Learning How to Write with a Social Robot

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par

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It is not your qualifications but your exposure in life that makes you who you are.
— Sadhguru

To my guru…

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At last, I would like to dedicate this thesis to my guru - '*Whatever exists or does not exist, for me everything is you...*'

Lisbon, March 2018 Shruti Chandra

Abstract

Learning handwriting is one of the main occupations for children in primary education. It is a complex skill that has been associated with children's learning and development. Poor handwriting skills affect children negatively concerning their academic performance and motivation. In schools, children with handwriting problems need extra support and one-to-one interventions from teachers. Personalised one-to-one support requires additional resources that most schools generally cannot afford. Therefore, there is a need to explore different methods of learning and contemporary technologies to develop new educational tools to foster children's learning process of handwriting.

The research presented in this thesis addresses the question of - "How to create a social robot that can help children to acquire handwriting skills?". Thus, we looked into three different research domains: education; pedagogic sciences; and social human-robot interaction (HRI). On the one hand, we investigated the types of errors commonly present in children's handwriting. On the other hand, we needed to explore different educational theories to find alternate learning methods that would maximise children's learning gains. In addition, we investigated various possibilities for integrating a social robot into educational scenarios and measured its impact on the children's learning process.

This thesis presents five studies that follow an incremental evolution of the research. The first three studies were based on the interaction between two children, in the presence of either a human or a robotic facilitator, with the children performing a collaborative writing activity. We explored the 'peer-learning' and 'peer-tutoring' methods and compared the differences in terms of interaction behaviour and learning gains. Further, we analysed children's interpersonal distance and feelings of responsibility towards their peers, both in the presence of a robot and human facilitator. Finally, we examined children's assessment behaviour towards their peers and self-disclosure towards the robotic facilitator. The outcomes of these first studies provided enough data to generate a taxonomy of children handwriting errors to be used in the subsequent studies. They hinted that the 'peer-tutoring' method had a positive influence on children's learning and corrective feedback to their peers in the presence of the social robot, providing positive support to the applicability of social robots as 'facilitators' in handwriting learning.

The next step was to study the effects of the robot in the peer-tutoring scenario when assuming the role of a peer, directly interacting and performing a collaborative writing activity with the children. Thus, we developed an educational system with an autonomous social behaviour of a robot exhibiting various levels of learning competencies. The tutor-child provides corrective feedback on the writing of the learner-robot and in turn, enhances his writing skills. The robot's writing was generated by an algorithm incorporating human-inspired movements and could reproduce a set of writing errors from the error taxonomy. We tested the system by conducting two longitudinal studies, each of them composed of four sessions. In the fourth study, we assigned the robot two contrasting competencies: 'learning' and 'non-learning'. We measured the differences in children's learning gains and changes in their perceptions towards the learner-robot. The fifth study followed a similar interaction scenario and research questions, but this time the robot performed three learning competencies: 'continuous-learning'; 'non-learning' and 'personalised-learning'. The findings of these studies show that the children improved more with the robot exhibiting learning, continuous-learning and personalised-learning competencies compared to the robot showing non-learning competency. The way children's learning and perception of the robot evolved over time confirmed the need for multiple sessions for the last two studies. This thesis presents some evidence that social robots can be successfully used as tools for enhancing children's handwriting skills in peer-learning scenarios.

Keywords : handwriting, child-robot interaction, peer-based learning, autonomous robot, collaborative learning

Resumo

A aprendizagem de caligrafia é uma das ocupações principais de crianças em educação primária. É uma habilidade complexa que tem sido associada com a aprendizagem e desenvolvimento das crianças. Fraca habilidade de caligrafia afeta negativamente as crianças no que diz respeito a seu desempenho e motivação académica. Nas escolas, crianças com problemas de caligrafia necessitam de suporte adicional e intervenções individuais dos professores. Suporte individual e personalizado requer recursos adicionais que a maioria das escolas não consegue suportar. Como tal, existe a necessidade de explorar diferentes métodos de ensino e tecnologias contemporâneas para desenvolver novas ferramentas adicionais para fomentar o processo de aprendizagem de caligrafia das crianças.

A pesquisa apresentada nesta tese tem como objetivo abordar a questão de - “Como criar um robô social que possa ajudar as crianças a adquirir habilidades de escrita manual?". Como tal, analisámos três domínios de investigação diferentes: educação, ciências pedagógicas e interação social pessoa-robô. Por um lado, investigamos os tipos de erros mais comuns na caligrafia de crianças. Por outro lado, precisámos de explorar diferentes teorias educacionais de forma a encontrar métodos de aprendizagem alternativos que maximizassem os ganhos de aprendizagem das crianças. Também investigamos várias possibilidades de integração de um robô social em cenários educacionais e medimos o seu impacto no processo de aprendizagem das crianças.

Esta tese apresenta cinco estudos que seguem uma evolução incremental da pesquisa. Os três primeiros estudos foram baseados na interação entre duas crianças, na presença de um facilitador humano ou robótico, com as crianças realizando uma atividade de escrita colaborativa. Nós exploramos os métodos ‘peer-learning’ e ‘peer-tutoring’ e comparámos as diferenças quanto ao comportamento de interação e ganhos de aprendizagem. Além disso, analisámos a distância interpessoal das crianças e os sentimentos de responsabilidade para com os seus pares, tanto na presença de um robô como na presença de um facilitador humano. Finalmente, examinámos o comportamento de avaliação das crianças em relação aos seus pares e a auto-divulgação para o facilitador robótico. Os resultados desses primeiros estudos forneceram dados suficientes para gerar uma taxonomia de erros de escrita para crianças a serem usados nos estudos subsequentes. Eles também forneceram suporte positivo para a aplicabilidade de robôs sociais como ‘facilitadores’ na aprendizagem de escrita manuscrita, sugerindo que o ‘método de ensino mútuo’ (método teve uma influência positiva sobre a aprendizagem das crianças e feedback corretivo) aos seus colegas na presença do robô social .

O próximo passo foi estudar os efeitos do robô no cenário de tutoria entre colegas ao assumir o papel de um parceiro, interagindo diretamente e realizando uma atividade de escrita colaborativa com as crianças. Assim, desenvolvemos um sistema com um comportamento social autónomo de um robô que exibia vários níveis de competências de aprendizagem. O tutor-criança fornece feedback corretivo sobre a escrita do aprendiz-robô e, por sua vez, melhora suas habilidades de escrita. A escrita do robô foi gerada por um algoritmo que incorpora movimentos de inspiração humana e pode reproduzir um conjunto de erros de escrita da taxonomia de erros. Testámos o sistema realizando dois estudos longitudinais, cada um composto de quatro sessões. No quarto estudo, atribuímos ao robô duas competências contrastantes: 'aprendizagem' e 'não-aprendizagem'. Medimos as diferenças nos ganhos de aprendizagem das crianças e mudanças nas suas perceções em relação ao aprendiz-robô. O quinto estudo seguiu um cenário de interação e questões de pesquisa semelhantes, mas desta vez o robô realizou três competências de aprendizagem: 'aprendizagem contínua'; 'não-aprendizagem' e 'aprendizagem personalizada'. Os resultados desses estudos mostram que as crianças melhoraram mais com o robô que exibia competências de 'aprendizagem', 'aprendizagem contínua' e 'aprendizagem personalizada' em comparação com o robô que exibia competências de 'não-aprendizagem'. A forma como a aprendizagem e perceção do robô pelas crianças evoluiu ao longo do tempo confirmou a necessidade de várias sessões para esses dois últimos estudos. Esta dissertação apresenta algumas evidências de que os robôs sociais podem ser utilizados com êxito como ferramentas para melhorar as habilidades de escrita da criança em cenários de aprendizagem entre pares.

Palavras-chave: caligrafia, interação criança-robô, aprendizagem baseada em pares, robô autónomo, aprendizagem colaborativa

Résumé

Apprendre à écrire est l'une des principales activités des enfants durant l'enseignement primaire. C'est une compétence complexe associée à leur apprentissage et leur développement. De faibles compétences en écriture se traduisent négativement sur leurs résultats scolaires et leur motivation. Dans les écoles, les enfants présentant des problèmes d'écriture ont besoin d'un soutien complémentaire et d'interventions individuelles de la part des enseignants. Un tel soutien personnalisé engendre des frais supplémentaires que la plupart des écoles ne peuvent généralement pas financer. Il est donc nécessaire d'explorer différentes méthodes d'apprentissage ainsi que des technologies modernes pour développer de nouveaux outils pédagogiques favorisant l'apprentissage de l'écriture manuscrite chez les enfants.

La recherche présentée dans cette thèse vise à répondre à la question - "Comment créer un robot social qui puisse aider les enfants à acquérir des compétences en écriture?" De ce fait, il s'est avéré nécessaire de se pencher sur trois domaines de recherche : l'éducation, les sciences pédagogiques et l'interaction sociale humain-robot. D'une part, nous avons étudié les types d'erreurs couramment présentes dans l'écriture des enfants. D'un autre côté, nous avons dû explorer différentes théories éducatives cherchant à trouver un mode d'interaction adéquat qui maximiserait les gains d'apprentissage des enfants. Nous avons également étudié différentes possibilités d'intégration d'un robot social dans des scénarios éducatifs et avons mesuré son impact sur le processus d'apprentissage des enfants.

Cette thèse présente cinq études qui suivent une évolution progressive de la recherche. Les trois premières études furent basées sur une interaction entre deux enfants, en présence d'un facilitateur humain ou robotique, où les enfants ont réalisé une activité d'écriture collaborative. Nous avons exploré les méthodes de 'peer-learning' ainsi que 'peer-tutoring' et comparé les différences de comportement durant l'interaction ainsi que les gains d'apprentissage. De plus, nous avons analysé la distance interpersonnelle des enfants et leurs sentiments de responsabilité envers leur pair, à la fois en présence d'un facilitateur robotique et d'un facilitateur humain. Enfin, nous avons examiné le comportement d'évaluation des enfants envers leur pair et l'auto-divulgation envers le facilitateur robotique. Les résultats de ces premières études ont fourni suffisamment de données pour générer une taxonomie d'erreurs d'écriture des enfants, que nous avons utilisé dans les études subséquentes. Ils ont également apporté un appui positif à l'applicabilité des robots sociaux en tant que 'facilitateurs' de l'apprentissage de l'écriture manuscrite, suggérant que la méthode de 'peer-tutoring' eut une influence positive sur l'apprentissage des enfants et des réactions correctives en présence du robot social.

L'étape suivante a consisté à étudier les effets du robot dans le scénario de 'peer-tutoring', assumant le rôle de camarade, en interagissant directement et en effectuant une activité d'écriture collaborative avec les enfants. Ainsi, nous avons développé un système où le robot possède un comportement social autonome ainsi que différents niveaux de compétences d'apprentissage. Le tuteur-enfant fournit des commentaires correctifs sur l'écriture de l'élève-robot et, à son tour, améliore ses compétences en écriture. L'écriture du robot fut générée par un algorithme incorporant des mouvements d'inspiration humaine et capable de reproduire un ensemble d'erreurs d'écriture à partir de la taxonomie d'erreurs. Nous avons testé le système à travers deux études longitudinales, chacune composée de quatre sessions. Dans la quatrième étude, nous avons doté le robot de deux compétences opposées : 'apprentissage' et 'non-apprentissage'. Nous avons mesuré les différences dans les gains d'apprentissage des enfants et les changements dans leurs perceptions à l'égard de l'élève-robot. La cinquième étude a suivi un scénario d'interaction et des questions de recherche similaires, mais cette fois le robot a effectué trois compétences d'apprentissage : 'apprentissage continu', 'non-apprentissage' et 'apprentissage personnalisé'. Les résultats de ces études montrent que les enfants ont avancé plus avec le robot aux compétences d'apprentissage de type 'apprentissage continu' et 'apprentissage personnalisé' qu'avec le robot manifestant la compétence 'non-apprentissage'. L'évolution de la perception des enfants envers le robot au fil du temps a confirmé le besoin de séances multiples pour ces deux dernières études. Cette dissertation démontre que les robots sociaux peuvent être utilisés avec succès comme outils pour améliorer les compétences d´écriture des enfants dans des scénarios de 'peer-learning'.

Mots-clés : écriture manuscrite, interaction enfant-robot, apprentissage par les pairs, robot autonome, apprentissage collaboratif

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1 Introduction

1.1 Motivation

Learning how to write is challenging! Handwriting is considered as a challenging, yet necessary skill to acquire for children. Often, poor handwriting skills affect children negatively in terms of academic performance, self-esteem and motivation. The capacities to acquire handwriting skills differ from child to child depending on their age and motor-perceptual abilities. In schools, children with handwriting difficulties need extra support from teachers in one-to-one teaching interventions. In order to master this skill, one requires coordination between cognitive, motor and perceptual abilities that demands a considerable amount of practice.

Over the past few decades, research in the field of education has demonstrated the benefits of peer-based learning methods. The interaction between peers performing a collaborative task stimulates them cognitively, creating an environment to reflect on each other's performance and consequently improve their skills. However, employing these methods in handwriting activities for children require careful experimentation. The process of learning handwriting is long, repetitious and time-consuming; therefore these learning activities should not only be effective but also joyful and engaging for the young ones. Contemporary technologies may contribute to the exploration of new educational tools that foster children's learning process of handwriting.

Researchers have started incorporating social robots in educational settings to seek new ways of fostering children's learning. The behaviour of such robots may be controlled to fit in specific roles in interactions with children. As the acquisition of handwriting skills is a physical task and often require physical assistance and interaction, such social robots can be used as a tool to supplement existing handwriting intervention methods for children. In this dissertation, we explore different educational scenarios where a social robot can fit and provide a favourable environment for children's learning.

1.2 Research Context

The research work presented in this thesis is part of the *Co-writer project*[1] which explores the following long-term research question:

How to create a social robot that can help children to acquire handwriting skills?

To address this question, we will explore the three research domains: Handwriting difficulties; Modes of interaction; and Learning benefits through child-robot interaction (CRI) through a series of studies (see Figure 7.5). We do not consider these domains as isolated from one another, but rather we approach them as overlapping aspects of our research. We present the research domains as follows:

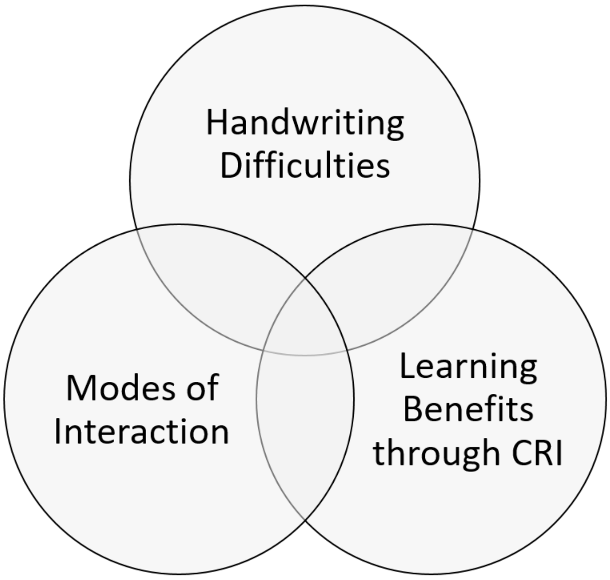


Figure 1.1 – This thesis envelops the relevant research domains.

1. **Handwriting difficulties** are one of the basic issues that we deal in this research. We explore children's handwriting errors in the age-group of four to eight years. The first motive of the exploration is to find the most common handwriting errors that children produce. The second motive is to synthesise the common errors digitally in order to use them in child-robot educational scenarios to further enhance children's handwriting skills.

2. **Modes of interaction** is defined in our research as an interaction approach that can be applied among participants in an educational setting to maximize their learning. In this thesis, we explore peer-based learning methods, such "peer-learning" and "peer-tutoring" that are based on educational theories and have been effectively used in

[1] http://chili.epfl.ch/cowriter

education. In these methods, the interaction generally occurs between two participants. In our research, we explore dyadic and triadic interaction with different combinations of children, robot and human.

3. **Learning benefits through child-robot interaction** provides a distinctive approach where a robot can be used to enhance child's learning and motivation. In our research, we use a social robot in educational settings based on the above-mentioned peer-based learning methods. We examine the impact of the social robot in different child-robot-human scenarios. We also investigate the effects of different roles and learning capabilities of the social robot.

1.3 General Research Questions

In order to address our long-term research question, we aim to investigate different aspects related to the three research domains. We formulate these aspects in a set of research questions that can be viewed under the light of seven different topics. By carrying out single-session and multi-session studies with children in school settings, we try to find answers to the following research questions:

1. **Exploration of peer-based learning methods.** In the context of handwriting, how would peer-based learning methods such as the 'peer-learning' and 'peer-tutoring' would impact on children's learning? How does a social robot compares to a human when integrated in these methods? Which method would be more effective in terms of children's learning gains? How does these different methods impact on interaction aspects such as feedback and self-disclosure when employed in the presence of a social robot ?

2. **Investigation of handwriting errors by children and synthesizing errors.** Which are the common handwriting errors children produce? How can these errors be synthesised digitally to be made by a social robot? How can these errors be used in a child-robot educational scenario to improve children's handwriting skills?

3. **Development of a system that incorporates an autonomous social robot with varied learning competencies.** How can we create a social robot that can interact with children autonomously and play a roles as a peer in a handwriting scenario? How can different competencies of this robot impact children's leaning? Can we use these robots to foster children's handwriting skills?

4. **Impact of the roles.** Which roles can be assigned to a robot and children in child-robot educational scenarios targetted handwriting? How would these different roles influence children's learning and interaction?

5. **Investigation of children's learning and perceptions of the social robot in longitudinal studies.** How do children perceive a peer social robot and its capabilities in an

educational setting in long term interactions? How do these perceptions change over time?

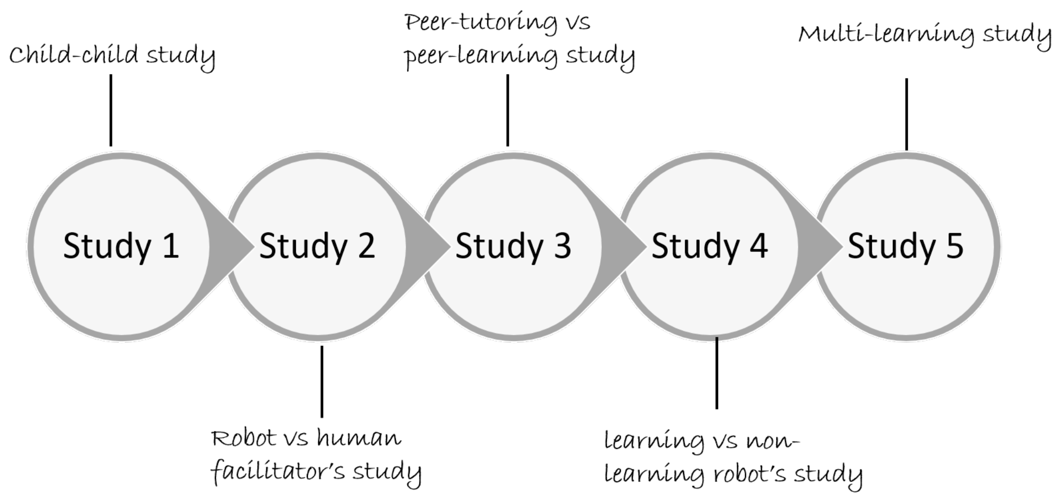


Figure 1.2 – Evolution of studies.

1.4 Contributions

We expect our work to contribute in the child-robot educational field in several aspects. In the past, peer-based learning methods have been mostly practiced without the use of social robots. In the context of learning handwriting, we have explored these learning methods in dyadic and triadic child-robot interaction scenarios, where we examined the impact of a social robot on various aspects of children's learning. By exploiting these methods, we explored different roles assigned to children and the robot in the interaction scenarios. The roles of the robot such as a facilitator or learner seems to fit well in the context of our research. To explore handwriting difficulties, we have explored children's handwriting errors and built a taxonomy of these errors which may extend the existing literature on handwriting. Moreover, we developed a system to provide a peer-based learning educational scenario; where a social robot autonomously interacts and performs a collaborative writing activity with a child. Further, we explored children's learning and perceptions of the social robot in two multi-session studies using this system. The conduction of these longitudinal studies proved to be relevant in understanding children's learning and perceptions over time. The testing of the developed system with children showed some evidence that social robots can be used as a tool to enhance children's handwriting skills.

Study	Mode of Interaction	Role	Duration	Participants	Focus
Child-child study **Study 1**	peer-learning, peer-tutoring	children - teacher/learner human - facilitator	10-15min	20 4-5 years 1 Session	understanding of modes of interaction, communication modalities, learning gains
Robot vs human facilitator's study **Study 2**	peer-tutoring	children - teacher/learner human/robot - facilitator	15-20min	40 6-8 1 Session	responsibility, learning gains
Peer-tutoring vs. peer-learning study **Study 3**	peer-learning, peer-tutoring	children - teacher/learner robot - facilitator	15-20min	40 6-8 1 Session	corrective-feedback, self-disclosure, learning gains
Learning vs. non-learning study **Study 4**	peer-tutoring	child - teacher robot - learner	13-15min	25 7-9years 4 Sessions	children's perception, learning gains
Multi-learning study **Study 5**	peer-tutoring	child - teacher robot - learner	13-15min	37 8-9 years 4 Sessions	children's perception, learning gains

Figure 1.3 – Overview of studies presented in this thesis.

1.5 Outline

The thesis is organized as follows:

The second and third chapter provide theoretical background and related work of our research. The remaining chapters four to eight present the incremental evolution of research. These five chapters discuss a series of five studies and how one study lead to another, see Figure 1.2. The overview of the studies is shown in Figure 1.3.

Chapter 2 presents the relevant **theoretical background**. The first section of the chapter concerns with handwriting where we discuss the importance of handwriting skills in schools and its development in children. Then, we present handwriting proficiency components, the consequences of poor handwriting skills on children, and briefly discuss about handwriting pedagogy. Following this, we will present the handwriting errors of children and their importance. The second section outlines the peer-based learning methods based on educational theories. Here, we first give a brief review about the peer-interaction and importance of roles in the peer-interaction. Then, we describe peer-based learning approaches and their prevalent practices in schools.

Chapter 3 reviews the **related work** concern with our research. We briefly outline the child-robot interaction in education and present a comprehensive review of variables used in child-robot interaction. Then, we discuss the design and evaluation of child-robot educational studies.

Chapter 4 presents our first study, **the child-child study**. This study explores the modes of interaction and explores the common handwriting errors produced by preschoolers. We discuss the findings about the children's understanding of the interaction modes, communication modalities used by children and their learning gains.

Chapter 5 reports the second study, **the robot vs. human facilitator's study**. This study explores the impact of integrating a robot vs. human facilitator on children in a collaborative writing activity. We present findings regarding children's feelings of responsibility towards their peers and interpersonal distance with both facilitators.

Chapter 6 describes our third study labeled as **the peer-tutoring vs. peer-learning study**. The study explores children's peer assessment and self-disclosure in the presence of an educational social robot. It also compares the two peer-based learning methods and their affect on children's learning behavior. Afterwards, we present the findings on how children's feedback, self-disclosure and learning gains vary in the two learning methods. Finally, we present the taxonomy of writing errors revised in the second and the third study.

Chapter 7 presents the **development** of an autonomous social robot with different learning competencies. We first describe the components of the system and how the overall system can be used to provide an educational scenario for children to foster their handwriting skills.

Chapter 8 describes the fourth and the fifth multi-session studies named as **the learning vs. non-learning study** and **the multi-learning study**. The study uses the system developed in the Chapter 7 and presents a peer-tutoring scenario where a child corrects the handwriting errors of a robot. The goal of the study is to explore children's perceptions and learning about the robot exhibiting varied learning capabilities over time. We present findings on children's learning and their perceptions of the robot's capabilities and behavior.

Chapter 9 reports the **summary** of the studies and highlights the important research findings and conclusions of the work. Finally, we present the limitations and future work concerning the research.

2 Theoretical Background

This chapter gives an overview on the theoretical Background that encompasses the significance of handwriting acquisition as well as pedagogical theories used for children and child-robot interaction studies in an educational domain. First, we briefly summarise the importance of handwriting for children in today's world. This is followed by discussing the development of handwriting in children, handwriting pedagogy and the consequences of children's poor handwriting skills. Finally, we discuss the prevalent peer-assisted learning methods that are used to foster children's learning.

2.1 Handwriting

> "Handwriting is a spiritual designing, even though it appears by means of a material instrument."
>
> - Euclid

As cultures and languages in human civilization evolved, need of communication has also evolved from an oral to a written form. The inception of *handwriting* emerges from the oral language to simple drawings and then to pictographs becoming standardised that eventually became a mode of retaining and preserving history. For some people, handwriting represents an art form such as a poetry or a story, and for others, it is merely a functional tool to put ideas into paper. Yet, all of us have used handwriting for one purpose or another.

