Introduction

In this chapter, we introduce our work that aims to address challenges in educational technologies by applying ideas from software engineering. We discuss the motivation and inspiration to our work that stems from grand challenges in computing and education in Section §1.1. We then present adult literacy case study in India as an instance of this challenge in Section §1.2. We present the problem statement of this thesis in Section §1.3 followed by the proposed contributions of this thesis in Section §1.4. Finally, we briefly define the research scope of this thesis in Section §1.5 followed by an outline of this thesis in Section §1.6.

1.1 Motivation & Inspiration

The role of technology in education has undergone a massive transformation in the 21st century promising to facilitate anywhere, anytime learning to everyone [16][17]. Supporting this trend, a plethora of educational technologies like computer aided instruction, web based learning, game based learning, learning management systems, computer-supported collaborative systems, virtual learning environments have emerged for a wide range of environments and contexts across the globe. Even though these technologies vary on several dimensions, software is a central theme of many of these technologies. In addition, there is also a need to constantly improve these technologies catering to emerging trends like personalized learning, gesture based learning, augmented reality, gamification [18] and Massive Open Online Courses (MOOCs) [19]. This further increases the complexity during the design of educational technologies and makes it an incredibly hard challenge to customize and adapt these technologies as per the emerging trends.

On the other hand, despite significant progress in educational technologies, there is also a strong criticism that most of them lack a pedagogical or instructional design basis leading to poor quality of instruction [20] [21] [22]. These emerging trends and issues with
current educational technologies present some key grand challenges for computing and engineering:

• Design of technologies to facilitate personalized learning

  “Everybody is a genius. But if you judge a fish by its ability to climb a tree, it will live its whole life believing that it is stupid!” - Albert Einstein

  - Advance personalized learning, Grand Challenge 14 from Grand Challenges for Engineering, National Academy of Engineering of the National Sciences

  - Provide a teacher for every student, from Grand Challenge 3 from Grand Research Challenges in Information Systems, Computing Research Association

  - A STEM Grand Challenge - Accelerate the development of problem solving, reasoning, and decision making skills

• Improve quality of education using technology

  “Education is not the learning of facts, but training of the mind to think!” - Albert Einstein

From a technological perspective, we construe these challenges as

“Design and customization of educational technologies for scale and variety while maintaining quality of instruction”

In the next section, we present the adult literacy case study in India as a sub instance of this challenge setting the context for this thesis.

1.2 A Challenge

How to facilitate design of eLearning Systems to teach 287 million adult illiterates in India spread across 22 Indian Languages, who are beyond the age of schooling, earning their livelihood, who speak their native language, but cannot read or write?

The world has undergone a rapid transformation into digital age with over an estimated 7 billion mobile users and around 2.4 billion Internet users worldwide. However, the same world has an estimated 775 million young people and adults who are unable to read or write even in the digital era. Surprisingly, India itself has around 37% of them, who are beyond the age of schooling, speak their language, but cannot read or write and spread across 22 Indian Languages.

In addition, according to reports from Government of India, the present average of adult illiterates taught by instructors is around 10^3, whereas even assuming 200 adult illiterates per year for 5 years would still need a dedicated force of 287,000 instructors.

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1 http://www.engineeringchallenges.org/challenges.aspx
2 http://archive.cra.org/reports/gc.systems.pdf
3 Personal Communication, State Resource Center Director, Telangana, India under the programme of “Each one, teach ten”
National Literacy Mission (NLM) of Government of India (GoI) has been striving to address this challenge since 1988 and has created a uniform methodology for teaching adult illiterates across India [26]. In the literature, there were several efforts of using technologies like radio, television and even mobiles to reach out to adult illiterates in India [27] [28].

