Identifying Higher Software Engineering Education's Design-Reality Gaps in Rural India

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***Abstract*—Over the last decade one of the major challenges of the Indian higher education system has been a discrepancy between the skills of computer science graduates and the needs of industry. The majority of India's private higher education sector is composed of over 38,000 affiliated colleges, most of which are based in rural India. We selected a college in rural India as a representative case to analyze the local computer science curriculum's implementation using a Design-Reality Gap Analysis. Our examination considers both students' and professors' points of view by conducting interviews and observations. Key findings suggest that inadequate professors skills, improperly implemented teaching methods and a missing curriculum evaluation, among others, play a major role in the Indian computer science graduates' skill deficiency.**

***Index Terms*—Higher Education, Software Engineering Education, Computer Science Curriculum, Curricula, Design-Reality Gap Analysis, Rural Higher Education, ICT4D, India**

I. Introduction

Due to the increasing demand for technically skilled workers in the Information & Communication Technology (ICT) sector in India since the 1980s, Higher Education Institutions (HEIs) responded by increasing the number of graduates in engineering disciplines. In order to cope with this growth while decreasing the investments from the government into the Higher Education (HE) sector, several state governments and the government of India urged the private sector to establish semi-self-financed engineering HEIs [8, 12].

Although the number of engineering graduates exponentially grew from 1998 to 2008, the quality of education students received was insufficient, leading to a mismatch between the needs of industry and graduates' skills [8, 12]. In 2012, a survey of the World Bank confirmed this mismatch and pointed out that *"64% of employers are only somewhat satisfied or worse with the quality of engineering graduates' skills"* [3]. In 2018, the National Employability Report by Aspiring Minds examined a sample of more than 170,000 engineering students from more than 750 engineering colleges across multiple Indian states which graduated [20]. According to this report, 52.5% are not able to write functionally correct code and 37.7% are not able to write compilable code. Candidates of colleges located in lower populated cities are overall less employable than from colleges of higher populated cities, regardless of the examined job role [20]. In 2019, more than 90% of the HEIs in India were private, so-called affiliated colleges, which implement curricula designed by nationally recognized state universities, also referred to as affiliating universities [21, 23]. The affiliating universities define curricula, which are taught at affiliated colleges and conduct the standardized examinations at the end of each semester. An affiliated college is not allowed to adapt the given syllabi of the courses or parts of the curricula [22]. The implementation of the curricula and teaching methods are in the hands of the affiliated colleges. According to the Annual Report 2018-2019 by the University Grant Commission (UGC), 40,489 such colleges exist in India and 60.53% of these colleges are located in rural areas [23].

This paper aspires to contribute to the Sustainable Development Goal (SDG) 4.4 by providing insights into underlying problems of higher Software Engineering (SE) education in rural India [24]. The specific goal of this paper is to examine the previously described key characteristic of the private higher education sector in the context of rural India. In order to achieve the specific goal, this paper takes a closer look at Computer Science (CS) curricula that are implemented at Indian HEIs of the private higher education sector in order to determine whether and to what extent gaps exists between the implemented curricula and their intended design.

The following Research Question (RQ) is addressed:

RQ. What gaps exist between a designed CS curriculum and their implementations at Higher Education Institutions (HEIs) in rural India?

II. Context

The partnership between a South rural Indian college and a European university was formed after a mutual desire to cooperate in 2016.

A. South Indian Partner

The research has been carried out in collaboration with an affiliated college in South rural India located in Andhra Pradesh. The partner institution was chosen as it is located in one of the states in the bottom 25 percentile of employability percentage of graduates [20]. It is 1 out of over 80 affiliated colleges that implement the same curriculum designed by a nationally accredited state university. The students are examined by standardized tests developed by the affiliating university. The college offers five bachelor programs, including CS and was founded in 2015.

B. European Partner

The European partner is a research group and part of a major European university of technology. The university has a history in engineering disciplines and finds international recognition in research as well as in teaching. The research group involved generally focuses on various large-scale software engineering applications, but also seeks to provide a practically useful and competitive educational pattern for software engineering students at their local university.