2.1.1 Why handwriting matters?

In today's world, handwriting serves both a means of communication as well as an inevitable skill. For example, conveying handwritten greetings on bouquets or cards, sending postcards, taking short notes, providing signatures or filling an application form. Moreover, handwritten text adds personalised touch and sometimes enhances the meaning of the content that cannot be substituted with the current digital technology.

Learning handwriting is a required skill in schools and is a need in education as it has been associated with childrens' academic achievement. Children spend approximately 31% to 60% of their academic day in fine-motor activities such as drawing, handwriting and finger-plays (McHale and Cermak, 1992; Marr et al., 2003). Learning handwriting does not only help to achieve motor skills but also boosts other learning abilities such as recognising a character (Longcamp et al., 2006, 2005; James and Engelhardt, 2012), reading (Kiefer et al., 2015), writing (Medwell and Wray, 2008), spelling and composing a story (Berninger and Graham, 1998; Berninger et al., 1997).

> *"I saw that bad handwriting should be regarded as a sign of an imperfect education, I tried to improve mine, but it was too late. I could never repair the neglect of my youth. Let every young man and woman be warned by my example, and understand that good handwriting is a necessary part of education."*
>
> -Mahatma Gandhi

In today's educational system, the extended use of digital media such as computers is constantly replacing the traditional handwriting activities. Despite this, acquiring handwriting skills is not only important but inevitable for young school-age children. Cahill (2009) reported that although "handwriting is a skill that is often overlooked in order to focus on other areas of the curriculum, but is still tied to academic achievement, especially to children's composition and literacy skills." James (2010) found that writing letters (that is related to sensory-motor skills) augmented the processing in the visual system of pre-school children for visual letter recognition. In addition, the easiness of typing may accelerate the writing abilities of children, especially with less developed sensory-motor skills. But, the process of handwriting enhances sensory and motor skills of children, further facilitates their writing composition abilities (Kiefer et al., 2015). For example, Longcamp et al. (2005, 2006) found that both adults and pre-readers show high accuracy in recognition of characters through handwriting compared to typing. Later he found that the process of handwriting also helps in discrimination of characters and their mirror images for longer duration than the typing alone (Longcamp et al., 2008). Additionaly, Kiefer et al. (2015) conducted a study where they found that in the task of word reading and writing, handwriting training to kindergarten children was superior to typing training. This result is again consistent with the influence of sensory-motor representations established during handwriting.

As note-taking with a laptop in schools is becoming common and often favoured by professors, a study by Mueller and Oppenheimer (2014) showed that students who took notes in longhand (handwriting) performed better in answering conceptual questions than the ones who took notes on laptops. Longhand note-taking allowed students to process information during lectures and re-framing the concepts in their own words. The findings of these studies suggest that learning how-to-write helps in building intellectual as well as mechanical skills. Although handwriting is considered as a complex skill to master and involves coordination between cognitive, motor and perceptual abilities of a person, it should be a joyful process of learning for young beginners.

2.1.2 Handwriting Development

It is believed that the development of handwriting in children, especially the achievement of motor skills, begins with early scribbling on paper or other surfaces. It has been proved that a child gradually learns to grasp tools for drawing or handwriting and the scribbling changes into deliberate basic shapes (De Ajuriaguerra and Auzias, 1975; Oliver, 1990). Eventually, the child learns to combine the basic shapes into some meaningful forms. Since children learn handwriting gradually, they should not be pushed to learn handwriting before acquiring adequate pre-handwriting skills as it leads to discouragement and poor writing habits become difficult to correct later (Lamme, 1979). These pre-requisite skills are documented as small muscle development, eye-hand coordination, holding a writing tool, basic strokes, letter perception, and orientation to printed language (Barbe and Lucas, 1974; Lamme, 1979)

Berninger et al. (2006) described the writing development of children as writers in four stages (see Figure 2.1). The first two illustrated stages show the writing progress and capabilities among infants and toddlers. The third and the fourth stage contain the writing tasks for the preschoolers and the first-graders to attain practice and mastery. The first two stages largely rely on perceptual-motor skills whereas the last two stages also add coordinating language such as learning the names of letters while forming their shapes. Thus, the authors concluded that the handwriting cannot be only a visual or a motor process but an integration of *orthographic codes* (letterforms), *phonological* (letter names) and *graphomotor codes* (written output) and consequently, termed as *Language by Hand* (Berninger and Graham, 1998; Berninger et al., 2006).

Moreover, the assessment of readiness for handwriting has been widely studied. Barbe and Lucas (1974) stated that the readiness phase of instruction in handwriting is “as important as a sound readiness program in reading". Related to this, Berry (1989) suggested that writing instructions should not be given until a child masters nine geometrical shapes described in his *Berry’s Developmental Test of Visual-Motor Integration* (Berry, 1989).The nine figures in the assessment include: a vertical line; a horizontal line; a square; a circle; a crossed t; a right-to-left diagonal; a left-to-right diagonal; an oblique x; and a triangle. He also stated that children’s formal handwriting practices should be postponed until a child is able to draw an oblique x. Drawing a ‘x’ requires the ability to draw the diagonal lines that are used in many letters and demands to cross the diagonal lines at a mid-point. It should be noted as that all these 9 figures almost take 6 years to complete: at the ages of 2-2.5 years, a child begins to form horizontal and vertical lines, circles at 3 years, followed by being able to imitate a cross at 4 years, squares at 5years and finally triangles at the ages of 5.5 years.

Additionally, competence in handwriting is often studied and associated with two factors: *legibility* and *speed*. These factors are also used as an index for assessment and automaticity

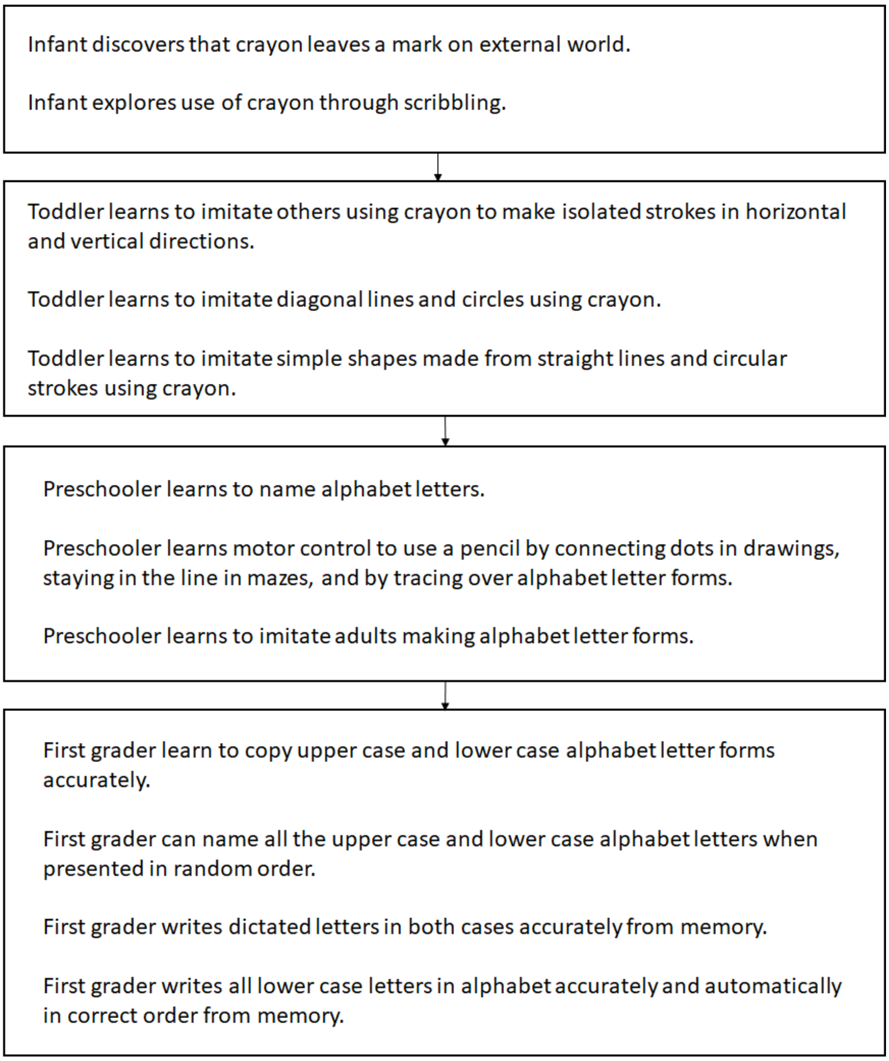


Figure 2.1 – Stages of Writing Development in beginners (Berninger et al., 2006).

in handwriting. Berninger and Graham (1998) analysed handwriting in terms of legibility and speed of 900 students from grades 1 to 9. Results revealed that the legibility tends to improve over time and reaches its peak in grade 6. However, the speed tends to increase as the grades increases and reaches a plateau after 6^{th} grade. Likewise, Karlsdottir and Stefansson (2002) performed a study with 405 children to assess the quality and speed of children's handwriting between grades 1 to 5. The result indicates that the typical time period to develop the quality of handwriting lies between primary school grades 1 to 5 (ages 6-11). Among these years, the level of skill improves more quickly during Grade 1 (ages 6-7) and reaches a plateau by Grade 2 (ages 7-8). Further development during the ages of 8 and 9 leads to the emergence of more automatic and organised letter formation, that is regarded as a foundation for fluent handwriting (Karlsdottir and Stefansson, 2002; Bonney, 1992). Overall, legibility, quality and speed are found to be independent measures of handwriting proficiency (Berninger and

Graham, 1998; Karlsdottir and Stefansson, 2002)

The handwriting has also been studied in terms of types of script (e.g, cursive, manuscript) and genders. Graham et al. (1998b) found that children who used a blend of manuscript and cursive writing scored higher in terms of speed compared to children who used a single script, however, no difference was found in terms of legibility. Regarding genders, the girls outperformed the boys both in terms of legibility and speed (Graham et al., 1998b; Berninger and Fuller, 1992; Overvelde and Hulstijn, 2011; Hamstra-Bletz and Blöte, 1993).

2.1.3 Handwriting Proficiency Components

Handwriting is a complex skill: a combination of cognitive; perceptual; and motor skills, and is primarily considered as a perceptual-motor act (Maeland, 1992). A number of researchers have identified the performance components associated with handwriting (Chapman and Wedell, 1972; Tseng and Cermak, 1993; Cornhill and Case-Smith, 1996). The perceptual-motor components may relate either to the perceptual/motor ability or to the combination of both abilities. The motor control aspects include: fine-motor skills; tactile and kinesthetic senses; motor planning; and in-hand manipulation. The others include visual perception, visual-motor integration and orthographic-motor integration. These aspects of perceptual-motor components and their consequences are described as follows.

1. **Fine-motor Skills and Kinesthesia Senses**

   Malloy-Miller et al. (1995) found that handwriting error patterns of children are related to their mild motor difficulties. Deficiency in *fine-motor skills* include inability to copy enough text; illegibility; and inefficiency to maintain speed of writing (McHale and Cermak, 1992). And to measure the deficiency, fine motor tests are performed that include a number of tasks such as visual, cognitive, manual dexterity demands and spatial organization. In particular, the matching of motor movement with an external visual stimulus such as copying a letter, is a strong predictor of children's achievement compared to other types of motor skills (Bart et al., 2007). Furthermore, Grissmer et al. (2010) and Murrah III (2010) provided evidence that the fine-motor skills predict later achievement in reading and mathematics for kindergarten children, first, third and fifth graders.

   Besides, *kinesthesia* is the ability to sense the position, movement, directionality and orientation of the body/body-parts. It also allows to be aware of the weight of the carried object, and the force and pressure applied to the object. Moreover, preciseness in kinesthetic perception is associated to the handwriting performance, *e.g.*, in the formation of a letter (Cornhill and Case-Smith, 1996; Ziviani et al., 1990). Thus, the kinesthesia is a necessary component of the motor control system (Laszlo and Bairstow, 1983).

2. **Motor Planning**

This aspect is related to kinesthesia as poor kinesthetic perception limits planning and hand movements (Benbow, 1990; Amundson and Weil, 1992). More specifically, motor planning impacts the child's ability in planning, sequencing, executing the shape of a letter and finally ordering the letters in a word (Amundson and Weil, 1992). As planning needs to execute unfamiliar hand movements, therefore, it is crucial that children first learn how to write (Amundson and Weil, 1992; Benbow et al., 1992). In order to investigate the impact of motor planning on handwriting, Tseng and Murray (1994) performed a study to test the relation between the legibility of handwriting and motor-perceptual abilities. They found motor planning contributed the most to the legibility of handwriting measured by the *Finger Position Imitation Test* (Drucker, 1980).

3. **In-hand Manipulation**

   Movements of an object within a person's hand refers to in-hand manipulation (Exner, 1990). It may consist of movement and stabilization of one or more objects, among or between the fingers, from palm to fingers or vice-versa (Exner, 1989). This ability is essential to perform the fine motor tasks such as handwriting when a child grasps, releases or moves a pen/pencil in her hand. It is supposed that the legible and functional handwriting needs precision, accuracy and speed including the rapid manipulation of the writing tool (Benbow, 1995).

   Various terms have been used for describing the in-hand manipulation techniques such as isolation, grading, translation and rotation of the tool among the fingers and thumb (Benbow, 1995; Exner, 1992). Humphry et al. (1995) investigated the frequency, increase and relationship between in-hand manipulation and hand-control activities (*e.g.*, drawing, picking, scooping) with children 2 to 7 years of age. They used three forms of in-hand manipulation: rotation, finger-to-palm translation, and palm-to-finger translation. The results suggested that the frequency of the finger-to-palm translation and rotation increased with age and all the three forms showed uneven nature of development. Clinical observation by Cornhill and Case-Smith (1996) exhibited that children with dynamic grasping pattern roll their fingertips to form some letters. The results showed in-hand manipulation has significant association to handwriting skill. Similarly, Case-Smith (1995) found significant relationship between in-hand manipulation and fine motor skills in motor accuracy test scores.

4. **Visual-motor Integration (VMI)**

   The coordination of visual perceptual abilities and fine motor control refers to visual-motor integration. With this skill a person is able to use his/her eyes and hands in an efficient and coordinated way. This aspect plays an important role in copying the content from printing material to cursive or manuscript writing. The process of copying involves visualizing the shape of a letter form and then providing a meaning to it and, finally reproducing it (Cornhill and Case-Smith, 1996). The developmental test of visula-motor integration by Beery (Berry, 1989) has been widely used in a number of studies which investigated the relationship of handwriting and VMI (Feder and Majnemer, 2007; Weil and Amundson, 1994). For instance, Maeland (1992) found that the VMI test was significant among other perceptual-motor tests in predicting the accuracy of handwriting of 4^{th}-grade children. Similarly, the study of Tseng and Murray (1994) with 143 Chinese children (grade 3 to 5) revealed that the legibility of handwriting is highly related to the test of VMI for both good and poor hand writers. On the contrary, the study of Marr and Cermak (2002) with 101 kindergarten children concluded that the VMI test could not be supported as a tool to identify their handwriting difficulties. However, the VMI results were significant for girls, except for the oblique x in the figures.

5. **Orthographic-motor Integration**

   It refers to a process where orthographic knowledge integrates with the motor ability of a person to produce letter shapes and words (Christensen, 2005). It requires mental coding and rehearsing visual representations and then transforming them to written form with the help of motor ability. Orthographic-motor integration impacts both the quality and quantity of the written content (Graham, 1990). Jones and Christensen (1999) examined the relationship between orthographic-motor integration regarding handwriting and the ability to generate well-structured written content. The results suggested that orthographic-motor integration accounted for 67% of the variance in written text. Lack of automaticity in orthographic-motor integration may impede a writer's capacity in composing a text as working memory resources are allocated for other mechanical requirements (Berninger and Graham, 1998).

6. **Ergonomic Factors**

   Besides the intrinsic factors that are related to the children's own capability, ergonomic factors may also affect their handwriting performance. The ergonomic factors include pencil grip; force required by the writing tool on the writing surface; writing tooltype; paper type and its placement on table; height of chair/table; and writer's posture. Several studies have identified the influence of these factors on handwriting, for example, Chan and Lee (2005) explored the effects of the task factors such as tooltype (pen/pencil), paper texture (coated/uncoated), writing plane angle (slant/horizontal) and four line spacings (lineless/ 3 mm/ 5 mm/ 7 mm) on the writing speed and personal prefrences of 33 adults 19-24 years of age. The results suggested that uncoated paper showed optimum effect on the writing speed and personal preference whereas tool type and writing plane angle did not. Additionaly, the preferred choices were the pen and a horizontal plane angle; and line spacing found to be at least 5mm to get an equilibrium between the writing speed and personal preference.

   Pencil grasp is also indicated in handwriting problems, often teachers' pay attention to child's pencil grasping position (Graham et al., 1998a; Rigby and Schwellnus, 1999; Rosenblum et al., 2006). It is commonly classified based on the position of the thumb, the number of supported fingers to grasp a pencil and finger joint positions (Schwellnus et al., 2013). Mostly, the two types of pencil grasps have been used: (1) *the dynamic grasp*, where the thumb and supported fingers are placed on opposite sides of the pencil; and (2) *the lateral grasp* that involves crossing of thumb over the pencil while balancing against the other supported fingers. Additionally, a tripod grasp includes three supported finger and a quadrupod grasp includes four supported fingers. Four different types of pencil grasps patterns have been identified: *the dynamic tripod, the dynamic quadrupod, the lateral tripod*, and *the lateral quadrupod* pencil grasps (Schneck and Henderson, 1990). Among these, dynamic tripod is widely recommended by teachers and therapists because it allows fine dexterous movements for fingers to write (Schneck and Henderson, 1990). Other three ones are considered as mature grasps in terms of speed and legibility in children's handwriting (Dennis and Swinth, 2001; Koziatek and Powell, 2003; Schwellnus et al., 2012). While gripping a pencil, there exists an axial force, called point pressure, that is applied from the writing tool to the writing surface in downward direction (Harris and Rarick, 1957). The variation in axial force has been associated with the legibility (Harris and Rarick, 1959; Baur et al., 2006).

Moreover, the posture of a writer can also reflect in his/her handwriting problems. Penso (1990) suggests that the quality of handwriting increases when the body and hand positions are comfortably supported. A suitable chair supports the thighs, the back is flexed at 90 degree to the hips. The feet are placed flat on the floor while the knees are flexed at 90 degree and the forearms are comfortably rested on the table. The height of a table differs according to the writer's position where he/she is standing or sitting. Traditionally, sloping handwriting surfaces were recommended for the young writers however children with medical problems may need a flat table (Penso, 1990). Sciacca et al. (2008, 2011) investigated the samples of adult's handwriting in four body postures: sitting, kneeling, standing and lying with two writing surfaces, horizontal and vertical. Variation in handwriting was found only in lying and kneeling posture with the vertical placement of the writing surface. In the similar line, Dziedzic (2016) compared three postures of 50 adults: standard sitting position, lying position with writing surface placed on bent knees, lying position with writing surface placed on a side table. The results suggests that the lying position did not interfere in identifying the writing of an individual.

Berninger and Graham (1998) described handwriting as a combination of forms of letter (orthographic codes), names of letter (phonological codes) and shapes of letters (graphomotor codes). Researchers have argued that memory, more specifically the ability to recall the shapes of letters and orthographic processes, is more accountable for handwriting skills rather than merely motor skills (Berninger and Amtmann, 2003).

2.1.4 Consequences of Poor Handwriting

"Handwriting is important because it influences both the reader and writer"

-Graham Harris, 2000

Feder et al. (2000) reported that "handwriting performance has a widespread effect on child's own image, academic achievement, attitude and behaviour". The development of young children's writing ability is not only considered an essential criterion for success in school (Sassoon, 1990; Stewart and Simon, 1985) but also a critical skill that will impact all of us throughout adulthood (Feder and Majnemer, 2007). A study by Karlsdottir and Stefansson (2002) with 407 primary school children regarding development of handwriting quality and speed concluded that 13% to 27% of the children suffer from handwriting difficulties. Handwriting problems in children affect them negatively with respect to both their academic performance (Christensen, 2005), motivation and self-esteem (Malloy-Miller et al., 1995). There are at least three unwanted consequences for young children (Graham et al., 2000) described as follows:

1. Poor handwriting skills may influence how a child is perceived by teachers. A few studies have indicated that handwriting can often be used to judge children in schools; students with poor handwriting are assigned lower grades compared to those with legible handwriting despite similar content (Chase, 1986; Sweedler-Brown, 1992).

2. Difficulties with handwriting can hinder the process of composing content. While composing, a writer may attend other handwriting processes (such as mechanical demands or to think about how to form a particular letter) and utilise working memory resources that consequently, may lead him/her to forget the ideas to generate the actual content (Graham, 1990; Berninger and Graham, 1998).

3. Poor handwriting skills restrain child's competency as a writer. Handwriting is causally related to learning to write (Graham et al., 2000) and difficulties such as orthographic-motor integration are strongly related to the ability of a child to create a well-structured and creative text (Christensen, 2005).

The literature has also shown the importance of handwriting in the transfer of lower-order transcription skills to higher order text-generation skills such as spelling or story composition from a very early age. Handwriting is not only related to the quality of the text but also with the quantity of the produced text (Graham et al., 2000, 1998a). The consequences of poor handwriting also include an inability to keep up with the written work required in the class, to obtain high scores in Mathematics, and to achieve sustained attention (Sandler et al., 1992; Laszlo and Bairstow, 1984). Quite often, children with handwriting problems are mislabeled as lazy, that in turn causes additional frustration and behavioral problems (Sandler et al., 1992).

Children with poor penmanship are often called *'clumsy'*. The term is used to describe children whose motor skills is below the norm but do not possess any neurological disease or intellectual deficiency (Henderson and Hall, 1982). The dominant characteristic is exceptionally poor motor-coordination. However, the term is ambiguously used and some researchers suggested to redefine the term accurately as all clumsy children are not poor writers and all poor writers are not clumsy (Maeland, 1992). Furthermore, when a child has writing difficulties without the diagnosis of nervous system, the difficulties are generally termed as *Dysgraphia* (S., 1984). The common characteristics of Dysgraphia are: production of illegible handwriting; maintenance of speed; and quantity of writing content specially in a classroom context. Even after providing appropriate amount of practice and instructions, children show lack of consistency not due to carelessness (Keogh and Sugden, 1985; Henderson and Hall, 1982) and fail to make sufficient progress (Smits-Engelsman and Van Galen, 1997). The other developmental motor related problem associated with handwriting is *Developmental Cordination disorder* (Miller et al., 2001b)

Mastering handwriting involves a complex blend of motor-perceptual abilities while ineffective motor skills are difficult to change once they are acquired. Hence, special attention should be given to sharpen the motor and cognition skills of preschoolers from the very beginning (Medwell and Wray, 2008) to prevent problems later on.

2.1.5 Handwriting Pedagogy

Handwriting pedagogy is comprised of two significant elements: one is knowledge of handwriting skills and the other is the specific pedagogical techniques for handwriting (Sharp and Brown, 2015). One of the first steps to ensure the development of good writing skills for children is to provide them formal handwriting instructions (Cahill, 2009). However, in order to teach handwriting skills, teachers must be skilled in different writing styles and should have handwriting pedagogical understandings including handwriting instruction (ARSLAN and ILGIN, 2010). A review by Feder et al. (2008) suggested that handwriting interventions benefited significantly for most children irrespective of the used approach and given treatment. Therefore, handwriting interventions are necessary to deal with handwriting problems (Medwell and Wray, 2008). The interventions to teach handwriting can improve not only children's handwriting, but also strongly impact on their written composition and poor automaticity (Medwell and Wray, 2008)

1. **Handwriting Instructions**

   "Initial handwriting instruction in elementary school is the responsibility of teachers" (Asher, 2006). Handwriting instructions that are primarily given by teachers in a school showed a preventing mechanism in handwriting difficulties (Graham et al., 2000). Three studies (Jones and Christensen, 1999; Berninger et al., 1997; Graham et al., 2000) have found that handwriting instructions not only improved the handwriting skills but also their writing performance including story writing, compositional fluency, generating creative and well-structured texts. Children who have writing readiness deficits can benefit from individualised instruction (Oliver, 1990).

   Although there is substantial evidence that has shown the significance of handwriting instructions, there have been speculations that handwriting instructions are not enough emphasised or in fashion as a part of a writing program (Berninger, 1999; Graham and Weintraub, 1996). A survey by Graham et al. (2003) with primary grade teachers in the United States indicated that the teachers are concerned about struggling children's need;

almost 50% of the teachers reported teaching handwriting daily, 25% reported providing handwriting instructions several times a week, 14% indicated teaching handwriting weekly and finally, 2% reported not teaching handwriting at all. However, the author re-conducted the survey again in 2007 with primary teachers in public as well as private schools across the United States. The results conclude that 80% of the school district require teaching handwriting and 90% of them give 70 minutes of handwriting instructions per week that corroborates with the findings of the previous survey. However, the percentage of teachers providing handwriting instructions weekly reduced to 10% and 10% of the teachers do not provide handwriting instructions at all.

