative, responsive, inventive, proactive, and meticulous.

3.1 Learning materials

In this section, the specific format of the learning materials is described. We further provide examples of the expected student responses for reflection exercises, and an example of a mini-vignette.

3.1.1 Reflection exercises

Reflection exercises are coupled with course assignments such as programming projects. At the completion of each assignment, students are asked two questions, a rating question and a descriptive question. The rating question asks students to rate the extent to which they exhibited specific behaviors associated with the disposition while completing the assignment. Examples of such behaviors include "When I encounter frustrating problems and obstacles on my assignment, I work hard at figuring out a solution" for persistence, or "I make time to read all the instructions of the assignment carefully to ensure that I meet the expectations" for meticulousness.

The descriptive question asks students to describe either an instance of applying the disposition while completing the project or the reasons why they could not apply the disposition. The hypothesis is that by being prompted to think about their behavior in the context of the course, students will become more aware and reflective of the importance of each disposition to their success. Student responses on the rating questions are used to compute descriptive statistics. Responses to open-ended questions are used to revise reflection exercises as described in the next section.

3.1.2 Vignettes

A vignette is a short narrative description of a scenario that allows readers to identify issues or dilemmas. Vignettes have been used for decades in various disciplines such as medical education [40], computing teacher training [41, 42, 43], computing education [44, 45], and psychology [46] because they produce more valid and reliable measures of respondent opinion than simple survey questions [47]. In our project, we use them to promote and foster dispositions, similar to the work of Pieper and Vahrenhold [41]. Although the design of vignettes varies, it typically includes two steps: presentation of a scenario and engagement of the learner. The scenario may be hypothetical [41] or from real life [48]. In our project, we are using vignettes based on real-life stories that illustrate the application of one or more dispositions. The vignettes are presented to students after assignments in a course, just as are reflection exercises. For engagement, students are asked to identify the disposition illustrated by the story, followed by the passage in the story that best illustrates the disposition. They are also asked to describe either an instance of applying the disposition while completing the assignment or the reasons why they could not apply the disposition. This is the same question that is used in the reflection exercises, allowing the results from reflection exercises and vignettes to be compared.

We are developing both mini-vignettes, which are constrained to 200 words or less, and full vignettes, which are multi-paragraph (500 words), so that instructors can choose materials that best fit their course. Here is an example of a mini-vignette which illustrates persistence.

> *Between 1878 and 1880, Thomas Edison tried to develop a high-resistance filament requiring less electrical power than arc lamps. In addition, he wanted to improve the existing bulb designs and make the incandescent bulbs burn longer, be more reliable, and glow at an acceptable brightness. At first, he tried using a thin wire of platinum in a glass vacuum bulb. But the bulb only burned for a few short hours. So, he considered using carbonized materials instead of platinum. Then, he began using carbonized strips of every plant imaginable, including baywood, boxwood, hickory, cedar, flax, and bamboo. Next, he contacted biologists who sent him plant fibers from places in the tropics. The Edison team developed business acumen and became goal-driven, working day and night, week after week, month after month. They eventually tested no fewer than 6,000 vegetable growths. According to Edison's own admission, it was tedious and demanding work. Finally, Edison decided to try a carbonized cotton thread filament. When he applied voltage to the completed bulb, it radiated a soft orange glow. The bulb lasted for fourteen and a half hours and had the brightness of sixteen candles.*

3.2 Research Design

In this subsection, we outline the research design and describe the mixed-methods quasi-experimental study protocol. We also elaborate how we adapt the protocol after each semester.

3.2.1 Research Questions and Goals

The research questions of this project include:

RQ1 To what extent do reflection exercises foster students' professional dispositions?

RQ2 To what extent do vignettes foster students' professional dispositions?

The expected outcomes of the study are:

1. A collection of revised reflection exercises targeting the dispositions listed above, along with guidelines for designing and using them.
2. A suite of vignettes targeting dispositions along with guidelines for designing and using them.
3. The results of evaluating the efficacy of using reflection exercises and vignettes to foster dispositions among undergraduate computing students from the participating institutions.
4. Dissemination of the surveys, exercises, vignettes, design and usage guidelines, evaluation results and guidelines for educators on fostering dispositions in undergraduate computing courses.

By providing reflection and vignette exercises that can easily be added to existing assignments in a course, and by promoting awareness of the importance of dispositions by presenting our results, the researchers hope to encourage more computing programs to include dispositions as a core part of student competency.