A technology initiative by Tata Consultancy Services (TCS), an Indian Software Consultancy Services firm, as part of their Corporate Social Responsibility program consists of 9 eLearning Systems for 9 Indian Languages and has made around 120,000 people literate [29]. While these experiments have yielded significant productivity increase over Government of India efforts, with decreasing dropouts and increasing pass rates [29], the instructional design was constant and the eLearning Systems are monolithic in nature making their customization a hard task. With the success of these eLearning Systems on the field, we have focused on improving the productivity during the design of these eLearning Systems. To this end, we have applied the ideas of software reuse and software product lines and were able to reduce effort from 5 to 6 person years spread over 2 calendar years to 5 to 6 person months in 6 calendar months for developing an eLearning System [7]. But this approach is for automating a family of eLearning Systems based on a fixed instructional design whereas the dire necessity is to design eLearning Systems for flexible instructional designs and further customize them for 22 Indian Languages and variants. This presents the following key requirements and challenges for adult literacy in India, setting the context for this thesis:

- Facilitate design of eLearning Systems for 22 Indian Languages and dialects (scale).
- Facilitate quality of instruction by basing the design of these eLearning Systems on instructional design.
- Facilitate the design of these eLearning Systems for flexible instructional designs (varying goals, processes and content) catering to the varying needs of 22 Indian Languages and variants.

Even though these challenges are specific to adult literacy, design of eLearning Systems for other forms of education like schooling, skills, engineering, and customizing them for varied contexts and delivering them in multiple languages makes it a grand challenge. Table 1 shows an example possibility of designing eLearning Systems for six subjects from K1 to K12 with each of them having varied goals/process/content to be delivered in 22 Indian Languages and variants. The problem in these cases is of scale and variety during the design of these eLearning Systems for varied instructional designs.
Table 1.1 Scope of Educational Technologies - An Example

<table>
<thead>
<tr>
<th>Class/Subject</th>
<th>1st, 2nd, 3rd Language</th>
<th>Maths</th>
<th>Science</th>
<th>Social</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>$l_1...l_{22}$</td>
<td>$l_1...l_{22}$</td>
<td>$l_1...l_{22}$</td>
<td>$l_1...l_{22}$</td>
</tr>
<tr>
<td>K2</td>
<td>$l_1...l_{22}$</td>
<td>$l_1...l_{22}$</td>
<td>$l_1...l_{22}$</td>
<td>$l_1...l_{22}$</td>
</tr>
<tr>
<td>K3</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>K12</td>
<td>$l_1...l_{22}$</td>
<td>$l_1...l_{22}$</td>
<td>$l_1...l_{22}$</td>
<td>$l_1...l_{22}$</td>
</tr>
</tbody>
</table>

Figure 1.1 Current approach for design of eLearning Systems in adult literacy

1.3 Problem Statement

This thesis explores the possibility of facilitating the design of educational technologies to create customizable eLearning Systems to address the challenges of scale and variety in the context of adult literacy in India. To this end, the current approach for developing eLearning Systems for adult literacy is presented in Figure §1.1. In this approach, the key input comes from a well-established methodology called Improved Pace and Content of Learning (IPCL) [26], from National Literacy Mission for teaching adult illiterates across India, which is then used as a base for producing instructional material for 22 Indian Languages. This approach is detailed in Section §2.1. With these inputs, eLearning Systems for 22 Indian Languages are developed by software development teams. The main problem with this approach is that these systems are monolithic in nature and any change at methodology, instructional material or software development process forces their re-development leading to massive efforts. In addition to the challenge of huge effort, this approach also does not support customization of eLearning Systems for varied instructional designs, which is at the crux of
this thesis. This strongly calls for explicit modeling of instructional design and its variants to facilitate scale and variety inherent in the problem domain.

Instructional Design has gained significant role in the field of Technology Enhanced Learning as an underlying and complex discipline often involving multiple perspectives and connotations. In the context of this thesis, we look at instructional design as an underlying structure that encompasses principles of instruction to facilitate design of educational technologies. To the best of our knowledge, we are not aware of research focusing on modeling instructional design for adult literacy. However, there has been extensive research on modeling instructional design for the last several years resulting in a plethora of educational modeling languages (EMLs) [30] [31] [32] like poEML [33], PALO [34], Web COLLAGE [35] as a way to model and reuse aspects of instructional design. Sampson et al. presented an open access hierarchical framework for integrating open educational resources at different levels of granularity [36]. IMS-LD emerged as a standard for learning design [37] and then focus shifted to tools like LAMS [38] and LDSE [39] that aim to support teachers. A vision paper aimed to create an approach that integrates most of these tools towards an integrated learning design environment [40]. Despite this rapid progress, many researchers have pointed to several shortcomings of modeling and reusing instructional design like complexity of authoring, lack of adequate tool support, interoperability and inability to support teachers [41].