2. **Occupational Therapists**

When children demonstrate severe handwriting and motor-related difficulties in a school setting, classroom remedies to improve their motor skills do not result in enough advancement, teachers often refer the children to occupational therapies (Oliver, 1990; Reisman, 1991). Hence, handwriting problems might become a most common and frequent reason for the referrals to school-based occupational therapists (Oliver, 1990; Hammerschmidt and Sudsawad, 2004). The role of a therapist is to determine the causes of the problem, motor, sensory, perceptual, postural that may delay the development of legible handwriting and consequently provide interventions to remediate the problem. However, Hammerschmidt and Sudsawad (2004) suggested that therapists should collaborate with school teachers as they provide handwriting instructions from the beginning and work with children daily. Moreover, it is also important to understand the teacher's perception and opinion about components of handwriting legibility, criteria to determine the acceptability of handwriting and the final outcome they seek from the occupational therapists while referring children (Hammerschmidt and Sudsawad, 2004; Hutton, 2009).

Feder et al. (2000) performed a survey across Canada among occupational therapists and found that the therapists used an eclectic approach in the treatment of handwriting and motor-related difficulties. The approaches included with majority of sensorimotor (90%), perceptual-motor (74%), motor learning (68%), cognitive training (64%), biochemical (64%), sensory integrative (50%) and neurodevelopmental (42%). Woodward and Swinth (2002) conducted a similar survey in the United States and found that 92.1% of the therapists used multisensory approaches to treat handwriting problems. Among 25 modalities and activities, chalk and chalkboard (87.3%), magic markers or felt pens (76.0%), verbal description while student writes (71.2%), finger writing in viscous substances (64.8%), and copying and tracing on regular lined paper (63.2%) approach were the majority. The approaches include the primary sensory system used as proprioceptive, visual, auditory and tactile.

For evaluating and determining the deficits in handwriting skills, Reisman (1991) suggested that the tests used by occupational therapists should provide quantitative as well as diagnostic information. Feder et al. (2000) surveyed occupational therapists to describe their common treatment approaches for children struggling with handwriting and motor-related problems. The findings concluded that the most common evaluation test used by therapists included: (1) Developmental Test of Visual-Motor Integration (90%); (2) Bruininks-Oseretsky Test of Motor Proficiency (74%) ; and (3) Test of Visual Perceptual Skills -Motor (74%). These tests are briefly described in the Appendix (page 205).

Moreover, a review by Hoy et al. (2011) concluded that the handwriting interventions that include handwriting practice for at least twice a week and a minimum of 20 sessions deliver effective handwriting improvements. The interventions that did not include the practice session found to be ineffective. Teaching and practice handwriting at least twice a week is preferable to teaching it once a week or less, as handwriting needs a motor skill that in turn is best learned through spaced practice (Graham and Miller, 1980).

2.1.6 Handwriting Errors

Handwriting errors refer to the deformations in the shape of letters or words produced by children during writing. Educators and psychologists have taken interest in these errors not only to improve legibility in handwriting instructional procedures but also to detect early signs of writing problems in children (Simner, 1982). Often, the errors have been associated with children's academic failure and teacher's judgment of their academic performances (Simner, 1979, 1980, 1981). As such, these errors are being used to develop handwriting readiness tests to identify children's writing difficulties (Simner, 1982; Berry, 1989). Additionally, educators have examined the handwriting errors of children particularly in the age group of 4 to 7 years. For example, in 1965, Lewis and Lewis (1965) investigated the writing errors of 354 first-grade children in 52 letter forms of the manuscript-style alphabet. The authors identified 11 types of errors shown in Figure 2.2.

Similarly, Simner (1991) discussed that the writing errors produced by kindergarten children include additions, deletions and misalignment in parts of a letter. These errors not only influence their academic performance in the kindergarten period but also throughout their first grade. Due to insufficient motor skills often observed in grade 1 children (ages 6-7 years), other common writing error include incorrect sizes of letters, placement of letters, and relationships among parts in a letter (Simner, 1982). The motor skill aspects include isolation, grading and timing of movements. Furthermore, the isolation and grading aspects resulted from the inadequate grasping of the pen. In addition, slow and haphazard writing are associated with the timing of movements affecting the flow of writing (Exner, 1989). The other type of error is termed as "reversal" where children either name or write a partial or full letter with reverse direction. Wolf et al. (1986) suggests that typically children in early stages of writing development make reversals.

The result of a survey with 169 primary grade teachers indicated that 23% (SD = 14%) of the children in their class faced difficulty with handwriting (Graham et al., 2008). In addition, the

Errors	Definitions
Reversal	The mirror image of a letter form
Partial omission	Any part of a letter form missing
Addition	Inclusion of a part not shown on the model
Incorrect relationship of parts	Any letter form in which a part is not correctly oriented
Incorrect size of letter form or parts of it	A letter form (or part) that is too large or too small in relation to the guide lines
Incorrect placement relative to line	Incorrect orientation to the writing line
Misshapenness	Distortion of all or part of a letter form
Rotation	A letter form rotated more than 15 degrees from an imaginary line drawn vertically through its axis
Retracing	Any letter form (or part) that has been reconstructed after an initial effort
Inversion	Any letter form upside down
Total omission	Any letter form not attempted

Figure 2.2 – Handwriting Errors (Lewis and Lewis, 1965)(*Adapted*).

most common handwriting problems experienced by students were related to overall neatness (76%), spacing between words (66%), letter size (59%), letter formation (57%), alignment of letters (54%), and reversals (52%). Insufficient motor skills of grade-1-children (ages 6-7years) result in common writing errors, for example, incorrect size of letters, placement of letters, relationship of parts in a letter (Simner, 1982).

Summary

Overall, we have studied the different aspects of handwriting including its relevance in today's educational system. The writing development with young writers begin from toddlers to first graders and during this period they go through various stages of handwriting learning such as scribbling; imitation; writing alphabet letters, words and sentences. As evidenced, the handwriting is considered as a complex skill which is a blend of cognitive, perceptual and motor skills. In order to master the skill require attention in different perceptual-motor aspects such as fine-motor skills, motor planning, in-hand manipulation, VMI and so on. Lack of any of these aspects can have poor consequences for children such as difficulties in achieving good grades, problems in composing content and restrictions in becoming competent as a writer. It seems necessary to provide handwriting instruction to young children, without forcing them, as it can prevent handwriting problems later. But special attention and treatment (*e.g.*, help with an occupational therapist) should be given to children associated with medical problems.

One of the major topic in our research is to explore the handwriting problems of children during their learning age. Thus, in this thesis, we target children between four to nine years of age, from preschoolers to second graders. Concerning handwriting difficulties, we specifically focus on using English alphabet letters (uppercase and lowercase) including two different writing styles: manuscript and cursive. More specifically, we study children's handwriting errors in terms of the deformations in the shapes of letters. The research is based on designing writing activities while considering the target age-group of children, their common handwriting errors and their cognition and motor skills. Furthermore, we consider children with both poor and good handwriting skills but without medical problems.

2.2 Peer Assisted Learning

2.2.1 Peer Interaction

Throughout the period of children's childhood and adolescence, peer interaction is essential for language, cognitive and social development (Damon, 1984). However, it is natural to ask the questions like *can children benefit each other cognitively and socially during interaction?* or *can a collaborative task affect their thinking process?* The questions encompass the cognitive and social development processes of children and to explore the questions, most research has been explored based on the theories related to either *Jean Piaget* or *Lev Vygotsky*.

The two theories differ in terms of how social influence impacts the cognitive development of a child. According to Piaget's theory, *equilibration* plays an important role in cognitive development (Piaget, 1975). A *cognitive conflict* occurs between a child's way of viewing the world (own belief) and what the world is reflecting on the child. Thus, the cognitive conflict motivates the child to re-evaluate his/her own conceptions and reform the way of thinking to construct a new conception that fits better. In this process, the child re-establishes the perturbed equilibrium between his own belief and the external belief. These conflicts may occur when a child interacts with the physical and logical environment, and once the equilibrium reached, the child is not in the process of acquiring new information and reaches a plateau (Piaget, 1997). On the other hand, Vygotsky's theory suggests that the cognitive development does not only occur with the individual learning but also envelops the learning through social interaction (Tudge, 1992; Vygotsky, 1980). He also defined a concept called *"child's zone of proximal development"* to indicate the skills that a child could not perform independently but can perform in an interaction with a more competent peer. He suggested that if a child does not show learning gains, it is because of inappropriate learning instructions (Vygotski, 2012; Vygotsky, 1980).

Albeit, both theories are concurrent on the significance of peer's understanding in an interaction but they do not agree on the competency of the peer. Piaget believed that the cognitive development is likely to happen when the peers differ in an initial understanding about some task, then they collaboratively work to arrive on a shared understanding (Tudge and Rogoff, 1999). However, Vygotsky stresses that the child is going to benefit more with a competent partner (peer or adult). The “zone of proximal development” exploits social interaction where a child can achieve far with a help of more knowledgeable peer such as adult or a teacher (Tudge and Rogoff, 1999).

In the same vein, Sullivan also described the effectiveness of peer-interaction in educational scenarios. He emphasised that during peer exchange, *co-construction* of ideas occur through co-generation and co-sensual strategies in a collaborative effort (Sullivan, 1953; Damon, 1984). Both parties in peer interaction benefit from each other as they both seek agreement, compromise willingly without authority relationship between them (Damon, 1984). Collaboration plays a crucial role as it allows peers to construct knowledge together and explore new ideas within the domain knowledge of both partners (Damon, 1984).

The above theories may not agree on the subtleties of development process in a child but they agree on the definite benefits of peer interaction in educational scenarios. Damon (1984) pointed out a few benefits of peer interaction as written below:

1. **Beyond misconceptions:** through the process of mutual sharing of knowledge and feedback, peers construct new ideas that encourage them to resolve misconceptions in the seek of solution.
2. **Mastering Social processes:** peer interaction helps participants to reflect on feedback, arguments, verification and criticism.
3. **Exploratory learning:** collaboration augments the process of critical thinking and exploratory learning.
4. **Encourage Interpersonal relationships:** It allows to reach the consensus in an atmosphere of mutual respect and fairness.

2.2.2 Importance of Roles in Peer Interaction

Sarbin (1966) analysed theoretically the importance of roles in peer interaction especially in the case of *tutor-tutee* relationship. He raised a question- *“Under what conditions, a tutee acquire skills as a result of being tutored by a child with no pedagogical training, whereas a classroom teacher is unable to influence the skills of the same child?"* He answered by taking the help of *role theory*. In the role theory, the prime factor is role enactment that can be appropriate or inappropriate depending on how the person self-locates with reference of other persons present in a social surrounding. And this self-location is comprehended by a term called *social identity*. Sarbin further explains the three-dimensional model of social identity in the context of role theory as: a sociological concept *status*; a psychological concept *valuation*; and the action concept *involvement*. A status is defined as a position of an individual with respect to others in a society that is further described in two categories: *ascribed* (granted) and *achieved* (attained) positions (Linton, 1942). According to the social identity model, different reactions obtained from the ascribed role (*e.g.*father) and the achieved role (*e.g.*teacher). The example of giving rewards for achieving ascribed role is positive reinforcement (*e.g.*, 'hug') and for the achieved role is effective response (*e.g.*, 'medal'). In the context of peer-tutoring, Sarbin explains that children interpret tutor-tutee as an ascribed role relationship with the concern of friendship and care. Whereas in the traditional way of teaching, the teachers role primarily is the achieved one but the child considers as an ascribed role relationship. Role confusion occurs due to the difference between the child's expectation of effective evaluation from the teacher's side and teacher's behaviour. On the other hand, in peer-tutoring scenarios, the tutor-tutee is more involving and reciprocal role relationship (Sarbin, 1966).

Role enactment produces changes in cognition, self-concept, attitude and behaviour (Allen, 1976; Lieberman, 1956). In fact, Sarbin (1966) describes the six variables that influence the appropriateness and convincingness of role enactment such as *accuracy of actor's role expectations*; *validity of actor's self-location*; *values and role requirements*; *role-taking skills*; and *reinforcing properties* from the audience. Additionaly, the enactment of role as a tutor or tutee produces behavioural changes due to role expectations (Allen, 1976). Philp et al. (2013) describes *peer interaction* as "*any communicative activity carried out between learners, where there is minimal or no participation from the teacher. This can include cooperative and collaborative learning, peer tutoring, and other forms of help from peers*". Examples of peer-based learning approaches include classroom study groups, team projects, peer-to-peer learning partnerships, workshops led by students and so on (Boud et al., 1999).

> *"The Peer learning approach is not a single, undifferentiated educational strategy and encompasses a broad range of activities"*
>
> -David Baud (Boud et al., 2001)

Boud et al. (2001) defined peer learning as *"students learning from and with each other in both formal and informal ways"*. This type of learning can occur in both formal and informal ways. Examples of informal ways are when discussions among students happen about assignments, projects in a casual setting without the intervention of teacher or staff involvement. These informal ways are best suitable for effective learners. However, formal peer learning includes when students study for a course or a team project designed by the teacher/facilitator or staff (Keppell et al., 2006). Formalised learning can strongly help students and often consider optimally in situations where there is a lack of teaching resources in school and universities. It also offers more practice and responsibility to students (Keppell et al., 2006). While practising this approach, equal focus is given to the learning process, the support that participants offer and the learning task (Boud et al., 2001).

2.2.3 Peer-based Learning Approaches

The different types of peer-based approaches have been widely compared and exploited individually. They all differ in at least three ways: (1) to encourage participant's interaction; (2) composition of the group; and (3) curriculum material (Damon and Phelps, 1989). However, they also contain elements *grey areas* and *creative blends* where they overlap with each other (Damon and Phelps, 1989). We present the four common peer-based approaches: *peer tutoring*; *reciprocal peer learning*; *cooperative learning*; and *collaborative learning* as follows:

1. **Peer Tutoring**

   Peer tutoring approach in today's educational scenario is borrowed from *Vygotsky's* theory. He suggests that children might have more benefit in their intellectual growth when they interact with more capable peers (Vygotsky, 1980). The approach is similar to the traditional *teacher-learner* relationship where it follows a linear model of knowledge transmission from a teacher to a student (Damon and Phelps, 1989; Topping, 1996). However, the peer tutoring and traditional teacher-student tutoring differs in reference to the authority level hold by a child-tutor over the peer tutor and a traditional teacher over a student. Additionally, the child tutor possesses less knowledge and instructional experience compared to the traditional teacher.

   Generally, peer tutoring approach is practiced between a pair of children, whereby one child plays a role of an expert and the other as a novice (Bloom, 1975; Cohen, 1984; Damon, 1984). The tutor-child teaches the second child (tutee) and need to have knowledge that the other child lacks. Therefore, peer tutoring usually happens between an older and a younger child or academically high achieving vs. low achieving children. Allen (1976) shows that the approach is not only beneficial to the tutee but also to the tutor. Sometimes, role reversals happens if there is temporary disparity of competence between the children. However, tutor-child has always more power in terms of information and instructional program than the tutee, either in the temporary or permanent disparity of knowledge. Therefore, they do not share the equal status in their teaching-learning relationship (Damon and Phelps, 1989). In addition, role reversal "from expert to novice can impart to the child a deeper and more sympathetic understanding of the educational endeavour (Damon, 1984)". In spite of having unequal status, the peer tutoring approach provides several benefits compared to the traditional teaching approach. For example, tutee may feel free to ask questions and give feedback to the tutor-child compared to a traditional teacher. Hence the approach can bring balance, mutuality in the tutor-tutee relationship and show benefits such as improvement in children's self-esteem, social adjustment, their attitude towards the school and so on (Damon and Phelps, 1989).

   Bowman-Perrott et al. (2013) carried out a rich meta-analysis of the effects of peer-tutoring studies across 26 single-case experiments with 938 students in grades 1-12. The findings revealed that the approach proved to be an effective intervention irrespective of duration, treatment, grade level and disability status of the participants.

Peer-tutoring approach has shown its benefits in various curriculum courses such as reading (Oddo et al., 2010), science (Bowman-Perrott et al., 2007)and maths (Hawkins et al., 2009). Moreover, Colvin (2007) discussed the social dynamics between peer tutors in higher education. The results indicated that due to unequal hold of power between a tutor and tutee, their interaction and relationship get affected with misunderstandings and power struggle. Besides the prominent benefits of the approach such as motivation (Carroll, 1996; Falchikov, 2001), learning (Entwistle, 1997) and empowerment for tutors (McKeganey, 2000), it is also used to provide economic savings (Miller et al., 2001a; McKeganey, 2000).

2. **Reciprocal Peer Learning**

   It is defined as *a reciprocal learning method whereby students play roles of both teachers and learners* (Boud et al., 1999). It usually involves participants from a similar class with no roles attributed to them and hence, they acts as both teachers and learners (Boud, 2001) Because of the inclusion of reciprocal and bidirectional factor, students do not hold power over each other as a result of their status, position or responsibility (Keppell et al., 2006). Focus is given to a participant's learning and how it can add to other participant's learning in a group (Boud, 2001). During the process, participants take responsibility of self-learning through communication, providing and receiving the feedback simultaneously that becomes it's prime advantage (Keppell et al., 2006).

   Asghar (2010) interviewed first-year students individually and in groups, to elicit their perceptions after experiencing reciprocal peer learning. The students benefited in self-regulation to become autonomous learners that was affected by their motivation, self-efficacy, time management and emotions. The benefits of reciprocal learning include for both tutor and tutee on various levels such as on cognitive, metacognitive and social((Falchikov, 2001; Topping and Ehly, 2001; Roscoe and Chi, 2007)). Similarly, De Backer et al. (2012) explored the potential of reciprocal peer learning to promote metacognitive knowledge and metacognitive regulation skills of 67 university students. The results indicated that the peer learning approach increased their metacognitive self-regulation skills but not metacognitive knowledge. Bentley and Hill (2009) reported that students supported the approach as they perceived it beneficial in terms of enhanced learning of topic; and more efficient use of time.

3. **Cooperative Learning**

   The cooperative learning approach is defined as a team-based approach where there are two or more students form a group to solve a task (Damon and Phelps, 1989). The task is generally given by a teacher and the group making is either done by a teacher or students in a classroom setting. Although group leading is present among the participants due to their different abilities, they all divide the task responsibilities and roles with equal status for completing components of the tota1 group workload. The evaluation is directed towards the group's joint activity and hence, participation and contribution of each participant becomes necessary. The examples of the given tasks are *demonstration,* *discussion, debate*. In this approach, participants may work together all the time or they may work separately. The consequences may result in "the blind leading the blind" or "pooling ignorance", or one person doing all the work (Topping, 2005). Therefore, coordination, structuring and planning is needed between the participants (Cohen, 1984; Buchs et al., 2004). Cooperative learning has different types of formats that are practiced and applied by researchers in an educational setting. The differences between each of the formats are based on the participant's individual or collaborative efforts, intrinsic (*e.g.*motivation, planning strategies) vs. extrinsic (rewards, competition between the teams) incentive structure in a group (Damon and Phelps, 1989).

Although researchers agree on the positive outcomes of cooperative learning, there exist different views on the conditions of cooperative learning that can affect student's achievement. Slavin (1990) have identified four theoretical approaches on the achievement affects of cooperative learning as motivationalist; social cohesion; cognitive-developmental; and cognitive-elaboration. Figure 2.3 shows a path model of cooperative learning processes adapted from Slavin (1990). The figure depicts the functional relationship among the theoretical approaches with cooperative learning. The model begins with a focus on goals of a group that is based on the individual learning of all group members. It assumes that motivation to learn, help other group members activates cooperative behaviors that consequently results in enhanced learning.

Reviews of research on a wide variety of courses have found the effectiveness of cooperative learning for secondary and elementary reading (Slavin et al., 2008; McCulloch and Crook, 2013; Slavin et al., 2009a) and mathematics (Slavin and Lake, 2008; Slavin et al., 2009b). In a national survey of the United States (1990), it was found that 79% of elementary school teachers and 62% of middle school teachers used the cooperative learning technique regularly with their students (Puma et al., 1993). Similarly, Antil et al. (1998) found that 93% of elementary school teachers from six schools and two districts in the States reported the daily use of cooperative learning in various courses to achieve academic and social learning goals. Overall, there might have been hundreds of cooperative learning studies focusing on a range of outcomes, including achievement, attitude towards mainstreamed handicapped students, intergroup relations and self-esteem (Rohrbeck et al., 2003; Webb, 1982; Slavin, 1990; Johnson and Johnson, 1987).

4. **Collaborative learning or Peer collaboration**

   Collaborative learning is an approach whereby two or more participants work together to learn or attempt to learn something (Dillenbourg, 1999a; Dillenbourg and Schneider, 1995). Some researchers have referred the term *collaborative learning* as peer learning and teaching but the range of its applications is broad without clarity (Boud et al., 1999). The learning task involves students working together to complete a single, unified and joint collaborative task such as *curriculum course, assignments* or a problem-solving task. All the participants have approximately same level of competence and work jointly at all times (Damon and Phelps, 1989). Dillenbourg (1999a) further elaborated the *collaborative learning* as a situation where there is no guarantee that a particular form of

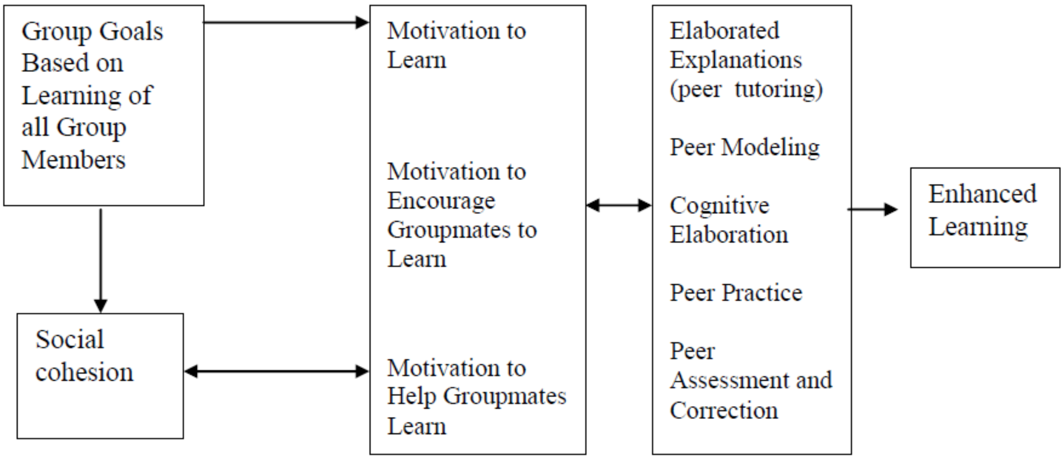


Figure 2.3 – Integration of Theoretical Perspectives on Cooperative Learning Effects on Learning (Slavin, 1990) (*Adapted).*

interaction would occur among the participants; however, he suggests four variables to increase the probability of the expected interactions by: (1) setting-up initial conditions (*e.g.*, group size, division of group based on gender); (2) including role-based scenario (*e.g.*, assigning roles to the participants during argumentation); (3) including interaction rules (*e.g.*, feedback from each participant); and (4) Monitoring and regulating the interactions (*e.g.*, providing needed pedagogical intervention through a facilitator). The ideal situation give rise to mutual discovery with rich engagement, reciprocation of feedback and frequent sharing of ideas (Damon and Phelps, 1989).