III. Related Work

In the past Bass and Heeks conducted research to find gaps between the reality and the implementation of curricula by using the Design-Reality Gap Analysis (DRGA) [2, 11]. Masiero extended the DRGA by a diagnostic model to identify the root causes of design–reality gaps, which carries relevance for future investigations [17].

In India the graduates' skills do not match the industry's requirements, according to various studies over the last 15 years [3, 8, 15, 16, 18]. The following is a summarized overview of (software) engineering graduates skills that are categorized as missing or insufficient:

- Communication skills (oral & written) [1, 3, 10, 13, 16]
- Ability to analyze and solve problems [3, 10, 13, 16]
- Collaboration, teamwork and social skills [1, 3, 13, 16]
- Creativity [1, 3]
- Reliability [3, 16]
- Self-motivated [3, 16]
- Willingness to learn, take new directions [1, 3, 10]
- Technical skills [1, 3]
- Use of modern (software) tools [3, 13]
- Management skills [1]

Furthermore, there is evidence in literature that India is not the only country facing these problem as Duell illustrates in her work focusing on Indian, Indonesian and Thai universities [9].

IV. Methodology

The following research methods were used to collect data, which were subsequently used to answer the RQ defined in Section I. Research was conducted with professors as well as CS students of the South Indian partner institution in order to gather data about the actual implementation of the CS curriculum and the everyday life of professors and students.

A. Semi-Structured Interviews

The authors chose semi-structured interviews as an appropriate interview type because of the significant importance of establishing a personal contact to subjects as well as the exploratory character [19, p. 324]. As is outlined in Table I, five professors of the partner institution holding one or more courses as part of the implemented CS curriculum were interviewed. Four students of the 4^{th} semester were interviewed to gather data about their everyday life and the challenges students can face. The students were chosen as they had recently completed a practice orientated programming courses from the curricula partly taught by the interviewed professors. The interviews took place in a face-to-face setting and were conducted with the help of an online conferencing tool. With the consent of the respective interview partner, the semi-structured interviews were recorded, transcribed and analyzed using a thematic analysis (see Section IV-C).

Table I
INTERVIEWED PERSONS, THEIR ROLE AND LEVEL OF EXPERIENCE

Pseudonym	**Role**	**Sex**	**Experience**
Frankie	Prof.	Female	<1 year
Glenn	Prof.	Male	1-3 years
Jordan	Prof.	Female	1-3 years
Morgan	Prof.	Male	>3 years
Riley	Prof.	Male	>3 years
Nuru	Student	Female	4^{th} Semester
Rory	Student	Female	4^{th} Semester
Sam	Student	Male	4^{th} Semester
Taylor	Student	Male	4^{th} Semester

B. Observations

The observations conducted are uncontrolled and participant. The uncontrolled setting is meant to ensure that professors and students are behaving as naturally as possible and therefore, existing problems are not covered by different behavior. The authors were participant observers by observing professors conducting a course or project review sessions as well as working with groups of students on their final project while revealing the role of the authors as researchers [19, p. 294].

Guidelines by Bortz and Döring as well as Saunders, Lewis, and Thornhill were taken into account when planning and conducting the observations [4, 19]. The observations took place in three different settings between March and June 2021:

1) Professors were observed teaching a class by recording a video call in which the professor was visible and audible in front of the whiteboard throughout the lesson. A regular course and a laboratory course were observed.
2) Two groups of four students each were observed working on their graduation project. The authors acted as assistant professors. To this purpose, regular "office" hours were held and a chat software workspace was set up where the group members could ask questions at any time.
3) Professors and all final year students were observed in project review sessions, in which the groups of students reported on the progress of their project and received feedback from the faculty.

An overview of the conducted observations is presented in Table II. The researchers conducted two observations as observers and two as direct participants. Both, the work with the groups and the project review sessions were not recorded but the authors took notes.

C. Thematic Analysis

Braun and Clarke outline a guide for conducting a thematic analysis and the method's 6 phases were consecutively imple-

Table II
OVERVIEW OF THE OBSERVATIONS, THEIR SETTING AND SCOPE

Observations	Conducted as	Scope
A	Observer	Curricular Course Sessions
B	Observer	Project Review Sessions
C	Participant	Assisting Final Project Group 1
D	Participant	Assisting Final Project Group 2

mented [5]. Statements and notes from interviews and observations were analyzed in terms of how the real implementation of the CS curriculum actually takes place as well as regarding respective problems and challenges a person or a group of persons expressed. The conclusions drawn from the thematic analysis regarding a student's or professor's reality were then used within the DRGA.