3.2.2 Study Protocol

The study uses a mixed-methods quasi-experimental research design that includes a pre- and post-survey, two experimental groups (reflection exercise group and vignettes group), and a control group. At the start of each semester, each researcher identifies 1) two or more computing courses; 2) for each course, three to five assignments; and 3) for each assignment, four to five professional dispositions relevant to the course. For each identified course, the following protocol is used. First, a pre-survey is administered at the start of each semester, covering all the dispositions enumerated for the assignments in the course. It lists the behaviors associated with those dispositions. For each behavior, students are asked to rate how often they engage in that behavior in their classes, on a scale of 1 (Never) to 5 (Always). Examples of behaviors that are used in the pre-survey include "When I encounter frustrating problems and obstacles on my assignment, I work hard at figuring out a solution." (persistent) and "I set aside time to double-check my assignment submissions." (meticulous). Students are also presented with the definitions of the dispositions that are used in the class, and asked how important each is to their career. Finally they are presented with various behaviors, and for each, they are asked to identify the disposition that the behavior demonstrates.

Here is an example:

Which of the following characteristics best reflects the statement: "I test my solutions exhaustively."

1. *Adaptable*
2. *Meticulous*
3. *Persistent*
4. *Responsive*
5. *Self directed*
6. *Not sure*

During the semester, after each project or assignment, students are presented with a reflection exercise or vignette along with the associated questions described in the previous section. At the end of the semester, a post-survey, which is the same as the pre-survey, is administered.

3.3 Semester to semester workflow

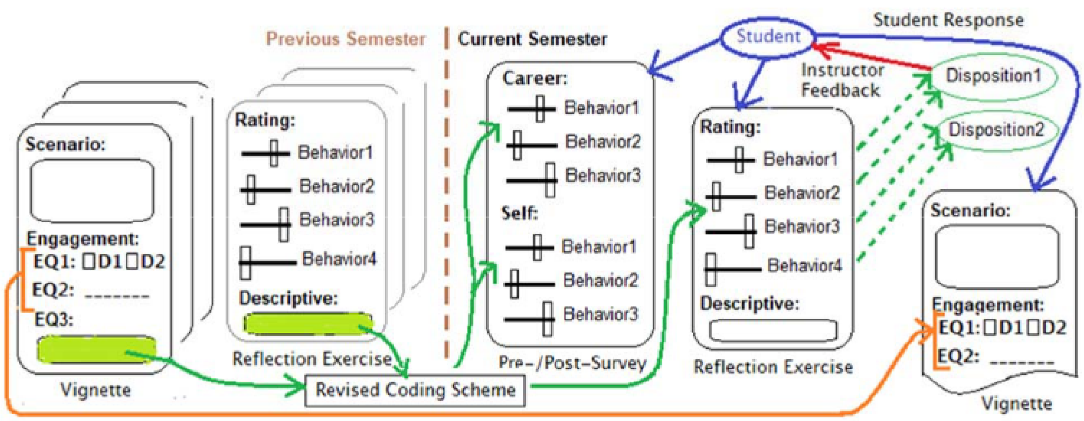

Figure 1: Surveys, reflection exercises and vignettes: evolving from one semester to the next

One of the most critical components of the study protocol is that results collected in each semester are used to modify the surveys presented to students in the following semester. In particular, student responses to the open-ended descriptive question in reflection exercises are qualitatively analyzed to generate the specific behavior statements used in all the instruments in the subsequent semester. This is illustrated by green arrows in Figure 1. Similarly, the responses to the open engagement questions in vignettes are qualitatively analyzed (orange arrows in Figure 1). During the qualitative analysis [49] of the responses to open-ended, descriptive questions, categories are extracted for each disposition. All the responses in each category are examined for usefulness as behavior examples in the pre- and post-survey or the rating questions of the reflection exercises in the following semester. Some responses, however may not be useful for the following reasons:

- The disposition is defined but no concrete example of behavior is included.
- The behavior is associated with a different disposition.
- The response is too abstract and does not contain any behavioral details that can be used for our instruments.

Responses that do not fall into one of these groups are considered to be good candidates for illustrative behaviors. The researchers review these responses and choose the most illustrative of them. The result is a set of representative behaviors for each disposition.

A focus group is used to test whether the behaviors indeed relate to the dispositions for which they were identified (dashed green arrows in Figure 1). Participants in the focus group fill out a form in which each candidate behavior is presented, and the participant chooses which disposition is best illustrated by the behavior. Behaviors for which at least 70% of the focus group does not concur on a single disposition are discarded.

4 Current Status of the Project

This section discusses the current state of our work and summarizes the lessons learned to date.

4.1 Pilot study

A pilot study was run in 2021-2022 to understand dispositions and how they translate to observable student behaviors. The goal of the pilot was to gather an initial set of data to inform the design of surveys, reflection exercises, and vignettes for the full study, and to test the use of reflection exercises. The five dispositions studied in the pilot were adaptable, collaborative, persistent, responsible and self-directed. Courses were identified at all four institutions for inclusion. The protocol followed was similar to the protocol being used in the full study, with a pre-survey, reflection exercises after assignments, and a post-survey. Instead of behavior statements, students were asked to rate dispositions in the instruments. A number of observations from this data led to refinements in our project protocols. Some of these refinements have been reported in an ITiCSE panel [50] and research paper [51], as well as in a SIGCSE special session [52] and poster [53].