Researchers have used collaborative and cooperative learning approaches as synonyms to each other (Romney, 1997; Chung, 1991). Johnson and Johnson (1989) and Panitz (1999) pointed out the numerous benefits of collaborative learning approach and can be classified into three major categories such as social, psychological and academic (Laal and Ghodsi, 2012). The social benefits cover social support system for learners; positive atmosphere for modelling and practicing cooperation; and developing learning communities. Additionally, the approach has psychological advantages such as increase student's self-esteem, reduces anxiety and develops positive attitudes towards teachers (Johnson and Johnson, 1989; Panitz, 1999). Further, it encompasses numerous academic benefits including critical thinking skills, active involvement, problem-solving techniques and enhanced motivation in a specific curriculum (Gokhale, 1995). Besides, computer-assisted collaborative learning (Koschmann, 1996) has been widely accepted by current educational system and promise tremendous aid to student's learning (Dillenbourg, 1999a). Alavi (1994) explored how the use of group decision support system in computer collaborative learning situation can enhance college student's learning and classroom's experience. Exploiting the approach, Hurme et al. (2006) examined metacognition with secondary school children of 13 years of age to support their problem solving task in a Geometry course. The students used knowledge forum learning environment

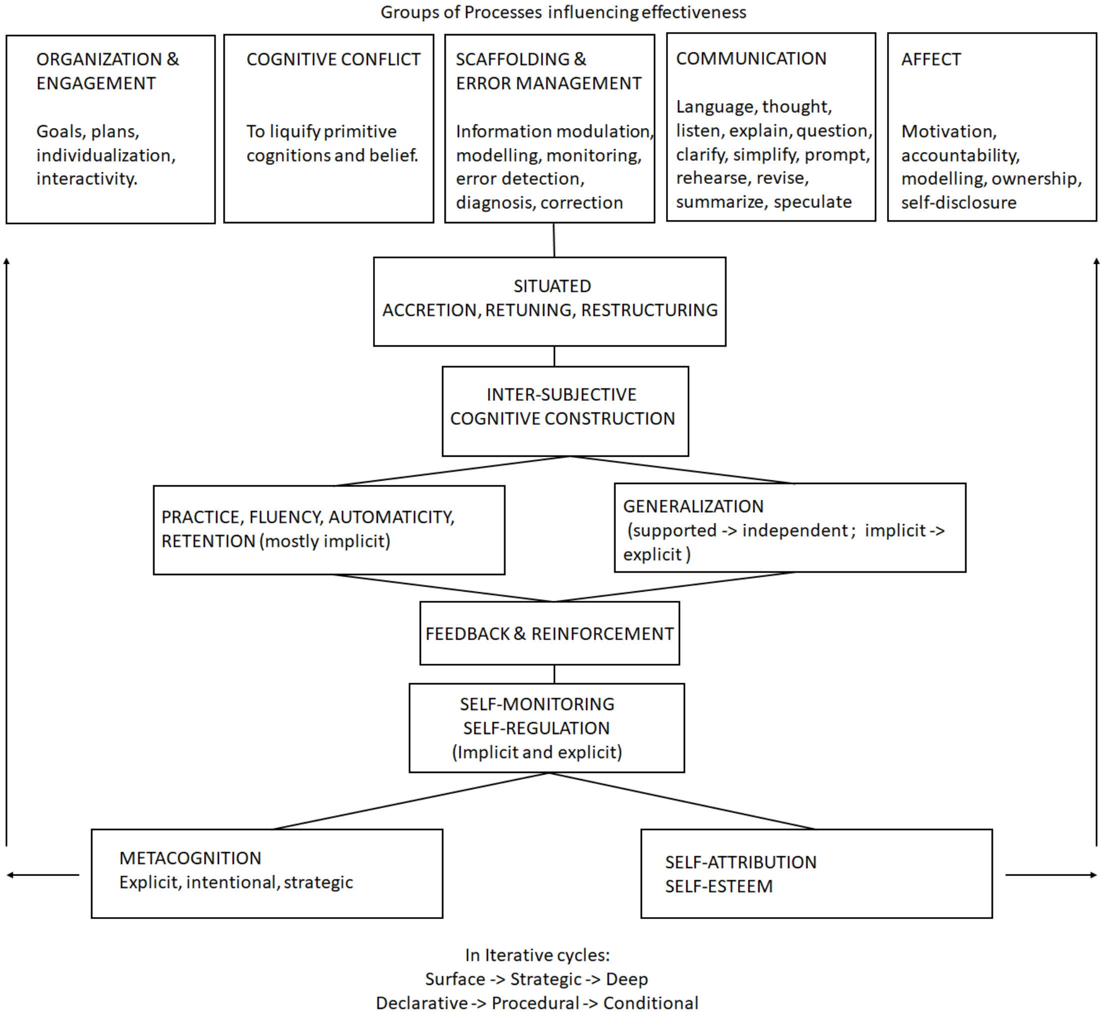


Figure 2.4 – Theoretical model of peer-assisted learning (Topping and Ehly, 2001)(*Adapted*).

and the result revealed that the metacognitive activity varied among participants and found related to the features of interaction. Educators have investigated the factors of academic motivation in collaborative learning situations. For example, Yang et al. (2006) and Järvelä et al. (2008) explored the dynamics of student's academic motivation, self-efficacy and social ability in a collaborative online learning scenarios.

2.2.3.1 Peer Assessment

Topping (1998) defined *peer assessment* as "*an arrangement in which individuals consider the amount, level, value, worth, quality, or success of the outcomes of learning of peers of similar status.*" The term assessment is often refer to grading, evaluating and rating and likewise, peer assessment refers to a method when peers evaluate, grade or rank each other's performance. Both formal and informal peer assessment exists, formal assessment includes amount, level, value and quality of learning outcomes contributed by each member of the group (McLuckie and Topping*, 2004). Furthermore, *Peer feedback* is defined as "a communication process through which learners enter into dialogues related to performance and standards (Liu and Carless, 2006)". However, peer assessment may include peer feedback and they both allow students to take an active role in self-learning (Liu and Carless, 2006). Additionally, they promote self-regulated learning where "students seek feedback from external sources such as peers' contributions in collaborative groups" (Butler and Winne, 1995); and develop objectivity in relation to standards while providing feedback on their peers (Nicol and Macfarlane-Dick, 2006). Peer feedback can empower students in self-assessing. Boud (2005) relates self- and peer-assessment as "the defining feature of self-assessment is that the individual learner ultimately makes a judgement about what has been learned, not that others have no input to it". Falchikov and Goldfinch (2000) performed a meta-analysis of 48 quantitative peer assessment studies that compared teacher and peer remarks. The results indicated that in terms of reliability, peer assessment resembled more closely to teacher's assessment. There also exist opposition to peer assessment practices. For example, Boud (2000) argues that"many forms of peer assessment are ineffective. These are processes in which peers are used as surrogate assessors to generate grades." Although, there have been arguments about the validity and reliability of peer assessment, peer feedback seems to have substantial support in the literature compare to peer-assessment (Liu and Carless, 2006; Falchikov and Goldfinch, 2000).

	Peer Tutoring	Reciprocal Peer Learning	Cooperative Learning	Collaborative Learning
Equality	Low	High	High	High
Mutuality	Varied	High	Varied	High
Participant's Status	Unequal	Equal	Equal	Equal
Participants Initial knowledge level	Tutor- high Tutee- low	Roughly same	May differ	May differ
Joint Effort	Varied	High	High	High

Figure 2.5 – Learning Approaches (Damon and Phelps, 1989; Philp et al., 2013)(*Adapted*).

2.2.3.2 Comparisons Between the Peer-based Approaches

Researchers have identified these different types of peer-based learning approaches that are commonly used in educational settings (Damon and Phelps, 1989; Damon, 1984; Philp et al., 2013; Boud, 2001; Boud et al., 2001; Keppell et al., 2006). Topping and Ehly (2001) presented a theoretical model of peer-assisted learning that includes five major sub processes such as organisation, cognitive conflict and affect as shown in Figure 2.4. The cited researchers believed in the potential of the approaches and, therefore, compared them based on various factors. For instance, Damon (1984) compared the *peer tutoring* and *peer collaboration* learning strategies based on the theoretical viewpoints of psychologists, specifically, *Vygotsky and Piaget.* The author suggested that both the strategies bring their different motivational and cognitive benefits; however, peer tutoring is mostly beneficial for transmitting information and peer collaboration for acquiring basic concepts and intellectual discovery. In continuation in his research, he later compared the *peer tutoring, peer collaboration* and *cooperative learning* approaches on the two dimensions of peer engagement *i.e.equality* and *mutuality*. He explains that the peer tutoring situation differs from cooperative learning and collaborative learning in terms of the roles given to the participants. In the peer tutoring situation, the tutor holds more knowledge and status compared to the tutee and, therefore, it is low in equality compared with the other approaches. However, he believes that all the approaches vary in terms of mutuality (Damon and Phelps, 1989). The comparison on these engagement indexes are shown in Figure 2.5. Similarly, the *reciprocal peer learning* and *peer tutoring* approaches have also been compared based on the role of the participants. For instance, Boud et al. (1999) explains that in the reciprocal peer learning situations, both participants acts as a teacher and a learner. While in the peer tutoring situation, there is a clear, unambiguous and consistent differentiation between the teaching and the learning role among the participants. The comparison of different learning approaches on the factors like equality, mutuality, status, initial knowledge level and joint effort is summarised in Figure 2.5

Summary

All the above-mentioned peer-based approaches have their own benefits for student's learning. Although, there are conflicting viewpoints about the best way to implement these approaches; nevertheless, the common denominator between all the approaches is reliability on interaction. Through discussion, argumentation, feedback, assessment and debate, the participants work out solutions to problems. In addition, they motivate one another to acquire new knowledge and generate constructive feedback that improves their reasoning abilities. Therefore, they are often compared with self-learning and traditional way of learning (teacher-student) methods. Moreover, in this thesis, we rely on the reciprocal peer learning and peer tutoring approaches in a dyadic scenario whereby same age children perform a collaborative task. The collaborative task is related to handwriting where they demonstrate English letters and words by writing. Regarding the learning environment and medium, we chose the school settings and used both paper and digital medium.

In the context of the research, one of the goals is to explore how the integration of a robot in an educational scenario with children can maximise their learning. In the next section, we will focus on child-robot interaction in the context of educational research. Particularly, we will look on different variables that make the educational child-robot interaction more versatile. Additionally, we will briefly study design and evaluation of child robot studies in educational context.

3 Related Work

This chapter covers the related work on child-robot interaction in an educational context. First, we briefly introduce the emergence of child-robot interaction specifically in the social context within the field of Human-Robot Interaction. Then, we present a comprehensive review based on different variables that mostly cover the educational robotics and discuss the effect of these variables in child-robot studies. Further, we highlight the concepts related to design, testing and requirements of child-robot educational studies. Finally, we briefly discuss the common evaluation variables in child-robot studies.

3.1 Child-robot Interaction in Education

In 1920, Karel Čapek, the Czech writer first coined the name 'robot' to a fictional humanoid in his play called R.U.R (Rossumovi Univerzální Roboti). Thereafter, the word 'robot' introduced to the English language and fictional stories. With the rapid advancement in technology, the robots passed the fictional world and reached to industries where they were initially used to perform repetitive and structured tasks. As robots become more autonomous, they have started to collaborate and cooperate with humans in task of higher complexities. As a consequence, this idea of collaboration between human and robots lead to a new endeavor of Human-Robot Interaction (HRI), the study of how humans interacts with robots. HRI can be defined as "the study of the humans, robots, and the ways they influence each other" (Fong et al., 2003). It is a multidisciplinary field where it borrows principles and concepts from different domains such as computer science, engineering, social sciences, and humanities. The fundamental goal of HRI is to develop the principles and algorithms for robot systems that make them capable of direct, safe and effective interaction with humans (Feil-Seifer and Matarić, 2009). Subsequently, it opens the door to explore how humans perceive and adapt with robots in social context.

Within the field of Human-Robot Interaction, social robots can positively contribute in a range of human-centered activities such as helping elderly, therapeutic aids, educational tool for children and so on. However, the way adults and children interact with a robot is different because children possess different and immature cognitive development (Belpaeme et al., 2013). Compared to adults, children react briskly and strongly to robots (Ros et al., 2011) that makes child-robot interaction (cHRI) inherently even more social (Salter et al., 2008). As a result, human-robot engagement is more effortlessly achieved with younger children compared to adolescents and adults (Ros et al., 2011). Usually, children not only perceive a robot as a tool or a toy but attribute living characteristics to it (Salter et al., 2008; Belpaeme et al., 2013). Pretend play and athropomorphisation are relevant variables in understanding the reason why children treat robots as life-like agents (Turkle et al., 2006; Belpaeme et al., 2013). In fact, their propensity to anthropomorphise is stronger at the age of three (Berry and Springer, 1993).

> *Child-Robot Interaction might be fundamentally different from Adult-Robot Interaction: children are not just small adults. Their neurophysical, physical and mental development are ongoing, and this might create entirely different conditions for HRI to operate in.*
>
> -Tony Belpaeme (Belpaeme et al. (2013))

Robotics is a multidisciplinary field and educators see it offering new benefits to education at all levels (Johnson, 2003a). Besides, general public and children find it fascinating and motivating, so it is socially meaningful to utilise it in education (Riedo et al., 2012). *Seymour Papert*, a founding father of educational robotics, envisioned a different approach to support classroom learning that he named as *"Constructionism"*. The theory of Constructionism can be seen in opposition to the traditional style of learning- "Instructionism" where the transfer of knowledge occurs in a top-down or one-way manner (from a teacher to a child). He believed that by providing children control over technology and personalised learning media would allow them to learn effectively by searching and finding the knowledge, and could be used as a new learning style (Papert, 1980, 1993). In mid-1960's, he developed a programming language called LOGO that is now widely used in many schools (Papert, 1980). Additionaly, for introducing the concepts of Geometry to elementary school children, he further developed a programmable computer sketching device called "LOGO Turtle" (Papert and Harel, 1991).

Other researchers have also identified several advantages of using robots in education. For instance, students gain functional level of understanding and abstract concepts by testing scientific and mechanical principles with the robots (Nourbakhsh et al., 2005); unlike finding a single solution for a real-world problem, that their class-teacher wants, robotic education enables them to creatively find multiple possibilities (Beer et al., 1999); and it fosters childrens' critical-thinking skills (Beer et al., 1999) instead of rote learning (Chiel, 1996). While building a robot and controlling its behavior, children see the robot as toys (Mauch, 2001) that provides the possibility of creating their own customised robot. This process does not only enrich their knowledge and learning but also seems to provide entertainment (Barker and Ansorge, 2007).

3.1.1 Variables in Educational Child-robot Interaction

In educational robotics, the use of robots raises various questions such as (1) *what types of robot's embodiment are used for children's learning?* (2) *What are the learning domains in educational robotics?* (3) *What are the roles assigned to robots in child-robot learning scenarios?* (4) *What are the behaviors employed to robots?* (5) *What are the techniques to control a robot during the interaction?* (6) *Which pedagogical theories can be applied in an interaction between a student and a robot?* (7) *How do participants perceive the robot and how their perceptions affect their own learning?* The identified questions are classified as variables in the domain of educational child-robot interaction. A comprehensive review by Mubin et al. (2013) about the use of robot's in education also identified these questions and presented similar dimensions of educational robotics. However, our classified variables provide an extension to Mubin's review. We now present the details of the variables as follows:

3.1.1.1 Types of Robot's Embodiment

> "Robots provide an embodiment and the ability to add social interaction to the learning context and hence an advancement on purely software-based learning"
>
> -Omar Mubin (Mubin et al., 2013).

In the context of learning, the embodiment of robot plays an important role. The range of educational robots lies between low-price single functional kits, to multi-functional mechanical kits, to high-price humanoid robots (Mubin et al., 2013). However, the use of an educational robot in a learning activity depends on the type of learning it could provide, for example, learning about mechanics and electronics, programming, science, health education, social interaction and so on. The concrete type of robots can vary from visual agents to tool-kits to humanoid robots. For instance, the uni-functional educational robots could illustrate one single mechanical flexibility (*e.g.*, OWI-9910 Weasel (McComb)); however, as the mechanical and electronic flexibilities increase, the robots become multi-functional (*e.g.*, Boe-Bot from Parallax (Lindsay, 2004), LEGO Mindstorms (Bagnall, 2002; Klassner and Anderson, 2003) and Nao humanoid robot[1].

It has been shown that adding social aspects to a robot can influence student's learning (Mubin et al., 2013; Shimada et al., 2012; Saerbeck et al., 2010). "Social robots have the potential to boost student's learning and may be used to supplement existing teaching structures to provide additional support to children" (Baxter et al., 2017). However, a significant amount of studies have used different embodiments of social robots to explore children's learning, engagement and interest with the robots (see Figure 3.4) Among several embodiments, the humanoid robots are one of the most popular as they give a strong impression to the users; can easily attract attention and almost mimic human behavior (Kanda et al., 2004a; Li et al., 2009; Lee and Lee, 2008).

[1] https://www.ald.softbankrobotics.com/en/robots/nao

(a) (b) (c) (d)

Figure 3.1 – Humanoid robots: (a) Nao; (b) Robovie; (c) Irobi; (c) QRIO.

In a study by Kanda et al. (2004b), two humanoids robots (**Robovie 1 and Robovie 2**, see Figure 3.2b) were placed at the corridor of classrooms of 6 to 7 and 11 to 12 years old children. The robots acted as social partners and peer tutors in a 2-week field trial with the aim of encouraging children to learn English words. The robots used wireless identification tags and sensors to identify and interact socially with students. The results suggests after the first week of interaction, most of the children lost their interest in the robot. However, the children who kept interacting with the robot could form relationship with the robot and improved their English skills. Motivated by the results of this study, the authors conducted a subsequent study again using the humanoid robot, Robovie with added capabilities such as calling children by their name using RFID tags, adaptation of interactive behavior according to each child's interaction and ability to confide personal matters with children. The aim of the study was to investigate the social interactions between the robot and children of 10 to 11 years of age for two months (Kanda et al., 2007). However, the study focused on the development of relationships between the robot and children, and did not focus on the children's learning outcomes. The results of the study revealed that the children who treated the robot as a peer-friend established friendly relations and continued interactions for the entire two months.

Furthermore, Tanaka and Matsuzoe (2012) used the **NAO**[2] humanoid robot (see Figure 3.2a) as a care-receiving interactive agent with 3-6 years old Japanese children to promote their spontaneous English learning. In their work, children teach the robot through a learning by teaching mechanism and results suggested that the care-receiving robot contributed to the enhancement of the children's spontaneous learning and motivation. Likewise, Han et al. (2008) used a companion robot, called Irobi (see Figure 3.2c) that can be used as both an educational and home robot. In their study, the robot was specifically designed for tutoring English language as a foreign language to Korean children. The aim was to promote children's concentration, interest and accomplishment in English learning. The results suggest that the robot proved effective in children's learning, concentration, learning interest and academic

[2]https://www.ald.softbankrobotics.com/en/robots/nao

(a) (b) (c)

Figure 3.2 – Other examples of social robots: (a) Wany; (b) iCat; (c) Keepon.

achievement.

Unlike the use of humanoid robots, Salter et al. (2004) carried out a study in the noisy school environment to explore patterns of interaction between children and a commercial wheeled robot called **Wany**[3]. The robot was capable of showing social behaviors by wandering and avoiding the obstacles. It was equipped with 15 infrared sensors to record the children's interactions. Five to eight years old children interacted individually five times with the robot for about 5 minutes. The results suggests that the children lost their interest after the third interaction. Due to this reason, the authors performed two modifications in the robot: addition of artificial eyes to the robot and speeding up the robot. Even after performing the modifications, the children did not seem to engage with the robot. The overall results clearly show the importance and effect of multi-session studies on children's engagement and interaction with the robot. Kozima et al. (2009) conducted a similar study to investigate the interaction between toddlers and **Keepon**[4], a small creature-like robot designed to interact through a wide range of simple, natural and non-verbal behaviors such as eye contact, emotions and stationary movements. A group of 27 children in the age of three to four years interacted with the robot in their playroom during 90 minutes for 20 sessions. The results suggests that the children did not loose their interest in the robot even after the 20 sessions. Additionally, children's perception of the robot changed over time, from a 'moving object' to a social agent.

Some researchers focused in investigating children's behavior and their perception of robot's social presence during the interaction. For instance, Tanaka et al. (2007) undertook the longitudinal study with the aim of exploring the toddlers behavior and engagement with **QRIO**, a humanoid robot for sustained period of time. The toddlers between the age of 18 to 24 months interacted with the robot during 45 minutes for 45 sessions spanning five months. The robot was capable of exhibiting several behaviors including choreographed dance movements, in addition, two inanimate toys were also placed along with the robot. The interaction in the

[3] http://www.wanyrobotics.com/
[4] http://www.mykeepon.com/

(a) (b)

Figure 3.3 – Toolkits: (a) LegoMindstorm; (b) RobotisBioloidKit.

study was divided into three phases with a varied robot's behavior. The results showed that the interaction improved over time and by the end of the third phase, the children treated the robot as peers rather than merely a toy. Additionally, the children hugged the Qrio most compared to other toys. Moreover, Leite et al. (2009) studied the children's perception of social presence towards a robotic chess companion changed over time. The children between the age of five to fifteen years played an entire chess match with a **iCat**[5] robot in a chess club over 5 consecutive week (once per week). During the match, the robot showed facial expressions corresponding to the moves of the participants. The results suggests that the children's perception of robot's social presence decreased over time in terms of perceived attention, behavior and duration of time which participants looked to the robot.

Not all educational robots require social interaction and are used as a tool in schools to learn concepts in the fields like robotics, programming, electronics and so on. These types of robots can be further be divided in two categories such as assembly kits and ready-to-use kits (see Figure 3.3 and 3.5). The assembled kits are used to construct a variety of robots and other mechanical configurations. Besides, building different mechanical configurations, they also need to be programmed to exhibit different behaviors. The process of assembling, building and programming provides numerous opportunities to students to design interactive robots using gears, sensors and motors; and actively engage them by creating playful experiences (Bers and Portsmore, 2005).

The examples of such assembled kits are **LEGO Mindstorms**[6] and **Robotis Bioloid**[7]. LEGO Mindstorms is probably most popular one of the robotic platform that provides a range of resources covering areas of the curriculum from preschool to secondary school. LEGO kits include a range of sensors (touch, lights, infrared, emitters), effectors (lights, motors), building blocks and a programmable control unit that supports a plethora of programming projects. Price et al. (2003) reported that the LEGO-based robotics is extremely absorbing and enjoyable for many children and adults. In addition to its affordable size and price, they also provide engagement and playfulness. Gawthrop and McGookin (2004) stated, "the LEGO

[5]http://www.hitech-projects.com/icat/
[6]https://www.lego.com/en-us/mindstorms
[7]http://www.allonrobots.com/bioloid.html

Robot's embodiments	Robot's capabilities	References	Duration	Results
Wany	Roaming; obstacle avoidance.	Salter et al., 2004	5 sessions	The children lost interest after 3 sessions.
Robovie	Human-like expression; recognizing individuals; gesturing; English speaking; autonomous.	Kanda et. al, 2004a	2 weeks	Engagement declined after 1 week; improved children's English skills who kept interacting.
Robovie	Identifying children; calling them by name; adaptation of interactive behaviors; ability to confide personal matters.	Kanda et. al, 2007	2 months	Children perceived the robot as a peer-friend; established friendly relations; and continued interactions for the entire two months.
Qrio	Choreographed dancing, walking, gesturing	Tanaka et al., 2007	45 sessions (5 months)	Interaction improved over time; children treated the robot as peers.
IROBI	Teaching English, speaking, children's input through robot's chest touch screen.	Han et al., 2008	1 session (40 minutes)	Improved children's learning interest, concentration and learning.
Nao	Locomotion; gesturing; speaking.	Tanaka et al., 2012	2 phases (each 1 session)	Enhanced children's learning and motivation.
iCat	Facial expressions.	Leite et al., 2009	5 sessions	Robot's social perception and eye contact with the robot declined.
Keepon	Non-verbal behaviors.	Kozima et al., 2009	20 sessions	Sustained children's engagement; children perceived the robot as social agent.

Figure 3.4 – Examples of studies used a variety of robots embodiment in social and educational context.

Mindstorms kit is relatively cheap, robust, reconfigurable, reprogrammable, and induces enthusiasm and innovation in students". However, some researchers also report about its limitations: the LEGO system is modular but centralised; it allows construction with LEGO parts but generates a lot of logistics problems in classes (*e.g.*managing all small LEGO parts); and, it is easy to program but requires a computer for it (Klassner, 2002; Gawthrop and McGookin, 2004). Robotis Bioloid[8] is another robot tool-kit and can be used to construct different configurations. Thai and Paulishen (2011) evaluated robotic systems of Robotis Bioloid to use it for engineering robotic course. The evaluation included checking the control and synchronization issues with multiple controllers on a same robot. The results showed that

[8]http://www.allonrobots.com/bioloid.html

(a) (b) (c)

Figure 3.5 – Ready to use: (a) Thymio; (b) Robotino; (c) Epuck.

the systems are effective in designing projects in embedded robotics (see Figure 3.3b).

Contrary to assembled kits, ready-to-use kits are ready made in terms of basic hardware and in-built behaviors such as following a line and obstacle avoidance. These kits are used in schools to teach basic robotics and programming. For example, **THYMIO**[9] is a small mobile robot and can be used to promote children's creativity and understanding of technology Riedo et al. (2012); Kradolfer et al. (2014). **Robotino**[10] from Festo is a mobile robotic platform with an open mechanical interface and is used for educational and research purposes. Robotino runs a real-time linux kernel and is built according to industrial standards. Nan and Xiaowen (2011) used Robotino to provide experimental platforms for students. The task was to implement obstacle avoidance, programming and optimization of the robot's motion. The results indicated enhancement of student's learning about the domain and provided basis system for research project (see Figure 3.5b). **E-puk**[11] is another mobile robot that specifically targets engineering education at under-graduate level(see Figure 3.5c). To propose more project-based exercises, E-puck can be used in a large spectrum of teaching activities such as signal processing, automatic control and embedded programming (Mondada et al., 2009).