In addition, several researchers have used ontologies as a means to represent different aspects of instructional design. Ontologies have been proposed to capture educational content [34] as well as learning design using IMS LD [42]. LOCO [43] was presented as an ontology to bridge the gap between learning objects and learning designs through context. Extending these ontologies further, an ontology framework was developed for creating an intelligent learning organization [44]. However, these ontologies and tools based on them are tightly coupled with each other and do not support for modeling instructional design variants making it difficult for design of eLearning Systems for scale and variety.

Designing reusable learning objects is another direction that has received significant attention from several researchers [45][46][47] [48] [49][50] [51] in educational technologies but most of these efforts have not been very fruitful due to lack of emphasis on other aspects of instructional design [52] [53] [54] [55] [56]. A direction that is of interest to this thesis is the use of software engineering approaches for designing a family of eLearning Systems for scale and variety rather than focusing on individual eLearning Systems. A software product line for generic digital information products was presented in [57] and an approach for development of web-based eLearning Systems focusing on web services and XML was presented in [58]. In our prior work, we have developed an approach called TALES for automating the development of a family of eLearning Systems based on software product lines [7]. However, none of these approaches focus on modeling instructional design as a
basis for eLearning Systems leading to criticism from quality of instruction perspective and leave supporting flexible instructional designs as an open research problem.

To summarize, existing approaches in the literature focus on either modeling instructional design or on software reuse and not both presenting a strong motivation and need for this thesis.

With this background, the key research goal of this thesis is:

“To create an approach that facilitates the design of educational technologies to support scale and variety in education with a focus on adult literacy in India”

For the last several years, we have been working on creating several technological aids to support adult literacy in India with our research spanning across educational technologies [59][60], software engineering [61] and human computer interaction (HCI) [62]. We have briefly summarized some of these different perspectives in [63]. However, the focus of this thesis is on applying software engineering approaches and principles to accelerate the design of educational technologies for scale and variety based on well-established learning methodologies. The progress of our research is summarized in Figure §1.2 and is detailed as part of contributions later in this chapter.

1.4 Proposed Approach & Contributions

Design of educational technologies for scale and variety while maintaining quality is a major challenge requiring research from several disciplines like learning methodologies, educational technologies, software engineering and human-computer integration. However, the focus of this thesis is to address an instance of this challenge in the case of adult literacy from a technological perspective. To this end, we rely on the following inputs:

- An educational philosophy that provides a strong basis for learning and teaching.
Figure 1.3 Existing and Proposed Approach for Design of educational technologies for scale and variety

- Instructional material devised by domain experts based on the above methodology.
- Field tested eLearning Systems based on this instructional material.

Figure 1.3 shows a simple schematic of the existing approach (top) and proposed approach (bottom) for design of iPrimers for adult literacy in India. In the existing approach, individual software development teams develop iPrimers for every primer and all these primers are based on a single instructional design methodology i.e., IPCL in the case of adult literacy in India. The core idea of the proposed approach is to systematically model different aspects of instructional design using patterns, concretely represent them using ontologies and then apply a software product lines approach for semi-automatically generating eLearning Systems for varied instructional designs and multiple languages. This allows for flexible modeling of instructional designs and creation of customizable iPrimers. An overview of our proposed approach is presented in Figure 1.4. Even though this approach takes the same inputs as in Figure 1.1, the key difference is the design of educational technologies that can handle the scale and variety for flexible instructional designs instead of re-developing eLearning Systems for every new case and every change in the inputs. To this end, the following are the main contributions of this thesis:

Contribution §1 - Pattern-Oriented Design
One of the strong criticisms faced by several eLearning Systems today is the lack of an instructional design basis leading to poor quality of instruction [21][64]. In addition, there is also a huge scarcity of qualified teachers across India⁴. As expressed earlier in Section §1.3, the key goal of this thesis is to design educational technologies for scale and variety rather than a single eLearning System.