D. Design-Reality Gap Analysis

The DRGA framework was originally designed by Heeks and is used as a tool to analyze the deviation as well as the extent of deviation of the resulting reality from its planned design [11]. It can be applied to the evaluation of an implemented IT/IS system, for example, to e-government projects, but also to a curriculum or its modified version [2, 6, 7, 14]. Heeks adapted the DRGA and used the OPTIMISM model (Figure 1) to consider the dimensions of a curriculum or the modification of it.

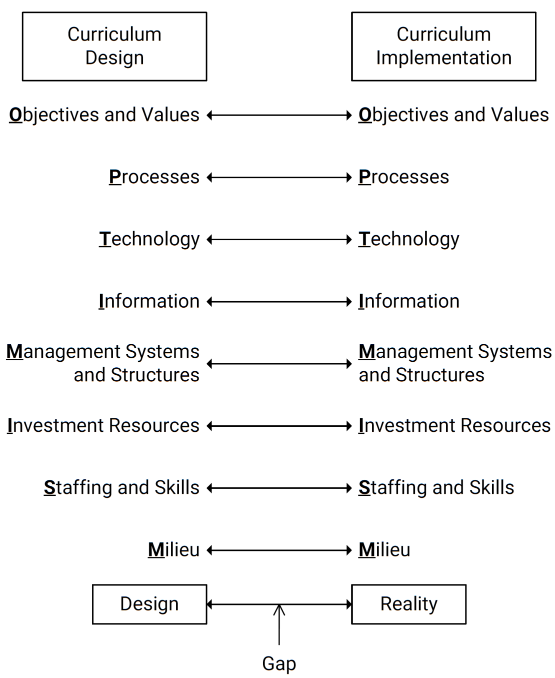

Figure 1. Adapted OPTIMISM model of Bass and Heeks [2, p. 6]

The following DRGA is structured according to these OPTIMISM dimensions. For each of these dimensions, the Design part is based on the CS curriculum itself and information that the affiliating university communicates through its websites. The majority of the curriculum consists of the course descriptions. The course description includes the "Course Objectives", "Course Outcomes", and the contents of each course unit. The Design part is complemented with the National Board of Accreditation (NBA) and National Assessment and Accreditation Council (NAAC) guidelines and criteria. The Reality part consists of the thematically analyzed interviews and observations of professors and students, as well as information that the partner institution communicates through its website.

The Design-Reality Gaps can be found in Section V. To illustrate the methodology, the following part IV-E exemplifies the DRGA in the dimension "Objectives and Values". The same approach was carried out for each dimension.

E. DRGA Example: Objectives and Values

This dimension considers the objectives of the curriculum and the values it wants to transport through its implementation.

1) Design: The NBA states that an institution must have a vision and a mission and a curriculum possesses multiple Program Outcomes (PO) and Program Specific Outcomes (PSO). The NAAC lists "Institutional Vision and Leadership" and "Institutional Values and Social Responsibilities" in its set of Key Indicators (KIs). The affiliating university and the partner institution are both communicating their individual vision and mission as well as the curriculum's POs and PSOs with the support of their websites. Regarding the POs and PSOs, all curricula offered on the affiliating university's website do not contain general or specific objectives, but they do explain within their methodology page which teaching methods they use to achieve certain objectives, such as preparing students to *"meet project requirements of the industry"* [source: website].

The CS curriculum defines objectives and learning outcomes for each course of the curriculum. In addition, each course is divided into individual units whose learning outcomes are listed.

2) Reality: The vision and mission of the partner institution are outlined on their website. They published a vision statement and mission statements for their curriculum implementation: *"Excellence in creating globally competent professionals and leaders in the field of computer science & engineering"*. They list PSOs for their curriculum implementation such as *"The ability to understand, analyze and develop computer programs in the areas related to system software, multimedia, web design, big data analytics, and networking for efficient design of computer-based systems of varying complexity"* [source: website].