Learning with Virtual Agents

One of the common application using virtual robots in the field of education is tutoring. These computer-based tutoring systems take advantage of learning from social models by following many aspects of one-to-one human tutoring. Besides, integrating with an agent paradigm intelligent tutors gives a lot of possibilities; for example, during interaction, the agent can ask questions and raises user's sense of responsibility that consequently results in deeper learning (Chase, 1986).

Frasson and Gauthier (1990) created learning companion systems that employed three agents: the human student; the non-embodied computer learning teacher; and the non-embodied computer learner. The computer student was designed to be at the similar level as the human student. In the learning scenario, the human student would learn from computer teacher and

[9] https://www.thymio.org/en:thymio
[10] http://www.festo-didactic.com/int-en/learning-systems/education-and-research-robots-robotino/
[11] http://www.e-puck.org/

then asked to teach the artificial student. It involved two tasks: one, learning by being tutored; and second, by tutoring that is similar to the *reciprocal type of learning* (whereby students play a role of teacher and a learner). The results showed that children enjoyed teaching an agent in a problem-solving task and they felt the task as a game. Learning-by-teaching was explored further by Brophy et al. (1999) in the teachable learning project whereby the children learned Ecology by teaching to a cartoon character. The result suggested that the children who learned in order to teach the virtual agent performed better than the one who just studied for the test.

In learning scenarios, social interactions are vital as they offer possibilities and opportunities for children to learn language and communication skills (Ryokai et al., 2003). Exploiting the benefits of embedding social interactions with an agent, Ryokai et al. (2003) created a social embodied conversational agent called *Sam* to increase learning literacy. The agent's task is to tell stories collaboratively to the pre-school children and to behave as a peer to them. The results suggested that the children who interacted with the agent told stories with more quoted speech and expressions resembled to the virtual agent.

Using the learning-by-teaching approach, Biswas et al. (2005) explored the *protégé effect* on students. The protégé effect is a result of the phenomenon when students make greater efforts to teach others to perform better rather than putting efforts for their own learning. Biswas et al. (2005) worked on a teachable agent (Betty's brain-teaching agent) to test the protégé effect on students to promote their deeper learning and understanding. Their study compared three conditions: a system where a pedagogical agent taught students; a learning-by-teaching system where students taught a first version of Betty (teachable agent) while receiving the tutoring help from the mentor agent; and a learning-by-teaching system, where students taught a second enhanced version of Betty with self-regulation feature while receiving the tutoring help from the mentor agent. Results indicated that the condition with the self-regulated Betty and the mentor enhanced student's ability to learn new concepts. Moreover, Chase et al. (2009) again worked on Betty's brain and conducted two studies regarding the protégé effect (learning-by-teaching). The first study consisted of two conditions: first whereby students learned biology to teach their teaching agents; and second whereby students learned for exam (for themselves). In the second study, they used a verbal protocol to check the causes of protégé effect. Results of both the studies indicated that the students spent more time in learning when they were teaching to teaching agents. In addition, the children behaved socially and responsibly towards the agent by attributing mental states to it.

Comparison of physical and virtual embodiment's of robots

A set of studies have examined the virtual vs. physical embodiment of robots in human-robot interaction scenarios. As such, some researchers have explored the effectiveness of the physical embodiment to their virtual analogues (Looije et al., 2008; Kose-Bagci et al., 2009; Wainer et al., 2007; Kennedy et al., 2014).

Fridin and Belokopytov (2014) compared the efficacy of an embodied robot-coach (Nao robot) and its virtual agent on preschool-children to test their performance of playful motor tasks.

The study compared the two conditions: one in which children have previous experience with the embodied robot; and the other in which children did not have previous experience with the embodied robot. The results revealed that the experienced children interacted less with the virtual agent compared to the embodied one; however, the inexperienced children did not interact at all with the virtual agent. Looije et al. (2012) developed a robot companion to educate children about health questions regarding diabetes disease. The authors compared the virtual robot (Nao robot) and the real robot on the aspects of learning, attention and motivation. In the scenario, the children played a quiz game with the robot depending on the condition they were assigned to. The authors did not find any difference in the children's performance and learning regarding embodiment but they preferred and attracted more towards the real robot. Similar learning results are found in a study by Kennedy et al. (2015a), where the author compared how the embodiment of a tutor robot (Nao robot) influences the interaction with a learner child in a guided discovery learning task. The embodiment of the robot was presented as a real robot vs. virtual robot. The results suggest that although the children gazed more to the real robot, but no significant learning difference of children was found between the real vs. virtual robot.

It is remarkable that the physical presence of social robots seems to have distinct advantages over virtual mediums. Belpaeme et al. (2015b) believes that "*the reasons for these results are unclear: it might be that the social and physical presence of the robot engages the learner more than just on-screen delivery and feedback, or it might be that the learning experience is a more multimodal experience thus resulting in a richer and em-bodied pedagogical exchange (Mayer and DaPra, 2012), or of course a combination of these two.*"

3.1.1.2 Learning Domains

Research in educational robotics proves its significance in several areas of education, for example, programming; robotics; science; design and innovation; mathematics, writing, language and games. Johnson (2003a) discussed that how robotics is different from other ways of supporting learning approaches and can be used to teach multi-disciplinary courses. He emphasised that the robotics compared to other learning media covers a large spectrum of learning. Learning with social robots has also shown some advantages over other learning mediums. For instance, Han et al. (2008) investigated children's learning and compared the effects of three types of learning media with the children: non-computer based media (a book with audio-tape); web-based instruction; and a humanoid robot, IROBI as a home robot-assisted learning robot. The results suggests that the home assisted robot was superior to other learning media in several aspects. The aspects include children's concentration, academic achievement, friendliness, interest in learning. The examples of studies that used a variety of robots in several educational domains is shown in Figure 3.6. Similar results are found in an experiment by Hyun et al. (2008), where 34 children of four years of age participated in a reading task with the aim of improving their linguistic ability. The study had two conditions: in one condition, half of the children dealt with the traditional media-assisted reading program, while in the other condition, the children interacted with the humanoid robot, iRobiQ assisted reading program. The results of children's learning significantly favored the robot-assisted program.

In addition, interacting with the robots which may not engage in social aspects have also shown positive outcomes in student's learning. For example, Barker and Ansorge (2007) explains that as a robot consists of different parts such as motors, sensors and controllers, working with robots requires knowledge of different fields including science, engineering, mathematics and computer science and students inevitably acquire knowledge in these fields (Rogers and Portsmore, 2004; Papert, 1980; Papert and Harel, 1991; Papert, 1993; Beer et al., 1999). However, not all the reported studies have shown positive effects of educational robotics. For instance, Fagin and Merkle (2003) measured the effectiveness of robots in two aspects: firstly, in teaching computer science in a year-long experiment with 800 students in two conditions, robotics vs. non-robotics sessions; and secondly, in encouraging students to choose computer science or computer engineering as a field of study. The results revealed that the students who used robots significantly showed worse scores compared to the ones who did not use robots. Additionally, the use of robots did not show any effect on their choice of discipline. The researchers believed the reason for these results is due to the limitation in the implementation of the course as the course lacked a simulator for robot programming that is an important part of the learning process. Nevertheless, due to the numerous educational robotics benefits in the literature, it cannot be denied that robots have a positive potential in benefiting students. Further, we describe common learning domains as follows:

Domain	Paper	Courses (examples)	Types of robots	Role of a robot
Technology	Crisman, 1996 Horswill, 2000 Kumar, 2001 Han et al., 2008 Ferrari and Ferrari, 2011 Riedo et al., 2012	Electronics Mechanical Electrical Programming	LEGO MINDSTORMS Sony Aibo system IROBI Thymio	Tool Tutor Companion
Science	Papert and Harel, 1991 Moore, 1999 Mauch, 2001 Fagin and Merkle, 2003 Robinson, 2005 Barker and Ansorge, 2007	Physics Geometry Maths	LEGO MINDSTORMS LEGO Turtle	Tool
Second Language	Kanda et al., 2004a Han et al., 2008 Han and Kim, 2009 Alemi et al., 2014 Belpaeme et al., 2015	English	Robovie Tiro IROBI Nao	Tutor Peer-tutor Companion Teaching Assistant
Health Education	Kohlhepp,2003 Robins et al.,2005 Baxter et al.,2011 Belpaeme et al.,2012 Henkemans et al.,2013	Diabetes Hygiene General healthcare	Foobie Nao	Coach Educator Instructor Motivator Caring

Figure 3.6 – Example of studies used a variety of robots in several educational domains.

1. ***Language***

   Use of robots seems to be promising in the acquisition of a second language for children. The most common language used with robots as a second language is English, due to its worldwide usage, it needs to be taught to children in non-English speaking countries. Kanda et al. (2004a) used a humanoid robot, *Robovie* with fifth- and sixth-grade students in an elementary Japanese school in a 18 days field trial. In the trial, robots behaved as English peer tutors for the students. The results suggested that the robot was able to encourage some students to improve their English and form a relationship with them. Similarly, Han and Kim (2009) used the TIRO robot (Han et al., 2009) to teach English to Korean children.

   On one hand, a number of studies have compared the robots with other learning media in the domain of second language. For instance, Han et al. (2008) compared the effects of non-computer based media (a book with audio tape), web-based instruction and human robot-assisted learning using a humanoid robot *IROBI* for Korean children to learn English. The results revealed that the robot was superior in improving children's interest and concentration for English as a foreign language. Similarly, Hyun et al. (2008) also explored the feasibility of using intelligent robots as a language instruction tool for young children. In total, 34 children participated in the study with two conditions, comparing the robot-assisted reading program using a humanoid robot,*iRobiQ* with the traditional media-assisted reading program. The results indicated that the children with the robot improved significantly in linguistic ability such as story making, understanding, word recognition, picture vocabulary test compared with the other media.

   However, on the other hand learning with robots have also been compared with the traditional way of learning (human-teacher teaching a human-student). For instance, Alemi et al. (2014) used Nao robot in a five-week study to explore the effects of robotics-assisted language learning on the vocabulary and retention of English as a foreign language for junior high school students in Iran. The study had two conditions: a human teacher accompanied with the robot assistant giving English classes to the students vs. teaching English in a traditional way. The results of the study revealed that the students who had classes with the robot significantly improved in vocabulary and retention compared with the non-robotic condition. In addition, the human-teacher in robotic condition perceived positive reaction, efficient and pleasurable learning environment during the class.

   L2tor, called Second Language Tutoring using Social Robots[12] is a European scientific research project that aims to design a child-friendly tutor robot, also aim to support teaching second language to children. The project aims to teach English as a second language to native speakers of Dutch, Turkish, German and to teach the native languages to migrants. The robot tutor would incorporate social behaviours for child-friendly interactions and will be designed to interact with children aged four years old in both the second language and the children's native language (Belpaeme et al., 2015b).

[12] http://www.l2tor.eu/

2. ***Writing or Drawing***

   Recently, a few researchers have used robots to improve children's learning and engagement in the process of handwriting and drawing. For instance, Matsuzoe and Tanaka (2012) explored how a care-receiving robot's (Nao humanoid robot[13]) learning abilities can help children to enhance their knowledge of English words by drawing various shapes corresponding to the letters. Although, the prime aim of the study was not to teach drawing but to find out the effect of three learning abilities of the robot on children's learning. In the study, the children tutored the robot to draw the shapes under three conditions: (1) where the robot knows all the correct answers; (2) where the robot is capable of learning; and (3) where the robot is not capable of learning. The results revealed that the robot which was capable of learning, improved children's knowledge of English words. Similarly, Hood et al. (2015) conducted studies with primary children where they teach the Nao robot to write letters. The study was based on the learning-by-teaching approach and aimed to test the built system and the impact on children's engagement with the robot. The results showed that the robot could improve children's writing skills and engage them successfully.

   Using the same learning approach, other researchers have investigated children's writing skills with different levels of writing skills (Lemaignan et al., 2016). For example, Jacq et al. (2016) explored three case studies with three different children struggling with writing difficulties. The scenario involves a child who teaches handwriting to a robot and the aim is to improve the child's writing skills. The study acknowledges the right rate at which the robot must learn; neither too fast nor too slow to keep the child engaged. The results of the studies showed positive observations in terms of children's motivation, self-confidence and commitment of being a teacher. During the interaction between a child and a robot in a learning scenario, it is important to take care of the child-robot spatial arrangement as it may affect children's learning aspects.

   Besides investigating writing skills of children, Johal et al. (2016) examined the influence of child-robot spatial arrangement on the child's perception of the robot and focus of attention. The study involves a child teaching handwriting to a learner-robot in two spatial arrangements: face-to-face; and side-to-side. The results showed that the children in the side-to-side arrangement paid more attention to the robot's handwriting mistakes and gave more feedback compared to the face-to-face arrangement.

3. ***Technology***

   Technical education refers to impart knowledge primarily about learning robotics and programming, *e.g.*, constructing robots, understanding the concepts of autonomy, artificial intelligence, learning electronics and so on. Some educators have used the robots as a tool to teach actual programming languages such as object-oriented programming Java and Ada (Pattis, 1981; Barnes, 2002; Fagin et al., 2001; Fagin and Merkle, 2003; Becker, 2001). Here, the main emphasis is given to teach introductory concepts,

[13] Aldebaran robotics: `https://www.aldebaran.com/en`

structuring of programming over mechanical and electronic aspects in robotics. It has also shown in the past that creative and hands-on projects significantly increased student's motivation to learn the computing concepts when they apply the concepts in building, designing and programming the robots (Klassner and Anderson, 2003; Kumar, 2001; Beer et al., 1999; Fagin et al., 2001; Klassner, 2002; Mazur and Kuhrt, 1997; Stein, 1996; Han et al., 2008).Many schools provide and encourage this form of leaning by giving a semester or yearly course for graduate and undergraduate students (Horswill, 2000; Crisman, 1996; Kumar, 2001). For example, the Northeastern University offers a semester team-based course, wherein students learn to build a small robot for a specific task (Crisman, 1996). EPFL[14] University organises robotic festival and workshops yearly to encourage creativity and promote the understanding of technology such as building, soldering and programming to students (Riedo et al., 2012).

4. ***Science***

   Robotic activities fit well to teach scientific inquiry skills that is usually missing in traditional teaching and learning (Williams et al., 2007). Inquiry-based learning require rich context to identify, investigate problems, scientific argumentation skills, gathering and analysing data, determining and interpreting the results (Baumgartner and Reiser, 1998; Williams et al., 2007). As mentioned before, Papert and Harel (1991) developed a programmable robot called *LOGO Turtle* to teach geometrical concepts for students. The robot helped students to think and allowed them to critically relate the concepts of programming, mathematics and motion. In addition, these relations may help in building mental connections between numerical and geometrical ideas (Papert, 1993; Clements et al., 1997). Rogers and Portsmore (2004) used the LEGO material and the ROBOLAB software to incorporate various subjects like maths, science, reading, writing and engineering as an additional tool for kindergarten to graduate students. They reported successes in many aspects including the student's curiosity, enthusiasm, finding and validating answers. For example, in teaching maths, the students learned decimals (second graders), calliberation between distance and time, interpolation/extrapolation (fourth and fifth graders) and additional complexity of hardware and software (undergraduates). Moreover, a study by Williams et al. (2007) explored the impact of summer robotics camp on middle school students' physics knowledge and scientific inquiry skills. The results had shown the camp enhanced students Physic's content knowledge but did not affect their inquiry skills.

5. ***Health Education***

   Another domain whereby robots seem to be influential is health education. The aim of a healthcare robot is to provide information and improve the health and lifestyle of the human user (Broadbent et al., 2009). For instance, Kohlhepp (2003) reported that a multi-media life-size interactive robot, called "Caring Coach" and is used in elementary schools in New Jersey to teach personal, social and cognitive health to

[14] École polytechnique fédérale de Lausanne

children. The robot has taught programs to approximately 2,259,000 children over 12 years[15]. Besides, Henkemans et al. (2013) explored the effects of personalised robot behaviors on motivation and acquisition of health knowledge of children with diabetes in the age group of 8 to 12 years. The children played diabetes quizzes on three occasions: once at clinic and twice at home. The robot had two behaviors: personalised and neutral. The results suggested that the children found the quiz and the robot funny and their knowledge about diabetes was increased. Furthermore, the children gave more attention to the personalised robot compared to the neutral robot. In the ALIZ-E project[16], that aims to promote long-term interactions between child and robot in the wild, Baxter et al. (2011) investigated the long-term interaction with children (ages 8-12) having metabolic disorders. Besides exploring the impact of the robot as a companion and health trainer to the children, Belpaeme et al. (2012); Baxter et al. (2011) also presented the technical challenges involved in child-robot social interaction.

Finally, literature indicates that people with autism generally have difficulty in social communication, interaction and imagination (Robins et al., 2005). As such, researchers have been investigating how to encourage social skills of autistic people with the aid of robots. For example, Robins et al. (2005) investigated how the simple imitation and turn-taking games can encourage social interaction skills in children with autism. In the study, four autistic children were exposed to a humanoid robot over a period of several months while playing simple games. The qualitative and quantitative analysis of video data revealed that the long-term interaction with the robot increased social interaction skills of children and demonstrated the potential and need of using robots with autistic children.

3.1.1.3 Assigned Roles to Robots

Robots can take a number of roles in the learning process. The educators and researchers choose the role of a robot based on two aspects: firstly, by pursuing the pedagogical theories (*e.g.*, tutor, peer-learner, instructor/facilitator); and secondly, as a learning material or a tool. In an educational scenario, it is commonly seen that a robot either has an active role or passive role (Mubin et al., 2013). When a robot plays an active role, it interacts directly with the user; whereas, in the passive role it does not interact directly and is used as a learning material. For example, a number of studies have shown that the robots can act as a tutor equivalent to a human-teacher (Han and Kim, 2009; Han et al., 2008; Hyun et al., 2008) or as a peer tutor (Kanda et al., 2004a). Likewise, based on the pedagogical theories such as the *learning-by-teaching* theory (Roscoe and Chi, 2007; Hood et al., 2015; Tanaka and Kimura, 2010), a robot can have a role of peer learner where it acts as a learner rather than a teacher (Kanda et al., 2007; Tanaka and Kimura, 2009, 2010; Hood et al., 2015).

In the situation of peer-learning and peer-tutoring, (Zaga et al., 2015) investigated children's

[15]http://www1.gmnews.com/2003/02/27/robot-teaches-healthy-lesson-to-school-kids/
[16]http://www.aliz-e.org/

task engagement and puzzle solving skills in two conditions. In one condition, the robot acted as a peer while in the second condition, the robot acted as a tutor. The results indicate that the children seems to engage more and solve the puzzles quicker and better with the peer robot compared to the tutor robot. However, more research needs to be done to understand the role assignment specially in child-robot interaction scenarios. In a similar learning scenario, (Kennedy et al., 2015b) conducted a study where a social v. asocial robot (Nao robot) taught prime numbers to children of 7 to 8 years of age. After the interaction, the children were asked to attribute a role to the robot out of 8 available options (brother or sister, classmate, stranger, relative , friend, parent, teacher, and neighbour). The results showed that the children consistently perceived the tutor-robot as a friend. In addition, the children learning gains increased significantly with the asocial robot compared to the social robot.

Besides the roles of a teacher or a learner, robots are also used as a human-teacher assistant for providing SET and health education (Alemi et al., 2014; Broadbent et al., 2009). Furthermore, in many schools, students use a robot as tool where they build and program it. The involvement of the robot is highly useful to enhance the learning effects, although it does not participate in a direct interaction with the students (Gawthrop and McGookin, 2004; Thai and Paulishen, 2011; Riedo et al., 2012; Nan and Xiaowen, 2011; Mondada et al., 2009).

3.1.1.4 Social and Learning Behaviour Employed in Robots

Since child-robot interaction is inherently social (Salter et al., 2008), it becomes crucial to investigate different aspects of the social relationship between robots and children. A number of aspects related to social behavior are being explored such as empathy, communication, attention building and personalization. For instance, Saerbeck et al. (2010) compared neutral and social behaviours of an 'iCat' robot that teaches language to children. The authors chose five aspects of social behavior to distinguish between the two above-mentioned behaviors: role model; nonverbal feedback; attention building; empathy; and communicativeness. The learning of the children was evaluated and the results indicated that the social robot enhanced and supported more in children's learning compared to the robot with neutral behavior. Similarly, Henkemans et al. (2013) investigated the effects of robot's personalised vs. neutral behavior on children with diabetes regarding their motivation and acquisition of health knowledge. The results suggested that the children interacted, mimicked and acquired health knowledge more with personalised robot. Additionally, the personalised robot was able to get more attention from them in terms of talking and gazing. In the same line, Baxter et al. (2017) conducted a 2-weeks study to access the effect of personalization and adaptation of robot's social behavior. The scenario had two conditions: the interaction involved a robot with personalized behavior to interact and teach primary school children; and the other interaction happend with a robot without the personalised behavior. The EMOTE project[17] addressed the role of empathy in educational robots, using a multidisciplinary approach (Jones et al., 2015). In this project, a robotic tutor with empathetic qualities is used to assist and engage learners

[17] www.emote-project.eu

in several topics such as sustainability and map-reading (Sequeira et al., 2016; Castellano et al., 2013). The results suggested that the children learned in both conditions but the children accepted more the personalised robot.

All these studies have shown positive outcomes in children's learning, but embedding social behaviors in robot does not always lead to success. For instance, Kennedy et al. (2015b) studied two different behaviors of a tutor robot: social vs. asocial behavior, in a scenario where children learned about prime numbers. The differences between the two behaviors included four variables: robot's verbal dialogues; gestures; gaze; and personalization. The results indicated that the tutoring strategy with the robot itself lead to significant improvement in the children's learning. However, the children with the asocial robot learned more compare to the social robot. Therefore, the results suggested that precaution is necessary in designing the social behavior of a robot. Besides the exploration of social behavior with a robot, Matsuzoe and Tanaka (2012) investigated robot's different learning behavior on children's learning. The study had three conditions: one with an excellent robot that knows all the answers; second with a robot that is capable of learning; and third with a robot that was not capable of learning. In the scenario, the Japanese children attempted drawing some shapes along with the robot, the shapes were associated with an English word. The results indicated that the children with robot that was capable of learning learned more compared to other two conditions.

3.1.1.5 Techniques to Control Robots

Generally, the human-robot interaction studies use three types of approaches to control a robot: (1) Wizard-of-Oz (Kelley, 1984), semi-autonomous and autonomous. The semi-autonomous studies may have a wide range but the most common method to control a robot in human-robot interaction studies is Wizard-of-Oz (WoZ) (Kelley, 1984). The Wizard in the name refers to a person who remotely operates a robot to control it's one or more functionality such as gestures, speech, navigation and movements (Riek, 2012). Usually, the participants in WoZ studies are unaware of this functionality and the Wizard is often hidden to the participants. Researchers use the method due to several reasons, for example, one of the reasons is due to the insufficient advancement in robotic technology, such as robust speech recognition, accurate detection/recognition of objects in the environment (Okita et al., 2011) and natural communication, especially, human-human like interaction. The other reason may be that the WoZ method allows researchers to envision future advancement in human-robot interaction (Riek, 2012). Although the WoZ method is widely used, some researchers have raised ethical and methodological concerns regarding the method. For instance, Miller (2010) and Riek and Watson (2010) discussed ethical problems like social deception, regarding the wizard (remote controller of a robot) who masquerades participants as the participants do not know with whom they are interacting with. Similarly, Weiss (2010) raised the methodological issue that the WoZ serves as a proxy that cannot be stated as human-robot interaction because in reality, it is human-human interaction via the robot. In the context of educational human-robot interaction studies, one of the disadvantage with WoZ method is its dependency on the wizard, as such the successful studies would be difficult to repeat with students/users as it would always need a wizard to control the robot. However, the benefit of reporting WoZ studies cannot be denied as they provide the potential of using educational robotics for the near future generation.

On contrary to WoZ, a robot's autonomous capability refers to "a robot's ability to accommodate variations in its environment" (Thrun, 2004). The author further stated that the degrees of autonomy vary in different robots and human robot interaction cannot be studied without considering the robot's autonomy. The robot's autonomy determines different tasks and their levels, that the robot can perform at. For example, Kanda et al. (2007) used a humanoid robot, Robovie, embedded with the sensory equipment like auditory, tactile, ultrasonic, and vision sensors, that allow the robot to interact with children autonomously. Each child was given a radio frequency identification tag, so the robot was able to identify more than one child. Bartneck and Hu (2004) indicated the need of autonomous control over WoZ approach. They stated that the WoZ technique sometimes lead to over smartness of robots than they should be.