One significant observation from the pilot study was that students rated every disposition as maximally important for their career and course, except for *adaptable* and *collaborative*. This is likely because questions on dispositions elicited idealized responses from students. To avoid such responses, the rating questions on the pre- and post-survey were changed to refer to behaviors instead of dispositions. Students rated their application of dispositions in course assignments statistically significantly lower than the importance of the dispositions for success in the course. Such candid admission is a good first step towards more consistently applying dispositions in coursework.

A qualitative analysis of the responses submitted for the descriptive questions in the reflection exercises and post-survey was also performed, to produce a set of categories of behaviors to use in future stages of the project [51]. An initial set of categories was developed based on a small sample of responses, and then refined on larger sets of responses by two coders. Disagreements on categories were resolved by verbal discussion. For each disposition, 3 to 7 categories were identified. For example, for *adaptable* disposition, the categories were “recognizing the need for changes”, "changing problem-solving strategies", "acting despite the unpredictable" and "overcoming difficulties with concepts or new tools". For *persistent* disposition, the categories were "increasing working hours", "investing constant effort despite frustration", "aiming at high quality", "achieving success or long-term goal", and "participating regularly over the project or course". All of the student responses were then coded based on the resulting set of categories and analyzed. For example, for *persistent*, the most frequently associated category was "investing time and effort despite frustration". Many students mentioned negative emotions related to "frustration", a result that has helped inform the development of vignettes as well as phrasing of behaviors used in the surveys. Another result that became apparent is that the context of the course matters. For example, for *self-directed* disposition, in an introductory Computer Science course, 54% of the responses were coded as "not pertinent", indicating that in an introductory course, self-directedness may not be very important for success. The impact of course learning objectives and pedagogical approaches clearly has an impact on student identification of behaviors for each disposition that is taken into account when choosing which courses to study for given dispositions.

4.2 Current Efforts

The project is scheduled to run during the academic years 2022-2023 and 2023-2024. Reflection exercises were incorporated into ten course offerings in the latter half of 2022 at all four participating institutions. Courses ranged from introductory programming to a database course to an advanced software design course. The behaviors identified from the results obtained during the pilot study described above were used in the survey instruments.

A set of vignettes and mini-vignettes were also developed. They are being used in two courses during the spring semester of 2023 Reflection exercises continue to be used in three more courses. In the summer of 2023, results from the first year of the project will be analyzed and preliminary trends and findings identified. As detailed in the study protocol above, the behaviors reported by students will again be used to revise the instruments used in the following years.

4.3 Lessons Learned So Far

The results from the pilot study, as well as the first semester of the project, have led to a number of observations and changes in our approach. This is expected, since our project design is based on the assumption that results from each semester will be used to modify materials in the following semesters. The changes that we have made based on the results obtained so far include:

1. We originally studied five dispositions in each course. As this led to survey fatigue, we have reduced the number of dispositions to four per course. Furthermore, we no longer use the same dispositions in all the courses. In each course, we target dispositions most appropriate for the course, e.g., *self-directed* in the advanced programming languages course, and *persistent* in the introductory programming courses.

2. We modified some of the descriptions of dispositions presented to students to clarify their meaning.

3. Behaviors are now used in the surveys instead of dispositions since students tended to rate the importance of all dispositions at the highest level.

4. We now use focus groups to rate how well each behavior ties to a specific disposition, since the pilot study results indicated some amount of overlap - students would mention a particular behavior for more than one disposition, because it seems challenging to identify clear cut boundaries between dispositions.

5. Two of the dispositions from the original CC2020 group, *responsible* and *professional* seem too broad and general to be analyzed in terms of associated behaviors related to coursework (see also [54]). So, they were dropped.

6. Both dispositions and the methods used to promote students' awareness of them are context specific and must meet the needs of the particular courses in which they are embedded. Thus, the reflection exercises and vignettes must be easily tailorable. For example, we are producing both full vignettes and mini-vignettes to meet the needs of different courses and target groups.

5 Conclusions and Future Work

This project is among the first to study professional dispositions in the context of computing education. The pilot study, conducted at multiple institutions and courses at different undergraduate levels, aimed to understand and promote students' awareness of the selected professional dispositions: *adaptable*, *collaborative*, *persistent*, s*elf-directed*, and *responsible*. The pilot study results were used to replace dispositions with behavior statements in the instruments. The deliverables of the project include reflection exercises and vignettes that can be adopted and adapted by other instructors for use in a variety of computing and engineering courses.

The immediate next steps of the project are to evaluate the extent to which vignettes can make students aware of professional dispositions and promote dispositions among them. After sufficient data is collected, the study will also explore whether and how reflection exercises and vignettes affect students from underrepresented groups in computing (including racial/ethnic minorities and women).

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