It was found that courses and their objectives change almost every two years due to a revision by the affiliating university. According to professors, there is a tendency for courses that combine the basics with new topics to replace the existing courses. Professors' main objective is that as many students as possible pass the final exams. Professors fully trust the end exams by the affiliating university to be able to verify the actual learning success and those students who have passed all the exams are then also expected to achieve the goals, listed skills and learning outcomes of the curriculum. However, some students feel that in this curriculum implementation they mainly study for the exams, but not to acquire practical knowledge. Students are very focused on becoming software developers or engineers.

Students and professors confirmed that the curriculum implementation is only useful in combination with internships. They confirmed that placements (future employment) are seen as a crucial part of the curriculum's implementation as they help students to enter the respective labour market in the first place.

3) Gap Analysis: As required by both accreditation organisations, the affiliating university formulates objectives and learning outcomes for the individual courses. The POs and PSOs are not listed in the curriculum, but the program-specific visions, missions and objectives are described analogously on the partner institution's website. The students' goal to become a software engineer aligns with the program-specific vision statement of the partner institution in terms of becoming a competent professional. The frequent changes to the curriculum and its courses are in line with the recommendations of the accreditation bodies regarding the continuous improvement of a curriculum.

V. Results: Design-Reality Gaps

As exemplified in Section IV-D, it was examined whether and to what extent the design of a CS curriculum deviates from the implementation in reality. The following section summarizes all discovered gaps and challenges. The authors noticed that there is thematically analyzed data which, strictly speaking, would not be taken into account by the DRGA, since no opposing design part existed to certain realities. These data, which therefore do not represent gaps between design and reality in the strict sense, are thus denoted "challenges" instead of gaps.

A. Gap 1 - Incomplete Student Skills

This gap results from the analysis of the differences between design and reality in the dimensions *Objectives and Values* and *Staffing and Skills*. The subject areas listed in the PSOs, in which students are supposed to be proficient at the end of their studies, correspond to the contents and objectives of the courses in the curriculum. Furthermore, it is of foremost importance to professors that as many students as possible pass the standardized final examinations and not whether the students actually achieve the course objectives and acquire the respective skills, which was also confirmed by students. There are indications that there is a big gap between the skills that students should have by design at the end of their studies and those that they actually have in reality. It was found that students did not possess certain skills, such as sufficient programming skills, that they should have acquired through several courses of the curriculum.

B. Gap 2 - Unmet Employability Goal

This gap is based on findings of the *Objectives and Values* dimension. It was found that the partner institution attempts to achieve the employability goal of the curriculum specifically through extra curricular courses. Therefore, the employability goal is not achieved through the curriculum. It is also noted that the resulting students' employability is limited to those companies that carry out the corresponding extra curricular course.

C. Gap 3 - Improperly Implemented Teaching Methods

This gap is based on findings of the *Processes* dimension. Although both the curriculum design and its implementation consider teaching methods such as Project-Based Learning (PBL), they are not properly implemented. This gap between PBL in theory and its actual implementation at the partner institution was found, for example in the graduation project course. It has been observed that both students and professors tend to copy a ready-made solution from somewhere else instead of developing their own solution to a problem. This implemented interpretation of PBL is not sufficient for students to actually achieve the intended learning objectives and acquire the respective skills that they should have according to the curriculum. Therefore, the actual implementation of the teaching methodologies constitutes a large gap between design and reality. From the point of view of the authors, the lack of experience of professors described in Gap 5 (Section V-E) is related to this Gap 3.

D. Gap 4 - Missing Curriculum Evaluation

The *Processes* as well as the *Management Systems and Structures* dimensions of the curriculum were examined with regard to the curriculum's evaluation. It was found that no processes exist to evaluate or revise the implementation of the curriculum. However, feedback is solicited from students in which they evaluate their professors and their abilities at the end of each semester. No management systems or structures were found that deal specifically with quality assurance and thus the evaluation and revision of curricula.

E. Gap 5 - Inadequate Professors Skills

Through the *Staffing and Skills* dimension it was found that professors lack both teaching knowledge and professional experience. Most professors have no professional experience before they start teaching, and some of them have no teaching experience either. In addition, professors are not informed by the curriculum or the partner institution about potential teaching methods and the teaching methods applied.