3.1.1.6 Pedagogical Theories Practiced in Child-robot Interactions

The literature suggests that before the inception of educational robotics, a few pedagogical theories have been adopted by educators to foster children's learning. As the use of robots has become prevalent in schools, the same pedagogical theories are either directly applied or improvised or adapted in human-robot interaction scenarios. For example, the theory of "constructivism" by Piaget and Inhelder (2008) suggests that humans acquire knowledge by experiencing things and construct their own mental model of understanding based on their previous knowledge and experience. Inspired by him, Papert and Harel (1991) coined a new theory called "constructionism" in the field of robotics where he suggests that when children build and program a robot, they take over the control of technology that in turn helps them to reflect on their problem solving skills and motivation. He further differentiated the difference between the Piaget's *constructivism* and his theory *constructionism*- "*Constructionism–the N word as opposed to the V word–shares constructivism's connotation of learning as "building knowledge structures" irrespective of the circumstances of the learning. It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe"*. Similarly, Kafai and Resnick (1996) also discussed the application of constructionism where constructing artifacts can lead to deep involvement in student's learning. The Lego toolkit is one of the examples based on this theory and has been well accepted by various schools (Kabátová and Pekárová, 2010; Álvarez and Larrañaga, 2016)

By following the traditional way of teaching students, robots have been used as tutors, teaching assistants or instructors in a range of courses, from teaching second language to the concepts of geometry (Han and Kim, 2009; Hyun et al., 2008; Henkemans et al., 2013; Robins et al., 2005). Different from the traditional teaching, peer-assisted learning theories such as *peer* *tutoring*, *cooperative* and collaborative learning theories were also tested and explored with children (Boud et al., 2001; Keppell et al., 2006; Topping and Ehly, 2001; Damon and Phelps, 1989; Topping, 2005; Dillenbourg, 1999a) without integrating the robot. Later the same theories have been applied in human robot interaction scenarios to seek new learning methods (Kanda et al., 2007; Tanaka and Matsuzoe, 2012; Hood et al., 2015; Biswas et al., 2004a, 2005; Matsuzoe and Tanaka, 2012). However, when the theories are applied integrating a robot, the robot may play an active and passive role in the scenarios, such as a learner(young/peer), peer tutor, facilitator and so on.

The theory of *active learning* (Freeman et al., 2014; Michael, 2006; Harmin and Toth, 2006)- "*learning promoted by interacting with one's environment*" (Linder et al., 2001) in contrast to lectures (a traditional way of teaching) is highly effective to develop students' capability to acquire knowledge. The active learning enhances students' motivation and learning gains through the process of querying, finding and creating possibilities to a problem. One of the robotic tool that is used to promote active learning is Lego Mindstorms (Papert, 1980).

The other theory that stems out from the theory of constructionist is *learning by making* and *learning by design* (Goldman et al., 2004; Fessakis et al., 2008), which promote hands-on approaches to motivate and attract students. These theories are apt in the field of robotics because working with most of the robots either requires to program or physically manipulate them in the process of learning (Klassner and Anderson, 2003; Gawthrop and McGookin, 2004; Kafai and Resnick, 1996).

3.1.1.7 Children's Perception of Robots

Instead of exploring the benefits of using a technology to enhance student's learning, some studies were focused on examining the learner's perception towards using the technology. For example, Petre and Price (2004) conducted observations and interviews with primary and elementary school children (age-group 6-18) attending Robotcup and RoboFesta competitions. The results indicated that the children found robotics stimulating and motivating; and they benefited in terms of teamwork, programming, problem-solving, electronics during the process of building and controlling the robots. In addition, the children learned the principles and concepts of engineering and programming that they previously considered difficult and inaccessible. Similarly, Nourbakhsh et al. (2005) gathered self-report data from high-school students who attended a summer 7-week, full-time course named 'Robotic Autonomy'. The course included hands-on approach from building to navigating to teleoperating robots. During the course, they performed initial, weekly and final surveys to track the success of the course and students' perception of their own learning regarding 6 themes in the course: mechanics, programming, teamwork, problem-solving, robot point of view and self-identification with Science and Technology. The overall results indicated that the course was effective and interesting for the students. Moreover, the initial expectations of the students were to learn only programming and mechanics, but in the final survey, they reported that they also learned the other four aspects.

Moreover, Bhamjee et al. (2010) examined young children's perceptions, interpretation of robots and robot behavior. Children between the age of seven to eight years participated in a study which included two phases. The first phase involved 144 children where they were asked to draw a picture of a robot and write a story about it. In the second phase, a small groups of children out of 90 children observed four 'e-puck' robot (described in Section 3.1.1.1) which were interacting in an arena. Then the children were asked three questions: (1) 'what do you think the robots are doing?'; (2) 'Why are they doing these things?' and (3) 'What is going on inside the robot?'. The overall results suggests that the children attributed animate as well as mechanical characteristics to robots and carry multiple understandings of robots simultaneously.

The studies that incorporate interactions between children and humanoid robots are also believed to engage and motivate students (Tanaka and Matsuzoe, 2012; Rohrbeck et al., 2003). For example, Kanda et al. (2004b), used Robovie, a humanoid robot, as an English peer-tutor for Japanese students and concluded that the robot encouraged some of the students to improve their English and form relationships with them. Similarly, Hood et al. also found that the Nao robot[18] was able to improve children's writing skills and engage them successfully Hood et al. (2015). However, *how do the children perceive these robots? How do these perceptions change over multi-session interactions? Do the children's perceptions affect their own learning?* Children's perception towards a robotic agent is related to several aspects such as the robot's role, physical or nonphysical behaviour, and appearance and indeed seems to be relevant in child-robot interactions (Kahn Jr et al., 2012; Okita et al., 2005). In fact, Beran et al. (2011) interviewed 198 children of 5 to 16 years of age after they observed a robotics arm with 5degrees of freedom that performs the block stacking task. The results indicate that a significant proportion of children were able to ascribe behavioural, cognitive characteristics to the robot. Likewise, Woods (2006) explored attitudes and feelings of 159 children of 9 to 11 years of age towards the designs of 40 robot images regarding robot's appearance, dimensions of robot's personality and robot's emotions. For each image, the children completed a questionnaire and the results revealed that children perceived the robot's intentions (friendly vs. unfriendly), capabilities and emotional expression based on it's appearance. Additionally, they perceived the human-like robots as aggressive and human-machine robot's as friendly.

Unlike the previous studies where the children provided their perceptions after observing the robot, Hyun et al. (2010) conducted a study where the children directly interacted with a robot. The author interviewed 111 five-year old children to explore their social, educational and moral perceptions towards a iRobiQ robot. The robot is capable of moving its head, arms and express emotions through lights. It interacted for an hour with the children over a period of two weeks. The interview questions consisted of 50 items under three categories, including comparison with other media, a perception survey, and the appearance of the robots. The results indicate that the children's social and educational perception of the robot was higher when it was placed in the classroom compared to hallways or office. In a study by Kahn Jr

[18]Aldebaran robotics: `https://www.aldebaran.com/en`

et al. (2012), where 90 children of nine to twelve years of age verbally and physically interacted with a 'Robovie' robot for approx 15 minutes. By the end of each interaction, an experimenter interrupted the participant-robot's interaction and put the robot in the closet. With the aim to investigate children's social and moral perceptions towards the robot in the described situation, the results showed that a majority of the children believed that the robot had mental states and was considered as a social being. Besides, when children learn in a situation where a robot acts as a tutor, the children's perception of the robot is not constant over multiple interactions. For instance, Alves-Oliveira et al. (2014) studied how children between 13 to 15 years of age perceived the role of a tutor robot with emphatic behaviour over a period of two months. The author found that the role assignment in educational HRI is a dynamic process and children's perception of the role of the robot in the study (*e.g.*. classmate, stranger, friend relative) changed over time.

Although there has been significant research on children's perception of robots, less attention has been paid to how children perceive the abilities of a robot in educational scenarios in long term interactions and how their perceptions affect their learning outcomes, particularly when the robot plays a particular role.

Summary

We have studied diverse aspects related to robots when integrated in education with children and classified seven variables such as type of robots, learning domains, role, behavior, experimental techniques to control robots, pedagogical theories, and children's perception of robots. Our classified variables together describe the innumerable number of applications and research done in the domain of educational child-robot interaction. In the context of our research, we describe the six variables used in the dissertation as follows:

1. **Type of a robot:** As the prime aim of our research is to explore how a social robot can benefit children's learning in the acquisition of handwriting skills; we wanted to use a child-friendly robot which can help children in learning handwriting using natural communication skills and sitting arrangement. For these purposes, we preferred a physical robot, over a virtual agent because of two reasons: 1) handwriting is a physical task that includes both motor and perceptual abilities. We believe that an impact of a physical robot exhibiting motor tasks would be more compared to a virtual agent; 2) the physical presence of a robot can socially benefit more to children compared to a virtual agent. In our experimental research, we chose Aldebaran's Nao humanoid robot due to its approachable design and commercial affordability (Gouaillier et al., 2008). Aldebaran's Nao is a biped autonomous robot, .57m tall, with 25 degrees of freedom, two cameras and speech capabilities. Additionally, due to its modular and lightweight design (4.5kg), it is suitable for close interaction with children.
2. **Learning domain:** In the context of our research, we consider educational activities targeting only handwriting tasks. Therefore, we designed writing activities considering

the target age-group of participants and research goals.

3. **Robot's role:** In the literature, robots has been seen to play a role of an instructor, tutor, assistant and learner in educational scenarios with children. In our conducted studies with children, we examine active roles of a robot where it directly interact with participants. Therefore, we attributed general role to robot as a peer-collaborator, more specifically, we investigate two different roles of the robot: one is a *facilitator or instructor* and the other is a *peer-learner.* These roles are given in different learning situations to further explore their effect on children.

4. **Robot's behavior:** As we discussed above, we attribute two roles to the robot in different learning situations. The behaviors of the robot in the two situations is partially dependent on the role that it plays. For instance, the first role is 'facilitator', where the robot provides task instructions to children and acts as a mediator. In this situation, we employ behaviors in the robot based on the skills which it has to exhibit as a facilitator. For example, the robot would show verbal behaviors such as giving task instructions, prompting for task feedback and asking social questions. In terms of non-verbal behavior, the robot would gaze and show hand gestures to children. Both verbal and non-verbal behaviors are employed to provide natural and fluid interaction with children, yet maintaining the social behavior. In the other situation, the robot acts as a peer-learner where a child acts its tutor. In this state, the robot would again exhibit similar non-verbal and verbal behaviors such as greetings, asking help in teaching handwriting and asking social questions. However, the robot's verbal behavior contains dialogues mostly filled with request and help aspects. In terms of its task skills as a learner, it shows varied writing skills to children, from learning to personalised learning to non-learning behavior.

5. **Experimental techniques:** In our studies, we control the robot's behavior either using the Wizard of Oz or autonomous techniques. We do not employ semi-autonomous approaches.

6. **Pedagogical theories:** As mentioned before, we explore the impact of designed educational activities concerning handwriting based on peer-assisted learning methods, particularly: *peer-tutoring or learning-by-teaching* and *reciprocal peer-learning* methods. We explore these methods in different child-robot scenarios.

7. **Children's perception of a robot:** We believe that children's perception of a robot and an educational activity in a child-robot educational scenario can bring deep understanding of several aspects such as how children's learning outcomes are affected by their perception; which interaction aspects did not affect their perception; and how their perception changes over a multi-session interactions. To explore these questions, we examine children's perception of a robot in some studies.

3.2 Design and Evaluation of Child-robot Educational Studies

The literature suggests that there are a number of reasons that makes the child-robot interaction studies appealing to researchers.

1. **Children's willingness** to engage with robots and treat them as a social agent has been shown by a set of studies (Breazeal, 2003; Salter et al., 2008). In fact, children not only can easily make physical and verbal social behaviors with a robot but they can also build social and moral relationships with the robot (Kahn Jr et al., 2012). Piaget studied the course of cognitive development from birth to adolescent and described that children in this period tend to ascribe life to moving inanimate artifacts. He named it *"animism"* and defined as *"the tendency to regard objects as living and endowed with will"*. Some researchers have explored children's perception of a robot related to the term animism. For instance, Melson et al. (2009) compared children's behavioral interaction and reasoning between a robotic dog (Sony's Aibo[19]) and a living dog. In the study, 72 children in the age group of 7 to 15 years participated and each of them interacted with both dogs separately followed by interview questions regarding four aspects: biological state; social companion; mental state; and moral understanding. The results revealed that more children perceived the live dog having the four above-mentioned aspects compared to the Aibo robot. However, surprisingly, more than 60% of children perceived the robotic dog with social, moral and mental states and 76% of the children attributed moral standing to the robotic dog that seems to be interesting. Similarly, Severson (2010) compared children's and adult's attributions to a personified robot dinosaur (Pleo[20]). The results revealed that children attributed significantly more perceptual capabilities, moral standing, psychological and social capabilities to the robot compared to the adults. However, they did not perceive it as a biological entity.

2. **A variety of applications** have been implemented using cHRI. One of the common application is education: a robot is being used in different roles such as a tutor, learner, instructor and can provide personal and tireless repetitive behaviors required in child-robot learning scenarios. In addition, they can also build social rapport by playing these different roles (Belpaeme et al., 2013) and promote motivation in children's learning. Health-care is another promising field where robots can be effective. Robot-assisted therapies are widely accepted and can provide companionship and therapies to children. A seal robot (Paro[21]) was used to provide children animal-assisted therapy effects such as psychological (*e.g.*, relaxation), physiological (*e.g.*, improvement of vital signs) and social effect (*e.g.*, stimulating communication). The results indicated that the robot helped them in socializing and relieved their anxiety in the absence of their parents (Shibata et al., 2005). Moreover, robots have been used as a companion and educator for children

[19] http://www.sony-aibo.com/
[20] http://www.pleoworld.com/
[21] http://www.parorobots.com/

diagnosed with diabetes (Blanson et al., 2012; Belpaeme et al., 2012) to educate about healthy lifestyle and hygiene (Kohlhepp, 2003)

3. **Cognitive system** is one of the recent and promising area for cHRI that proposes a different view about the impact of social interaction on cognitive development (Belpaeme et al., 2013). For maturing children's cognition skills, social interaction is essential as many of cognitive functions are social in nature such as reasoning, multi-modal interactions and critical thinking (Lopes and Belpaeme, 2008). The traditional opinion on cognitive development views the cognitive systems as a product combining one's brain and body. However, a more recent perspective regards cognitive interaction as the result of two agents which are not necessarily fully cognitive. In the case of cHRI, although possessing limited capabilities compared to humans, a robot can affect and help in children's cognitive development (Belpaeme et al., 2013).

Salter et al. (2008) suggested two prime concerns in conducting a successful social child-robot interaction. One is the *multidisciplinary teams* and the other is *real-world testing*. Multidisciplinary studies are more complex than traditional and mono-disciplinary studies as they require variety of set of skills and expertise. However, the author pointed out the three dominant factors that differ from study to study:

1. **Research expectations** and goals of a study should be agreed and clarified among the multidisciplinary parties involved. For example, a psychologist may have different point of view compared to a robotic developer to capture a child's behavior while interacting with a robot.
2. **Experimental setup** includes various elements such as target participants, indoor/outdoor setup, conditions, control group and so on. Due to the involvement of people from different background and experience may lead to different viewpoints to conduct a study. These issues should be resolved to avoid unnecessary iteration of developed work.
3. **Results and Evaluation:** the goals of the experiment should also be in a line with the type of data collection. Due to the different desired goals of the practitioners, for example, qualitative and quantitative analysis of the data may lead to completely different sets of results. It should be ensured that the different goals do not conflict or mutually exclusive.

3.2.1 Real World Testing

Salter et al. (2008) further stated that "*going into real-world environments is without a doubt a long and difficult process. Limitless variables and factors come into play.*" In the same vein, Belpaeme et al. (2012) expressed that the reason to have limited cHRI studies 'in the wild' is due to the technical challenges including coordination and synchronisation of multiple action systems to support timely and coherent behaviors of robots. Despite these challenges, the importance of testing the robots in the real world has been supported by (Salter et al., 2008, 2010; Belpaeme et al., 2013, 2012; Sabanovic et al., 2006)

Moreover, Salter et al. (2010) proposed a taxonomy of “wildness" in child-robot interaction to interpret cHRI experimentations. The taxonomy was based on two dimensions; participants and a robot, and each dimension was associated further to *autonomy*, *group* and *environment*. For example, a participant’s autonomy in terms of interaction with a robot included free, natural, controlled interaction. Similarly, the participants group represents the number of participants involved in the interaction (*e.g.*, large, medium and small group; paired, singular). Moreover, the participants environment included free (*e.g.*, home,school), natural (*e.g.*, play group), familiar, adapted and sterile (*e.g.*lab). Likewise, a robot’s autonomy included variables such as autonomous, fixed, combination, WoZ. The robot’s group included plethora (*e.g.*, combination of robotic devices, autonomous agents, animate and inanimate toys), multi-agent, robot with animated toys, robot with in-animated toys and singular. Furthermore, the robotic environment included variables such as open, secured, adapted, engineered and controlled.

3.2.2 Experiment Protocol

Most of the child-robot educational studies reviewed in this thesis follow a common protocol. The selection of participants generally depends on the target age-group for the study. By following the HRI consents rules, only participants who assented and whose parents signed a consent form participated in the study. Depending on the chosen location of the study i.e. in the wild or in laboratory or in the school settings, mostly researchers try to conduct the study where the participants feel comfortable. We now present the procedural steps as follows:

1. **Convey experimental information to participants** Before starting the study, a researcher introduces participants regarding different aspects in the study that are related to the participants. These aspects may or may not be necessary for the researcher to convey as it depends on the type of educational activity. However, some examples of these aspects are described as: the context of the study; about the interaction with a robot; duration of the interaction and the study; role of the participants; about turn taking etc. Usually, due to moral and ethical concerns, the participants are also informed that they can leave the study anytime if they wish to.

2. **Tutorial** The aim of this step is to provide information about the practical use of the technology that the participants would use in the study. Although the step is optional, but in some cases, it becomes crucial that the participants would get used to the materials before using in the main study. If a participant would have technical handling problems during the experiment, s/he would ask the researcher that can create bias in measuring the participants performance. Therefore, this step would also help to avoid discrepancies in the results.

3. **Pre-test & Pre-questionnaires:** Generally, the goal of the child-robot studies is to measure the impact of the robot on child's learning. And to measure their learning gains, it is important to know their initial level of knowledge (before conducting the experiment). These tests are often called as pre-and post-tests. However, based on the study design, these tests can be performed with or without the robot. Besides these tests, a set of questionnaire can be presented to the participants to explore their experience such as their perceptions about the robot, study or learning.

4. **Interaction with a robot**

   Mode of Interaction: In designing an activity for children in the age-group (4-18), it is pertinent to define a protocol that can be followed by children through the activity. The protocol or a mode of interaction would set up the rules and instructions, facilitate the flow of interaction, and eventually make the evaluation easier in a systematic way. Depending on the design of the study, the interaction may be dyadic or can be between more than two children with or without a human facilitator while involving a robotic agent. However, the interaction between participants and the robot also needs a protocol to follow. Some studies have followed the protocol described below:

   (a) **Welcome greeting** It includes an introduction between the robot and the participants before starting the activity. This introduction can be initiated either from the participant's side or from the robot's side based on the study design. Generally, the robot sends the participants greetings, which is followed by an introduction of activity tasks. This step helps in creating an environment required for the activity.

   (b) **Main activity with the robot** This includes the learning part of the study where participant/s would perform the tasks in the presence of the robot. The task can be collaborative or solely performed by either the robot or the child depending on the design of the study. Some studies may conduct this step in multiple sessions and may involve different activities in between.

   (c) **Goodbye greeting** After finishing the activity, the robot greets the participants for spending time with it. These greetings may differ according to the study design (short-term or longitudinal). For example, the robot may greet and would ask the participants to meet again if the study is longitudinal.

5. **Post-test & Post-questionnaires:** In this step, the researcher would ask the children to perform a post-test and post-questionnaires, identical to the pre-test. Moreover, the tests and questionnaires can be performed multiple times if the study design incorporates multiple sessions.

Data collection: Different types of data can be collected through the study, for example, to evaluate children's performance in the learning task, their behavior and interaction with the robot. Depending on the type of activity, children's data can be collected on paper or any other digital device, *e.g.*, tablet, computer and later can be analysed to see the progress of children during the study. In addition, the audio/video data can be recorded and later can used for analysing different variables such as verbal and non-verbal behaviors occurred during the interaction.

3.2.3 Necessary Requirements in Child-robot Experiments

Researchers also suggested the number of factors required in wild child-robot studies. For example, Salter et al. (2008) suggested six factors as necessary requirements and need to be considered for child-robot experiments:

1. **Robust:**The robot should be robust enough to handle and withstand playful children as they can be sometimes harsh. A series of trials must be done that simulate child play to test the robot and to avoid the intervention of a researcher during the experiment, that also disrupt the observations and results.

2. **Uncomplicated & Inexpensive:** If robots are to perform in a wild setting or without a professional, they must be able to be operated by unprofessional people like teachers in school or parents. At the same time, the whole setup including the robot must be uncomplicated and simple to be operated. The cost of the robot is another factor to provide its accessibility to a diverse range of users.

3. **Longitudinal:** For sustaining the long-term studies or multi session studies, the robot's hardware should be able to provide consistent performance including animations, behaviors and battery power. It is important to test the system on several occasions to test this factor.

4. **Flexibility:** The design of the experiment and development of robot's behavior should be independent of the environment and specific conditions. For example, special lighting and color of the walls.

5. **Safety:** One of the primary concern in child-robot studies is the safety of children. Special attention should be paid to the type of equipment used in the study such as open wires, sharp corners and jerky movements of the robot.

3.2.4 Common Evaluation Variables

By integrating robots in educational activities with children, it becomes necessary that the robots interact with them in an entertaining, engaging and seamless manner. Aspects of social behavior such as gestures, gaze, speech have been used by robots to attract student's attention to enhance their learning. Although the abilities of the robots compared to a human being is limited but it's worthwhile to test the existing abilities with people. For instance, Turkle et al. (2006) stated "When a robotic creature makes eye contact, follows your gaze, and gestures towards you, you are provoked to respond to that creature as though it were a sentient, (and even caring) other". The literature shows that researchers have explored a range of variables that may affect student's learning while interacting with a robot. The variables include the communication modalities (*e.g.*, speech, gaze), proxemics (*e.g.*, physical and interpersonal distance) and their academic learning (*e.g.*, learning gains) and we briefly present them as follows:

1. **Communication Modalities** A number of communication modalities have been used with robots to increase their life-like and social interactive capabilities. Saerbeck et al. (2010) compared the iCat robot (Van Breemen, 2004) with two behaviors- neutral and social supporting behavior; and investigated the effect of the behaviors on the learning performance of students. The behaviors varied on 5 dimensions such as the role, empathy, attention guiding, non-verbal feedback and communicativeness. In all these dimensions, they used gaze; gestures like nodding and shaking of the head; machine vs. life-like personality; and demanding vs. suggesting dialogues. The results suggested that the employing social supportive behavior increased children's learning efficiency. Similarly, Szafir and Mutlu (2012) applied verbal and non-verbal behaviors such as gaze, nodding and gestures to a robot to attract student's attention when they disengage. The robot was able to monitor student's attention in real time using measurements from electroencephalography (EEG). The results revealed that the robot significantly improved students recall abilities and improved female student's motivation. The exploitation of social behaviors does not always lead to improvement in learning and sometimes they may divert attention of a learner. For instance, Kennedy et al. (2015b) explored the aspects of social and adaptive behaviors in a robot that can support children in their learning. In the scenario, a tutor robot exhibits two behaviors: social vs. asocial and teaches about prime numbers to children. The results suggested that the children with the asocial robot significantly learned more than the social robot. In addition, the presence of a physical robot lead to an improvement compared to the virtual robot, however, the social behaviors in the robot should be implemented carefully to avoid children's distractions.

   > *"Feedback is powerful in its effect when it is addressed to a learning context and it is most powerful when it addresses faulty interpretations".*
   >
   > \- (Hattie and Timperley, 2007)

   Robot's verbal feedbacks have been used to enhance the learning process by giving cues or suggestions or corrections (Kennedy et al., 2015b). Among other verbal feedbacks, corrective feedback facilitates the acquisition of learning especially in the cases where the content is difficult to learn alone. Haas et al. (2017) used two types of feedback to investigate pre-schoolar's learning and engagement. The two feedbacks were peer-like where they use explicit negative feedback (Long, 2006) and adult-like feedback where they use both explicit positive and implicit negative feedbacks. The results showed that the peer-like feedback influenced children to work independently but not their engagement. The literature defines *peer assessment* as an integral part of the learning experience for students while performing peer-assisted learning methods. Sadler (1989) suggested that formative assessment includes both feedback and self-monitoring. Furthermore, most effective types of feedback are in the form of cues, reinforcement, evaluation and corrective feedback to learners (Hattie, 1999).