**Problem:** How to base design of eLearning Systems on instructional design while facilitating scale and variety?

We propose patterns and pattern languages as a first step towards modeling different aspects of instructional design based on commonly accepted principles and practices in the literature. While there is extensive work on patterns for instructional design like Pedagogy Patterns Project [65], E-LEN [66], the main focus has been on patterns from a pedagogy perspective than on designing technologies, which is the focus of this thesis. In addition, researchers have focused either on domain patterns (instructional design) or on technology patterns, and not both. In this context, we propose a patterns-based approach to design of educational technologies based on instructional design. The crux of this approach is to create a structure of solution in instructional design and integrate it with a solution in technology based on patterns. We propose a set of patterns for instructional design in the context of adult literacy in India. More specifically, we propose a pattern for modeling

Instructional material and map it to Bloom’s taxonomy [14] and a pattern for modeling instructional process and map it to Merrill’s first principles of instruction [2].

For example, we proposed a structural pattern called ContentPattern for modeling instructional material indicating gradual knowledge progression as (facts → cases → rules → models → theories) and an example instantiation for adult literacy is: ContentPattern 1: syllables (म, क, न) → words (नम, मकान) → rules (क +◌ा = का) → phonetic model → eclectic method. Here, each of the aspects of facts, cases, rules, models and theories provide variation points such that they can be varied for different contexts. For example, the above example with variations for Telugu language can be syllables (మ, క, న) → words (మనం, మǀం) → rules (న+◌ం=నం). This pattern is driven by goals, which are also modeled using a GoalPattern based on Bloom’s taxonomy: Capability (remember, understand, apply, analyze, evaluate, create), Condition, Criteria. An instantiation is GoalPattern 1: The learner should be able to remember syllables (म, क, न) and recognize them from a newspaper in less than a minute. This approach and patterns are detailed in Chapter §3 of this thesis.

Contribution §2 - An Ontology Based Modeling Framework

In order to achieve the goal of semi-automatically generating eLearning Systems, there is a need to concretely represent instructional design such that it can be processed by tools.

Problem: How to systematically represent different aspects of instructional design based on patterns?

There is an increasingly widespread use of ontologies in educational technologies with several applications; ranging from representation of domain knowledge [67] to the extent of personalization and generating adaptive content based on learner styles [68]. In this thesis, we explore the use of ontologies to systematically represent different aspects of instructional design like context, goals, process, content, role, evaluation and environment based on patterns. More specifically, we focus on the aspects of goals, process and content in this thesis. We rely on existing ontologies like ALOCoM [69] for content, IMS LD [70] for process, LOCO [43] for context, as inputs to our framework and adapt and extend them for our specific needs. This framework is detailed in Chapter §4 of this thesis.

For example, goals are specified using GoalsOntology. Some properties associated with this ontology are description, priority, prerequisites and so on. The GoalsOntology points to the process through which these goals will be achieved, the content that is required and the evaluation to be performed.

Contribution §3 - Pattern-Oriented Software Product Lines

Instructional Design lays a strong foundation for design of eLearning Systems with a pedagogical basis [71]. However, it is an extremely effort intensive activity to adapt and customize instructional designs to cater to varying needs.
**Problem:** How to model a family of instructional designs to drive creation of eLearning Systems for scale and variety?

In this thesis, we explore software product lines as an approach to address this challenge of modeling a family of instructional design variants as well as a family of eLearning Systems for adult literacy. The core idea of this approach is to look at modeling instructional design not as a single problem but as a family of similar but distinct problems. However, this critical challenge of reducing effort for creating and customizing flexible instructional designs is often considered as a one-off problem in the literature rather than a family of problems. In this approach, the key inputs for domain engineering phase of software product lines come from patterns and ontologies of instructional design, which are then customized during application engineering to facilitate the design of customizable eLearning Systems. We have elaborated this approach in Chapter §5 of this thesis.