The lack of professional experience was particularly evident in those situations where the professors had to review students' projects. It was found that none of the professors were able to recognize even obvious errors or inconsistencies in presumably elaborated small software applications.

Furthermore, professors were not able to properly implement other teaching methods that were not teacher-centered. For example, it was found that professors in different courses provide students with solutions in advance instead of letting students work out the solutions themselves (see Section V-C).

F. Challenge 1 - Difficulties in Self-Learning

This challenge results from the *Technology* dimension: Students find it very difficult to work independently on curriculum-related topics, to study for them or to educate themselves. One reason for this is that only very few students have their own computer or laptop available. Another reason is the lack of space available for students. In addition, students are only allowed to stay outside the campus until a certain time in the evening, which means that potential places outside the campus are also only available to a limited extent.

G. Challenge 2 - Excessive Student Workload

According the findings of the *Investment Resources* dimension, another very significant challenge is the workload that students have. Due to the combination of curricular and extra-curricular courses, students are usually busy from early in the morning until 07:00 PM in the evening, with the exception of some smaller breaks and a longer lunch break, continuously for 6 days per week. This also leaves students relatively little time for self-study of content, even if a computer and a suitable study space were available to them.

H. Challenge 3 - Ever-Changing Course Assignments

This challenge concerns the constant reassignment of professors to courses that was found in the *Staffing and Skills* dimension. Professors get courses assigned according to the staffing needs of the faculty. However, it frequently happens that professors with no previous experience in the respective subject areas of a course have to teach this course by themselves. From the point of view of both the professors and the students, this situation constitutes a new challenge every term.

VI. Conclusion & Future Work

This paper investigates through a DRGA if and which differences exist between a curriculum designed by an affiliating university and its implementations at an affiliated college in rural India. Semi-structured interviews and observations were conducted with students and professors. The gathered data is thematically analyzed along the OPTIMISM dimension (see Figure 1) and rated with *small – medium – large* in Table III. The results then served as the reality part for the DRGA. The design is compared with the reality along each OPTIMISM dimension of the curriculum. The identified gaps were elaborated based on the dimension findings and summarized as follows:

- **Gap 1:** Incomplete student skills **(V-A)**
- **Gap 2:** Unmet employability goal **(V-B)**
- **Gap 3:** Improperly implemented teaching methods **(V-C)**
- **Gap 4:** Missing curriculum evaluation **(V-D)**
- **Gap 5:** Inadequate professors skills **(V-E)**

It was found that students and professors face challenges when implementing the curriculum that, strictly speaking, are not to be considered as gaps, because the curriculum does not contain design counterparts:

- **Challenge 1:** Difficulties in self-learning **(V-F)**
- **Challenge 2:** Excessive student workload **(V-G)**
- **Challenge 3:** Ever-changing course assignments **(V-H)**

Table III
Summary of Design-Reality Gaps with Rating

OPTIMISM Dimension	**Rating**	**Comment**
Objectives & Values	large	Gap 1, 2
Processes	large	Gap 3, 4
Technology	small/medium	Challenge 1
Information	–	–
M. Systems & Structures	medium/large	Gap 4
Investment Resources	medium	Challenge 2
Staffing & Skills	large	Gap 1, 5; Challenge 3
Milieu	–	–

Limitations:

1) This paper evaluates the implementations of a curriculum in relation to their underlying design. The curriculum's design and whether it is suitable for increasing the number of CS graduates with sufficient skills is not examined.
2) The results of this paper are based on one implementation of one curriculum design. This paper provides first insights, examining different implementations of the same curriculum or adapted versions of it are scheduled for future work.

A. Future work

The curriculum itself should be evaluated in further work to determine whether the structure and content are fundamentally suitable for equipping students with sufficient skills at the end of their studies. The Institute of Electrical and Electronic Engineers (IEEE) & Association for Computing Machinery (ACM) guidelines for CS curricula could be used in the evaluation of the curriculum's design and the skills to be acquired through the curriculum.

It was beyond the scope of this work to investigate the actual root causes of the particular gaps and challenges. For instance, it is not known whether the teaching methods are used incorrectly due to insufficient or against better knowledge. Future work will investigate the root causes of the respective design-reality gaps based on the work of Masiero to develop counter measurements to narrow down or even close the discovered gaps [17].

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