Moreover, *self-disclosure* is the act of verbally disclosing personal information about oneself to another, including feeling, thought and experience, and is considered as a key in the growth of close relationships (Collins and Miller, 1994; Dindia et al., 2002). In the context of the peer tutoring situations, one of the pedagogical advantages for the tutee is self-disclosure (Topping, 1996). Furthermore, within HRI some research has examined the self-disclosure behavior of people towards a robot. Mumm et al. (Mumm and Mutlu, 2011) found that the people who disliked the robot also disclosed less to it.

2. **Proxemics**

   In human-human interaction, one of the critical elements is *proxemics*—the amount of physical and psychological space that people feel necessary to set between themselves and others (Hall and Hall, 1969). According to Hall, these distances can be categorised in four classes: *intimate*, *personal*, *social* and *public*. These specific distances preferred by people depending on their relationship with other individuals during interaction; their environment; their feelings; and cultural background. Research in human proxemics has been extensively studied and models have been developed to explore proxemic cues that may affect human communication (Gouldner, 1960; Argyle and Dean, 1965; Hall and Hall, 1969; Firestone, 1977; Patterson, 1976; Kaplan, 1977). These models explain the physical and psychological distancing such as physical proximity, mutual gaze, initial attraction, type of conversation, gender, age (Hall and Hall, 1969; Hayduk, 1981). (Kaplan et al., 1983b) described the four interpersonal models: *reciprocity* (Gouldner, 1960; Jourard and Friedman, 1970);*compensation* (Argyle and Dean, 1965);*attraction-mediation* (Kaplan et al., 1983b; Firestone, 1977);and *attraction-transformation* (Patterson, 1976) as follows:

   (a) **Reciprocity model**

   This model explains the psychological and interpersonal distance between people (see Figure. 3.7). According to this model, during an interaction, when one person decreases the distance (or increases closeness), the other reciprocates by increasing the closeness (Jourard and Friedman, 1970; Gouldner, 1960). For example, if one person maintains eye contact with another for a long time, the other would verbally disclose more in return. Jourard and Friedman (1970) evidenced a linear relationship between the participant's self-disclosure and the experimenter's verbal disclosure.

   (b) **Compensation (or Equilibrium) Model**

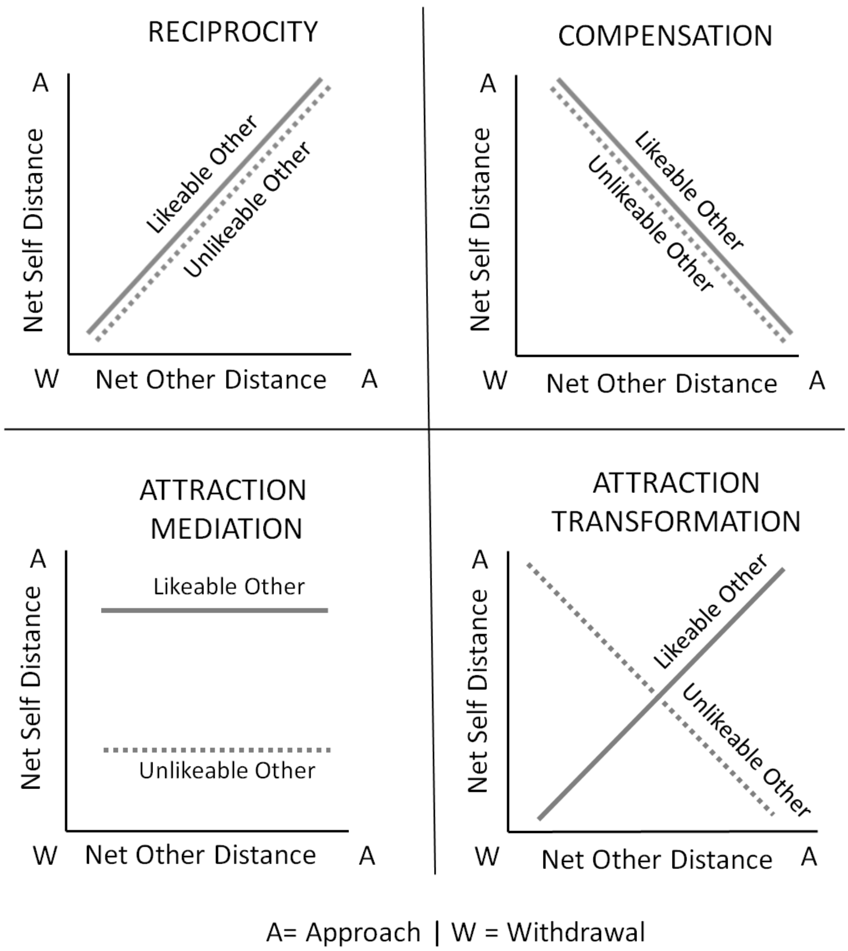


Figure 3.7 – The four models of interpersonal distancing (Kaplan et al., 1983a; Mumm and Mutlu, 2011).

According to the *Compensation model* developed by Argyle and Dean (1965), there is an equilibrium for physical proximity and eye contact between two individuals (see Figure 3.7). If this equilibrium is disturbed in one of its constituent dimensions, *e.g.*, by increasing physical proximity there will be complementary changes along the other dimensions. For example, if one person maintains eye contact to another person only for short time duration, the other person will verbally disclose more. Here, distancing is considered in terms of eye contact, physical proximity, intimacy of the topic and amount of smiling.

(c) **Attraction-Mediation Model**

The model describes the level of attraction between the individuals at the opening moves of interaction that decides the distancing attitude between them (Kaplan et al., 1983b; Firestone, 1977) (see Figure 3.7). Individuals with high level of attraction in the initial phase of interaction will maintain greater mutual closeness *e.g.*, disclosures; however, individuals with low levels of attraction will maintain low levels of mutual closeness regardless of changes in their partners' distancing attitude.

(d) **Attraction-Transformation Model**

The model combines the reciprocity and compensation model and suggests that intimacy behaviors between two individuals at the beginning of the interaction determine reciprocal or compensation attitude between them (Patterson, 1976) (see Figure 3.7). If the two individuals initiate the interaction with positive labelled behaviors, it facilitates reciprocal behavior by the other individual. On the other hand, if the onset interaction is negatively labeled, it facilitates compensatory reactions from the other individual. Both the aroused reactions aid to increase comfort and satisfaction between the two individuals.

In the human-human interaction, Kaplan et al. (1983b) compared all the four models of interpersonal distancing and investigated dyadic exchange of intimacy regarding verbal and visual distancing. The scenario consists of an interaction between a confederate as an interviewer and an individual, regarding intimate and non-intimate questions. The results revealed that the verbal interaction between them followed the reciprocity model while the eye-contact interaction followed the attraction-transformation model. Participants' gaze (non-verbal behavior) followed a different behavior, they reciprocated the liked interviewer by gazing more and compensated with the disliked interviewer by gazing less. On the contrary, in human-robot interaction field, a number of studies have explored the proxemics while considering a robot as a “social being" (Walters et al., 2005b; Syrdal et al., 2006; Walters et al., 2005c; Walters, 2008; Walters et al., 2008). For instance, Mumm and Mutlu (2011) explored the proxemic behavior of people to investigate the psychological and physical distance they establish with a robot,'Wakamaru[22]'. In the study. the researchers tested the above-mentioned four models how people physically and psychologically distance themselves with the robot. In the controlled interaction scenario, participants interacted with the robot to perform two tasks examining physical and psychological distancing established by the participants based on two variables-likability and gaze behavior with the robot. The results of physical distancing suggested that the individual who disliked the robot compensated for the robot's gaze and maintained a greater physical distance. On the other hand, the psychological distancing revealed that those disliked the robot also disclosed less to the robot.

Moreover, in the child-robot interaction field, only a few studies have explored the area of proxemics and as per our knowledge none of the studies have explored proxemics in educational cHRI. Nevertheless, we present some cHRI studies that are not related to educational domain but have still investigated physical and physiological distance. For example, Walters et al. (2005b) compared personal space zones between child groups and single adult with the PeopleBot robot [23]. The results revealed that the child

[22] http://www.plasticpals.com/?p=235
[23] http://www.mobilerobots.com/ResearchRobots/PeopleBot.aspx

groups preferred “social zone" distance (1.2m-3.6m) comparable to distance when people talk with stranger. On the other hand, adults preferred ‘personal zone’ distance, compared to distance when people talk to their friends. Similarly, Okita et al. (2012) examined the physical distance between children (ages 5-7) vs. adults with Honda’s humanoid robot[24]. The physical distance was compared based on: who initiates the approach (human vs. robot); prompting (verbal invitation vs. non-verbal gesture); and informing (announcement vs. permission vs. nothing). The results showed that when the children and adults initiated approaching the robot, without prompting, the children significantly maintained longer distance between themselves and the robot compared to the adults. Additionally, when the robot initiated approaching the children, they distanced themselves significantly lower when the robot asked permission compared to when the robot did not say anything or announced.

Yamaji et al. (2011) investigated the proxemic distances with children using a social trash box robots. He concluded that the proxemic distances depend on the robot’s behavior: when the robots moved individually; and when they moved in groups. The children preferred “personal-social" and “public" spaces (in reference to Hall’s spatial zones) when the robot’s were moving individually; however, they preferred “personal", “social" and “public" zoned when the robots moved together. Similarly, Vázquez et al. (2014) examined children’s (ages 4-10) behavior with an expressive furniture robot and its robot lamp sidekick. The results indicated that the presence of the sidekick did not affect the children’s physical proximity but did increase the engagement.

3. **Learning Gains**

A set of studies have employed qualitative and quantitative methods to explore the impact of robotic activities on students (Barker and Ansorge, 2007; Nourbakhsh et al., 2005; Petre and Price, 2004; Robins et al., 2005; Sklar et al., 2000); but other studies have provided the empirical support for the use of robotic kits in science education and have also assessed student’s learning. The most common criteria to evaluate student’s performance is to employ pre- and post-tests; however, it may include questionnaires in addition to the tests. For instance, Wagner (1998) compared elementary school student’s achievement in three educational mediums using: robotics; battery powered (non-robotic manipulative’s); and traditional way in the field of science and overall problem-solving skills. The results revealed that no significant differences were found in science achievement between students using robotics and battery powered manipulative. However, a significant difference was found between them in programming logic-problem solving. In addition, both robotics and battery powered manipulative had significant effects compared to the traditional medium group.In the same vein, Barker and Ansorge (2007) examined the student’s (ages 9-11) achievement scores to promote science and technology using robots. The evaluation was paper-and-pencil based and consisted of 24 multiple-choice questions (out of four questions, one is correct) derived from activities within robotics curriculum. The results revealed that the students

[24]http://world.honda.com/ASIMO/

with robotics intervention scored significantly higher in the post-test compared to the control group that had no significant change from the pre-tst to the post-test scores. In addition to K-12 classrooms, Williams et al. (2007) conducted a two-week summer robotics camp to investigate the middle school student's physics content knowledge and scientific inquiry skills. For both physics content knowledge and scientific inquiry skills, students gave pre- and post-test including 12 multiple-choice question for physics and five questions with problem scenarios for inquiry skills. The results suggested that the camp enhanced the student's physics content knowledge but failed to improve but did not improve their scientific inquiry skills.

Besides using robotic kits to enhance building and programming skills, other researchers have exploited humanoids to enhance student's learning. Interestingly, the humanoids were also compared to the other media to examine children's learning (Hyun et al., 2008; Han et al., 2005; Kose-Bagci et al., 2009; Kennedy et al., 2015a). For instance, Hyun et al. (2008) compared robot-assisted with media-assisted group of students in linguistic ability. For evaluating the linguistic abilities, they conducted four tests- story-making test, story understanding test, vocabulary test and word recognition test before and after the experiment. The results revealed the robot-assisted group improved significantly compared to the media-assisted group. Similarly, the study by Han et al. (2005) included pre-and post-tests as well as questionnaires. They compared student's learning with a humanoid robot IROBI robot, media and web-based and found that the home-assisted robot was superior to other learning mediums.

3.2.5 Challenges in Child-Robot Educational Scenarios

With the advent of learning advantages for children through educational advancement, multifaceted challenges are bound to happen. We present here a number of obstacles faced by researchers, specifically, in child-robot educational scenarios as follows:

1. **Age**

   Despite the ongoing advancement of human-robot communication technologies, there is still some time to fully achieve natural communication with robots. And in child-robot interaction, it becomes more difficult especially in the case of young children and children with communicating disabilities. With the children 2-4 years of age, the designed interaction needs to be simple, fun, engaging and needs a presence of a facilitator throughout the activity. Since these young children use minimal verbal communication and more non-verbal communication, often it is difficult to interpret their perception. On the other hand, children older than 4 years usually use both verbal and non-verbal communication and may need less assistance during the study compared to the younger ones. Okita et al. (2011) evidenced that the quality of interaction between children and robot differ according to their age. For 4-5 years old children prefer timely conversation with a robot and turn-taking rather than the content of a task they perform. As children grow, between the age of 6-8 years, they listen and answer the robot more carefully rather than talking. Further, 9-10 years old children understand more the robot's capabilities and only make remarks within the limit of robot's potential.

2. **Technical**

   In an interaction with a robot, users often assume and expect the robot to possess same perceptual modalities as they have. In the case of children, their expectations and assumptions are relatively higher than the adults. The perception is one of the obstacle that AI is still struggling with. Among several perceptions, visual, speech, action selection are the common barriers in achieving human-human like interaction. Artificial visual perception has been broadly used in social robots to accomplish semantic understanding tasks such as face recognition and detection; facial expression recognition; gesture classification; and overall human body tracking and identification.

   As humans receive approximately 75% of daily information through visual signals, these signals became desirable and popular in social robotics too. Besides recognition functionality, low computational cost/computational efficiency and autonomy are also important requirements. Even after a long way of 50 years of constant improvement, the current technology has only reached a fraction of human capability (Belpaeme et al., 2013). Currently, these functionalities are used in confined scenarios (Yan et al., 2014; Kruijff-Korbayová et al., 2011). Similarly, audio-based tasks have also been widely used in human-robot interaction such as speech recognition, sound event classification, emotion recognition. There has been a tremendous amount of research done in the field of natural language processing and the current systems work well in constrained and static domains such as automatic booking and reply systems. However, when it comes to flexible linguistics situation such as open-end communication, two-way dialogue model (human to robot and robot to human) (Fong and Nourbakhsh, 2005) and child speech recognition, the systems are still are not reliable and complex systems are needed (Roy and Reiter, 2005). Due to lack of language understanding, especially for child-robot interaction, many studies that use language are restricted to use wizard-of-oz control methods (Belpaeme et al., 2013).

   Another challenge in cHRI and HRI is action selection- *how does a robot determines which action to take next?* As the robot's complexity increases, the collection of possible actions for the robot also increases that in turn contributes to a large search space (Breazeal, 2004). When a user interacts with the robot, s/he has well-defined expectations of the robot's response that seem to be technically challenging to select the correct response in open and unbounded scenarios (Belpaeme et al., 2013).

3. **Evaluation**

   Depending on the goal of a study, different interaction metrics are being used in child-robot studies such as duration of interaction; physical and psychological distancing; and biometrics. Often the educational scenario aims to acquire the contribution of a robot in children's learning. In some cases, pre- and post-test can serve to measure children's learning gains. However, for measuring indirect effects, the significant outcomes might need large sample size. One of the major complication in cHRI compared to HRI is to measure its effectiveness. As cHRI involves children, it becomes difficult to investigate their real perception through survey questions due to their propensity towards pleasing the interviewer (Belpaeme et al., 2013). Compared to children, adults answer the questions truthfully and their responses are more reliable. For instance, Likert scale answers from children often have extreme responses and sometimes they feel shy to give the honest response (Belpaeme et al., 2013).

Children's attention, involvement and engagement in a task plays significant role in their learning. To measure these behaviors, audio and video recordings are done during the experiments and analysed later. The verbal and non-verbal interaction between children and a robot may provide important clues. For example, eye contact is one of the non-verbal interaction that is used to measure attentiveness and involvement (Anderson, 1987). Children's body movements and non-verbal behaviors (*e.g.*, oculesics) are used to determine their involvement with a robot (Okita et al., 2011). Although the analysis of audio and video data can reveal children's responses but are not sufficient to measure their physiological changes. For example, often, children do not express their emotions fully and hide it out of shyness and embarrassment. In these cases, physiological sensors such as wireless skin conductance sensors can be used to measure the subtle triggers and levels of arousal during the interaction (Okita et al., 2011).

4. **Expectation**

   When a social robot interacts with children, the expectations of children increases as they presume about the robot's capabilities (Okita et al., 2011; Belpaeme et al., 2013). In addition, they expect to get *timely response*, *social behavior*, *response to their sudden questions* and *flexibility*. Therefore, it is important to set the right expectations before the young users and adults who use the robots. It is seen that children do not get troubled by robot's unmet expectations; however, it takes more effort to adjust according to adults' expectations (Belpaeme et al., 2013).

Summary

Designing child-robot educational studies involves multidisciplinary teams and due to the increased complexity extra attention needs to be paid in terms of research expectations, experimental setup, results and evaluation. In addition, we found that real-world testing is a long and challenging process. As our research targets to children to improve their handwriting skills, we chose classroom environment and thus, we conduct all the studies in a school setting. Before conducting a study, we present and discuss the study with the school director and school-teachers. On their approval, we ask consents of targeted children and their parents. The design of our educational activities include people from different domains such as educationalists, psychologists, computer-scientists and school-teachers.

In this dissertation, we investigate two educational scenarios: one is a triadic scenario, where a pair of children perform a collaborative writing activity in the presence of a facilitator (robot or human adult); the other is dyadic scenario where a child and a robot perform a collaborative writing activity. Both scenarios are either based on peer-tutoring or peer-learning approaches. The educational scenario follow a protocol similar to what we have studied in Section 3.2.2. Moreover, in the studies we examine different evaluation variables such as communication modalities, interpersonal distance between participants (children, facilitator) and children's learning outcomes.

4 Peer-based Learning with Children: An Exploratory Study

As a first step we investigate two research domains of the *Co-writer project*: (1) *exploration of interaction modes*; and (2) *children's handwriting errors*. This chapter presents such explorations by conducting a short-term study, referred to as '**child-child study**', that explores the impact of peer-interaction modes on children and investigates their handwriting errors in an educational scenario. The chapter first describes the motivation and expected contributions for the study. Then, we outline the research questions and hypothesis that guided the study. This is followed by a description of the design, conditions and methodology. Finally, we wrap-up the chapter by discussing the findings and limitations of the study.

4.1 Setting up the Scene:

4.1.1 Motivation and Contributions

The initial phase of the research was mostly exploration driven and was focused on the design of writing activities for children as they develop their handwriting skills. One of the goals of the research is to enhance children's handwriting skills. As such, it was important to design realistic writing activities that are engaging and enjoyable for young writers. The design of an activity for learning how to write includes various factors such as the number and age of participants; type of activity; mode of interaction; materials used in the activity and so on. An activity can be in a form of a game in which one or more child can write and learn letters or words. For our intended activity, we selected a dyadic interaction where one child performs a collaborative learning activity with the other child. We believed that the dyadic interaction would provide a social and collaborative learning benefit to children. However, to design these type of activities, we needed some form of interaction which could help us to see different aspects of children's behavior towards their peers. These forms of interaction can be called styles of interaction or interaction modes as they may affect the learning behavior of children and enhance the fluidity of an activity. Thus, to design the interaction modes, we relied on peer-assisted learning methods which have already proven their effectiveness in educational settings with children.

Mostly, the development of children's handwriting begins at the age of four, thus we wanted to design the writing activity targeted to the age-group between four to five years. In the mentioned age-group, children are in the process of learning letter forms and produce handwriting errors which can become difficult to correct later if necessary attention is not paid during early learning period. Simner (1991) discussed that the writing errors produced by kindergarten children include additions, deletions and misalignment in parts of a letter. These errors not only influence their academic performance in the kindergarten period but also throughout their first grade.

In order to assess the designed activity and to explore children's common handwriting errors, we first conducted a study in a school environment.

Peer-assisted learning methods do not only boost student's learning but also augment other aspects in a student such as responsibility, social and interaction behavior, deep understanding of domain. In the study, we would explore the impact of learning methods on children's learning and communication modalities. Based on this exploration, we examine which learning method can maximize children's learning gains and other factors that supports their learning. The other expected contribution of the study is to collect a database of children's handwritten letters in order to identify their common handwriting issues.

4.1.2 Research Questions and Hypothesis

In the current study, we explore dyadic interactions between two children with ages of four to five years when they perform a collaborative writing activity in the presence of a human facilitator. The role of the facilitator is to provide task instructions required during the study.

For designing the interaction approach between the two children, we used two peer-based learning methods: *'peer-learning'* and *'peer-tutoring'*. These methods are commonly used in education; both of these differ in the way they encourage student's interaction and the quality of peer engagement. Usually, the interaction in each of these methods occurs between two students.

The *peer learning* is a reciprocal learning method in which there is a mutual benefit to both students; they both act as a teacher and as a learner (Boud et al., 2001). The reciprocal nature of this method is a key point, as students do not hold power over each other by virtue of their responsibilities or position (Keppell et al., 2006). Contrasting to the peer learning method, in *the peer tutoring* method there is a consistent distinction between the learning and teaching roles among the students (Boud et al., 2001). It also creates an unequal situation due to the position of responsibility that one student would hold (Keppell et al., 2006). The peer tutoring is often supported on the grounds of the *learning-by-teaching* method. Research shows that when using this approach, most of the students benefited in some way, and that same-age tutors were as effective as cross-age tutors (Topping and Ehly, 2001; Fuchs et al., 2005). Here, we present the two designed interaction modes as follows:

- **Peer-learning mode**: Both children perform a writing activity and assess each other's writing performance. The children hold an equal status and roles in terms of peer assessment.
- **Peer-tutoring mode**: One child is assigned a role of a teacher and the other as a learner. The learner-child performs the writing activity and the teacher-child evaluates his/her writing performance. After the evaluation, the method is repeated by exchanging the roles between them.

We analyse the interaction modes based on two factors. The first factor is related on *the functionality of the mode*; where we examine the impact of the two modes on children's learning. In particular, we evaluated and compared children's learning gains between the two modes. The other factor is associated to the *type of interaction*, where we analyse the difference in children's interactive behavior between the two modes. Besides, the objectives of the study are presented as follows:

- To form a database of children's handwritten letters to explore the most common handwriting errors.
- To classify the identified handwriting errors and build a taxonomy of these errors.
- To assess the effectiveness of both interaction modes in terms of children's learning.
- To explore the communication modalities between children's dyadic interaction.

On one hand, we wanted to investigate whether both interaction modes introduced in the activity are comprehensible for four to five years old children. On the other hand, we were interested to examine if the designed writing activity is pertinent to distinguish the two interaction modes. The peer-learning mode is a two way learning approach and offers equal opportunity to participants to collaborate and discuss together. Contrary to this, the peer-tutor mode is a role based mode where each participant behaves according to his/her role (teacher/student). In addition, it is a one way approach, *i.e.*, where a teacher is supposed to provide information and evaluate the learner's performance. Both these approaches have their own benefits in children's learning and social interactions. As child-child experiment was supported by these peer-based approaches, we formulated some research questions and hypotheses regarding the interaction modes and learning gains.

- **Research Question 1:** Would children be able to understand the two interaction modes? How would children find the writing activity?

  Hypothesis 1: In the study, the facilitator presents an interaction mode like a game to the children, we hypothesise that the children would be able to understand both the interaction modes. The designed activity comprised of copying the English letters from a letter card (printed with a letter) on a sheet of paper and on a tablet. As the participants (children) are in the process of learning the shapes of letters at their school and home, we hypothesise that the activity would not be new to them and can be easily understandable.

- **Research Question 2:** Which interaction mode would lead to more interactions (verbal and non-verbal) between the children?

  Hypothesis 2: As the peer-learner mode provides equal status to the participants in order to evaluate each other's performance, we hypothesise that the children in the peer-learner mode would communicate more compared to the peer-tutor mode.

- **Research Question 3:** Which interaction mode would enhance more children's learning gains?

  Hypothesis 3: Due to the effectiveness of each learning approach, we believe that both interaction modes would increase children's learning. However, due to the presence of role enactment in the peer-tutor mode, we hypothesise that the children in this mode would benefit more in terms of learning gains as their assessment towards the peers may be more intensive compared to the peer-learner mode.

4.2 Study 1: The Child-child Study

4.2.1 Participants

We conducted the study in 'Ecole Internationale 'school in Geneva, Switzerland. 20 English-speaking children (reception class) in the age-group of 4 to 5 years participated in the study. The study followed the ethical norms of privacy and responsibility. As such, only children who assented to the study and whose parents signed the consent form participated.