**Evaluation** - We demonstrate the core contributions of this thesis through design of two prototype platforms (i) A platform for modeling instructional design variants (ii) A platform for semi-automatically generating eLearning Systems from instructional designs. Using these platforms, we have developed a few prototype eLearning Systems for multiple Indian languages to demonstrate scale and variety. The platform uses principles of software product lines and is developed using basic web technologies like Python, JavaScript, Jena API, XML Schema and so on. Technical architecture is discussed in Chapter §6 of this thesis. Recently, we have semi-automatically generated two eLearning Systems for Hindi and Telugu languages.

### 1.5 Scope of Thesis

The grand challenges introduced in Section §1.2 require rigorous interdisciplinary research cutting across software engineering, educational technologies and HCI. However,
This thesis takes a technological perspective and only focuses on facilitating the design of educational technologies for addressing scale and variety in the context of adult literacy in India. To this end, this thesis relies on IPCL, a well-established methodology for teaching adult illiterates from National Literacy Mission, instructional material that is based on this methodology. In addition, the focus of this thesis is not to study the effectiveness of eLearning Systems for literacy, as we rely on field tested eLearning Systems developed by TCS for 9 Indian Languages, which has made around 120,000 people literate [29].

The scope of this thesis is to investigate approaches to facilitate design of educational technologies for scale and variety and demonstrate it for adult literacy in India.

- This thesis works at the intersection of instructional design, ontologies and software product lines as shown in Figure §1.5.
- This thesis relies on well established learning methodologies rather than creating new ones.
- This thesis does not aim to conduct field studies with teachers or learners but relies on commonly accepted and field-tested approaches, and technologies.
- This thesis utilizes existing ontologies for instructional design as a basis for creation of proposed ontologies.
- This thesis leverages existing open source tools and creates research prototypes for demonstration of ideas.
- Modeling all dimensions of instructional design from all perspectives is an uphill task and in this thesis we confine to the main aspects of goals, process and content and briefly discuss other aspects in the generic context.

1.6 Organization of this Thesis

In this chapter, we have provided an overview of the thesis, its motivations and summarized the key contributions of this thesis. We briefly summarize the organization of this thesis as shown in Figure §1.6. In Chapter §2, we detail the adult literacy case as running example throughout the thesis. We then present related work of the thesis from an instructional design perspective and software engineering perspective and list unaddressed challenges from the literature that are relevant to this thesis. Chapter §3, Chapter §4 and Chapter §5 address the thesis problem stated in Section §1.3 by applying the ideas of patterns, ontologies and software product lines respectively. In Chapter §6, we present two platforms that support evaluation of the ideas in this thesis. In Chapter §7, we present the
Figure 1.6 Structure of this thesis

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Provides Introduction, Motivation, Thesis Statement and Contributions</td>
</tr>
<tr>
<td>2</td>
<td>Describes Background, and exposes challenges from literature space</td>
</tr>
<tr>
<td>3</td>
<td>Presents pattern oriented design as an for design of educational technologies based on instructional design</td>
</tr>
<tr>
<td>4</td>
<td>Describes an ontology based framework for instructional design based on patterns</td>
</tr>
<tr>
<td>5</td>
<td>Introduces a pattern oriented software product line approach for modeling a family of instructional designs</td>
</tr>
<tr>
<td>6</td>
<td>Evaluation and two prototype platforms (i) Instructional Design Editor Product Line (ii) iPrimer Product Line</td>
</tr>
<tr>
<td>7</td>
<td>Summarizes the conclusions of this thesis along with major future research directions</td>
</tr>
</tbody>
</table>

Conclusions of this thesis and provide some perspectives on future directions. A part of the work described in this thesis is based on previously published papers listed after §7.2.4.