4.2.2 Materials

The materials used in the study consisted of an experimental record sheets, writing paper sheets, tablets (tactile devices), tablet pens, a camera with a microphone, and target cards with printed letters. For the pre- and post-test, we chose eight letters, a combination of upper- and lowercase letters (α, π, y, j, S, N, m and Q) printed on eight separate cards called as target cards. We selected the letters based on different geometrical shapes. Out of the eight letters, we included six letters (α, π, y, j, S and Q) in the main writing activity. We included the α and π letters among other English letters to observe the transfer skill, as we knew that the children did not have prior knowledge of these Greek letters.

In addition to the paper sheets, we also used tablets for the main writing activity in the study and the children did not use them in the pre-post tests. Regarding the tablet, we[1] developed

[1] My colleague developed the writing application with dual-user interactive mode.

a specific writing application to provide the dual-user interactive feature: when a shape is drawn on one tablet, it can be observed on the other tablet in real time. The drawn shape on each tablet is assigned with a different color to identify the drawings. In addition, an eraser button is provided for the children to erase their own writing. This functionality allowed a pair of children to correct each other's writing on their own tablet in real time.

4.2.3 Conditions

Designing modes of interactions

The two designed interaction modes were termed as 'peer-learner mode'and 'peer-tutor mode 'and served as two conditions for the first study. The scenario of each interaction mode involved a pair of children performing a collaborative writing activity in the presence of a human facilitator. The role of the facilitator was to provide the task instructions to the children during the activity. The conditions as modes are explained as follows:

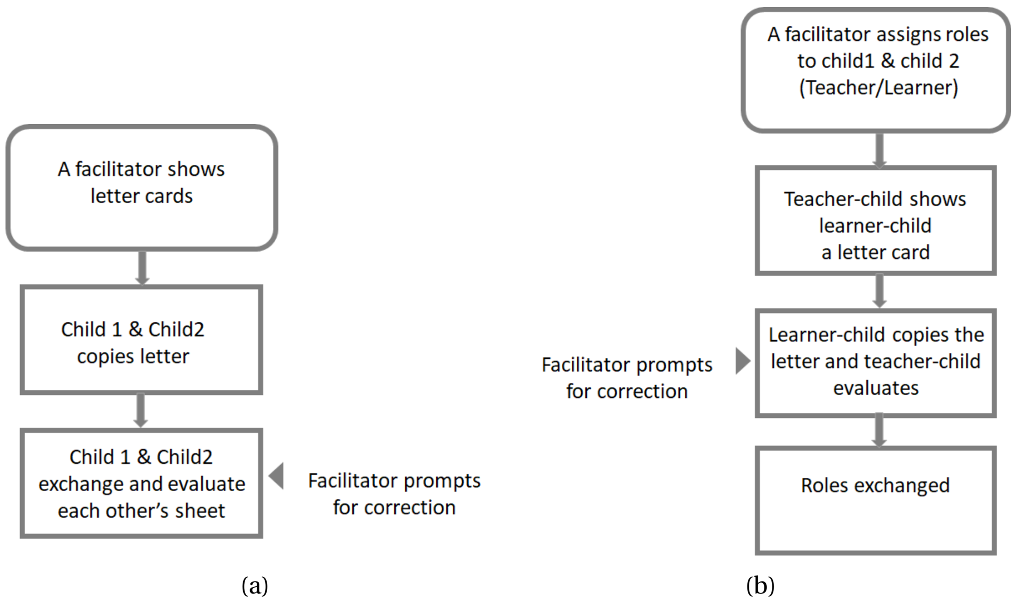


Figure 4.1 – Modes of interactions: (a) Peer-learner mode; (b) Peer-tutor mode.

- **Condition 1-Peer-learner mode**: In this mode, no role is assigned to the children. The facilitator shows a letter card to both children and asks them to copy the letter onto their respective sheets. After they finish writing, the experimenter prompts them to provide corrections on each other's writing performance (see Figure 4.1a). The activity is repeated with other letter cards. For half of the letters, children used a paper sheet, whereas for the other half, they used a tactile device (one per child).
- **Condition 2-Peer-tutor mode**: In this mode, the facilitator (who was also the experimenter) assigns roles to the children: one child acts as a learner, and the other acts as a teacher. The experimenter asks the teacher-child to show a letter card to the learner-

(a) (b)

Figure 4.2 – The study setup: (a) children using paper sheets; (b) children using tablets.

child so that s/he could copy the letter onto a paper sheet. Then, the experimenter prompts the teacher-child to provide corrective feedback on the learner-child's writing performance (see Figure 4.1b). Here, the children again used both paper sheets and tactile devices. After copying half of the letters, the experimenter exchanged their roles, and the activity was repeated with the remaining letters.

4.2.4 Protocol

The study consisted of a between-subject design, and out of 20 children, 10 children (5 pairs) participated in the peer-learner mode (M = 4.95, SD = .15; 6 male and 4 female), and the other 10 participated in the peer-tutor mode (M = 4.95, SD = .41; 3 male and 7 female). Figure 4.2 depicts the classroom setup of the study. In addition, the school teachers of the children helped us in the design and conduction of the study.

During the introduction of the study, the facilitator explained to the participants that they were going to perform a collaborative writing activity in which they would write some letters on a paper and then on tactile tablet. Then, the facilitator introduced the above mentioned protocols as games to the children. In the activity, the participants and the facilitator used eight target letter cards (a letter is printed on a card) to display during the game (see Appendix B). Moreover, the facilitator also informed the participants that if they do not wish to continue the learning activity, they could stop but no participant left during the study. Every group was tested on the pre-test; the writing activity based on either peer-learner mode or peer-tutor mode; and the post-test. Each session lasted approximately 10-15 minutes. The study followed the phases detailed below:

- **Pre-test**: In this phase, an experimenter displayed the eight target letter cards on the table to a pair of children and asked them to write the letters individually on a paper sheet.

- **Writing activity**: After finishing the pre-test, the experimenter performed the writing activity with six target letter cards according to one of the interaction modes selected for the children (explained in the Section 4.2.3).
- **Post-test**: After finishing the writing activity, the pre-test activity was repeated and also served as a post-test. The facilitator would greet the children for their participation in the study.

4.2.5 Analysis

With the purpose to examine the interactions during the study, we performed video and audio analysis of all the sessions. We further coded and annotated the communication modalities (verbal and non-verbal) used by children during the interaction. Two independent coders performed the annotations using the ELAN multimedia annotation tool [2].The Cohen's Kappa was run and the reliability of the scores showed good agreement between the two coders, $\kappa = .85$, $p < .05$.

Furthermore, to analyse the children's learning gains and writings errors, we collected the data from the paper sheets and tablets. First, the pre- and post-test data were tested for normal distribution using the Shapiro-Wilk normality test. The hypothesis that the data comes from a normal distribution was not confirmed, hence we analyzed the data using the non-parametric Exact Wilcoxon rank-sum (Mann-Whitney U) test which was also appropriate for the unequal sample size data. In addition, we calculated the learning gains of children by subtracting the pre-test scores to the post-test scores. Once again, we used the Shapiro-Wilk normality test to check the normality of the data. Since the test results neither showed the normal data distribution nor symmetric, we performed the *exact sign test* to compare the differences of the scores in the pre-and post-test.

To investigate the writing errors in children's handwritten letters, we analysed all the letters collected from the main writing activity and pre-post test data. Two independent coders analysed each letter based on various factors such as shape, type of deformation, missing part and so on. Based on this analysis, we identified some error patterns that were common to several letters. Afterwards, we classified the errors into categories and built a taxonomy of errors based on the classification.

Regarding the pre- and post-test data, once again, two independent coders analysed each letter based on its legibility by comparing it to the correct sample of the letter (target letter card that was displayed during the study). The coders rated each letter in the scale of 1 to 3 and the coding metric is given as follows:

-1 = unreadable; if the letter is illegible and can not be recognised as a target letter.

0 = readable; if the letter is legible but contains several errors such as missing sub-trajectory,

[2] `https://tla.mpi.nl/tools/tla-tools/elan/`

alignment and proportion.

1 = identical; if the letter is legible, written similar to the the target letter and does not contain any errors.

In terms of the reliability of the participant's writing errors and learning gains, Cohen's kappa showed agreement values of .68 and .65, indicating a good agreement.

4.3 Findings

4.3.1 Communication Modalities

In the context of the study, the communication modality refers to an approach that the children used to communicate their feedback, either to their peers or to the facilitator. In both conditions, the children were asked to provide corrective feedback on their peers' written performance. Since, we were interested to find the impact of the modes on children's behavior, we examined the interactions only in the context of peer-assessment. And we did not explore the other social behaviors during the study. Hereof, to better comprehend the interactions

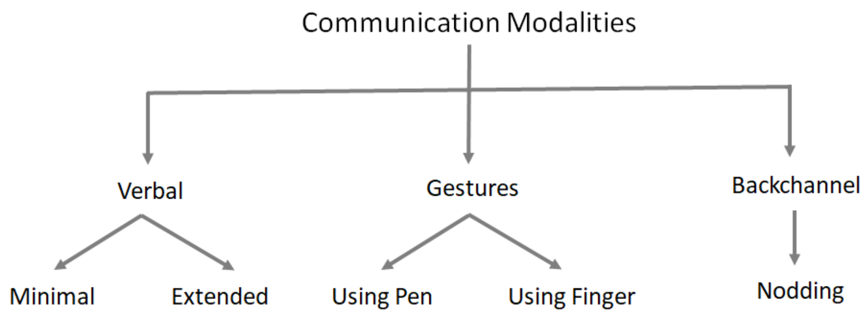


Figure 4.3 – Identified communication modalities during the study.

regarding feedback among the children include verbal feedback, feedback through hand gestures and head movement (nodding), we classified the communication modalities in three categories such as verbal feedback, gestures and back-channel as shown in Figure 4.3.

The first type of feedback used during the study is verbal feedback, which is further divided into two categories such as *minimal feedback* and *extended feedback*. The minimal feedback describes the short answer without any explanation; that generally contains single word. During the study, the children used various words such as *yes*, *no*, *correct* and *incorrect*. Contrary to this, the extended feedback describes answers that includes explanation and often includes a sentence. The answers given by children are *this part should be rounded, this side should be longer etc.*.

The second type of feedback used by children is gestures (see Figure 4.3). Sometimes, they showed the shape of a letter's trajectory using the pen or their finger. Thus, the gesture category is further divided into two types: *using pen* and *using finger*.

Lastly, the children gave the third type of feedback by moving their head, *i.e.*, *nodding* (see Figure 4.3). The nodding gesture refers to their *agreement* or *disagreement* behavior but through the head movement.

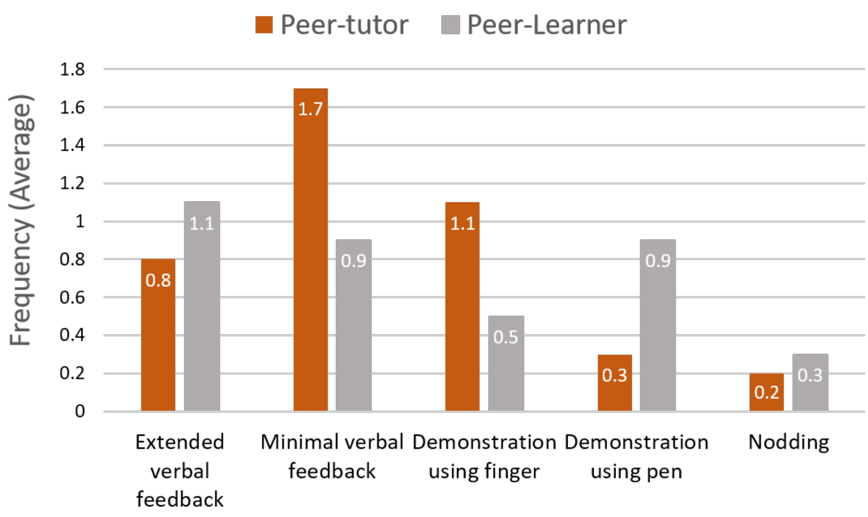


Figure 4.4 – Different communication modalities used by children to provide corrective feedback.

Due to the small size of the sample data, we discuss the general results of communication modalities in terms of their frequencies (see Figure 4.4). Regarding the verbal corrective feedback, we found that the children in the peer-learner mode provided more extended feedback compared to the peer-teacher mode. On contrary, the children provided more minimal feedback in the peer-tutor condition compared to the peer-learner condition. These results do not provide the significant figures; however, illustrate the verbal collaboration of feedback. Additionally, we observed several times, the children were not able to provide explanations on their peers performance. We believe that due to their young age (4-5 years), they might not be able to express their feedback verbally.

The second most common communication modality was gestures; demonstrating the correct trajectory of a letter through a finger or a pen (see Figure 4.4). When the facilitator prompted children for correction, most often, instead of verbal feedback, they exhibited the correct trajectory of the letter by over displaying on the incorrect trajectory using their pen or finger. This observation suggests that some of the children were aware of the errors present in the letter but due to their incapability of explaining the errors verbally, they used their pen or finger to demonstrate the correct shape of the letter. The children in the peer-tutor mode used their fingers more times compared to the peer-learner condition, whereas they used the pen more times in peer-learner mode compared to the peer-tutor mode (see Figure 4.4). In addition, they did not use the nodding gesture often. Figure 4.5 shows combined frequencies of communication modalities between the two interaction modes.

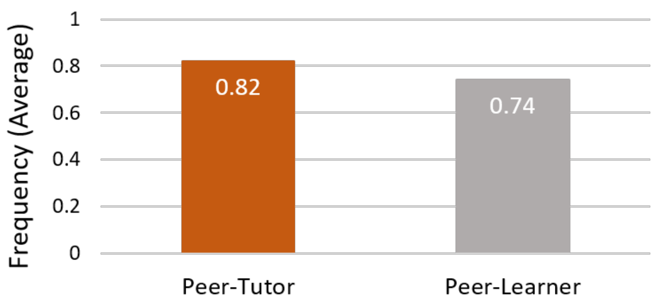


Figure 4.5 – Combined communication modalities used in the two interaction modes.

4.3.2 Classification of Handwriting Errors

As mentioned in the Section 4.2.5, we first analysed all the handwritten letters in the collected data and identified error patterns in them. Then we subsequently classified the error patterns and built a taxonomy of writing errors. A set of errors found in children's handwritten letters is shown in the Figure 4.6. In the Figure, the left side image for each letter represents the correct sample of the letter and the right side image represents handwritten child's letter including the error. The different types of errors in the taxonomy include *breaks*, *mirroring*, *multiple strokes*, *alignment*, *merges* and so on. For example, the error named *break* occurs in a letter, when the trajectory of the letter is disconnected. Likewise, the error named mirroring happens in a letter, when a part or sub-part of the letter's trajectory is inverted.

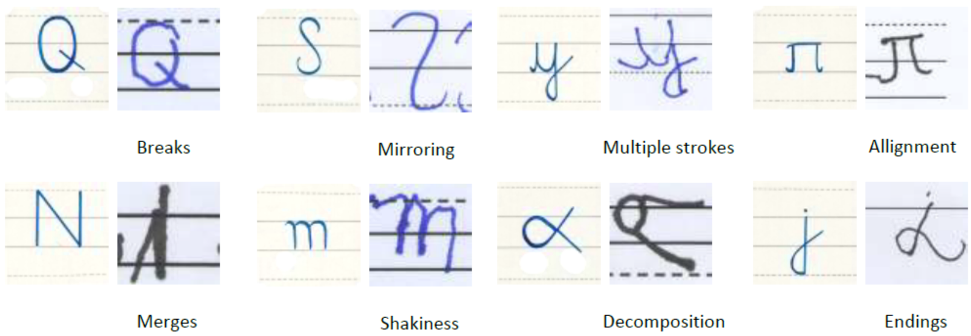


Figure 4.6 – Sample of errors corresponding to the correct letters.

Taxonomy of handwriting errors

Furthermore, we classified the errors and built a taxonomy based on the classification. The taxonomy is presented in the Figure 4.7. Primarily, we classified the writing errors into two broad categories: morphology and extrinsic factors. These categories are further divided into subcategories. The definitions of the major categories are explained as follows:

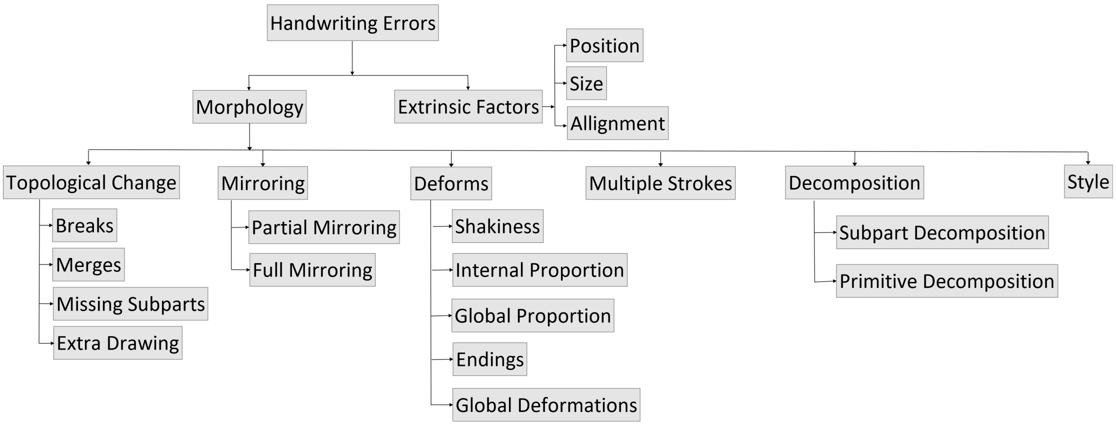


Figure 4.7 – Taxonomy of handwriting errors based on the identified errors in children's handwritten data during the study.

Morphology is defined here as the study of the shapes of letters. The writing issues that show a change in the morphology of a letter belong to this category and are further divided into 6 subcategories: *topology changes, deforms, multiple strokes, reversals, directional trajectory*, and *style.*

Extrinsic factors- errors do not produce a change in the shape of a letter and therefore are not related to the morphology of a letter. In addition, this error does not affect the topology of the letter.

The errors presented in the taxonomy are based on letters in English alphabet incorporating both: manuscript and cursive handwriting styles; and uppercase and lowercase letters. The classified errors are based on children's handwritten letter database in the age-group of 4-5 years. Since every child has different motor and perceptual ability, it should be noted that not all children in this age-group produce all the classified errors. However, we found that some of the errors have higher frequency compared to others. The error classification is not particular to this age-group and can be applied for older children. We think that some of the presented errors may disappear as children cross the age of 5 years. Due to this belief, we further explore the writing errors of children in the age-group of 6 to 8 years. As a result, the built taxonomy is further revised in two more studies and are detailed in Chapter 5th.

Evaluation of handwriting errors

We further present the types of errors that were produced and recognised by children while they provided corrective feedback. The frequencies of the produced and recognised errors are compared and are shown in the Figure 4.8. The results suggest that the children during the corrective feedback period were able to recognise only five types of errors: *missing subparts*; *merges*; *global deformations*; *position*; and *size*. As shown in the Figure 4.8, the frequency of all the five errors is lower compared to its production frequency. Additionally, these errors seem to be easily apparent for children compared to other errors. For example, missing subpart refers to an error when a part or sub-part is missing in a letter. For children, may be this error was easy to understand and therefore, they recognised this error more times compared to other unrecognised errors.

Moreover, regarding the difficulties in writing the letters, we observed that for most of the children, the letters α and π were difficult to write compared to the other letters. This difficulty might have arisen due to unfamiliarity of these letters.

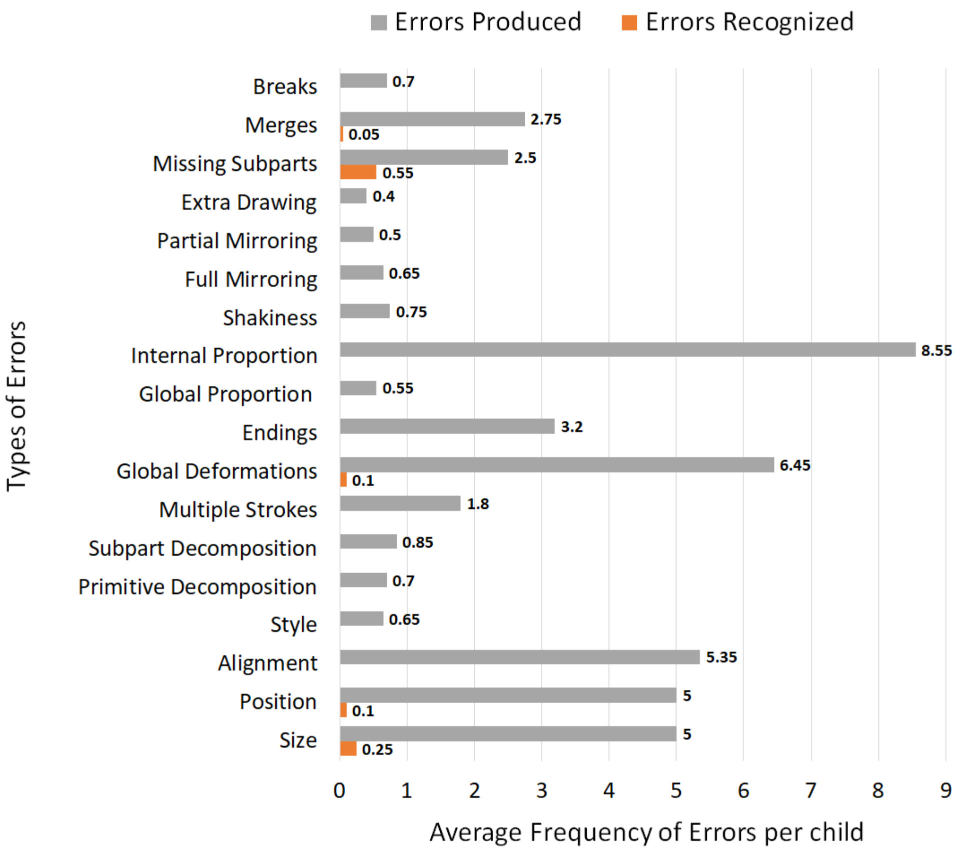


Figure 4.8 – Types of handwriting errors produced and recognised by children.

Evaluation of learning gains

Finally, to explore the impact of the two interaction methods on the children's learning, we first compared the pre-and post-test scores of the children in each condition. As depicted in Figure 4.9, the results of the exact sign test suggested that all the children showed improvement in the post-test compared to the pre-test. However, we did not find significant differences between the pre-and post-test scores of the peer-learner mode(Mean: pre-test = 0.9; post-test = .75, $z = 1.58$, $p > .05$) and peer-tutor mode (Mean: pre-test = -1.2; post-test = 0.85, $z = 1.58$, $p > .05$).

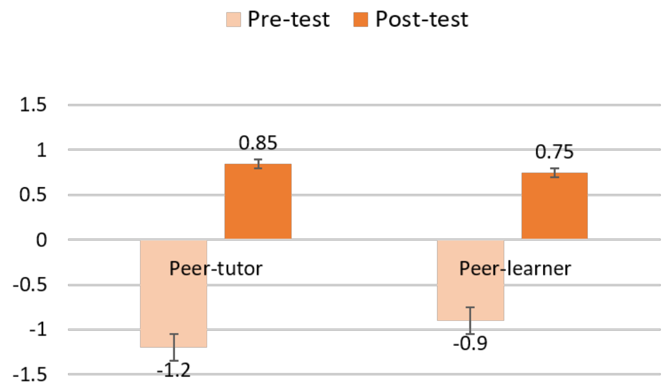


Figure 4.9 – Results of the pre-post test scores.

Furthermore, we compared children's learning gains between the two conditions. The learning gains were calculated by taking the difference between the post- and pre-test scores. As depicted in Figure 4.10, the results of the Mann-Whitney U test would seem to indicate that the children in the peer-tutor condition showed improvement compared to the peer-learner condition but no significant difference was observed $p > .05$, effect size $(r) = -0.034$.

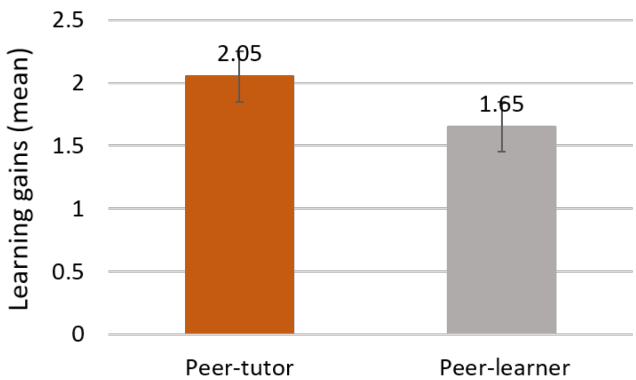


Figure 4.10 – Results of the learning gains.

4.4 Discussions and Conclusions

Understanding of the interaction modes: In general, the children were able to understand both modes, as none of the group showed difficulty in executing the writing activity according to the design steps of the interaction modes. We observed that the children were interested to participate because of the collaborative nature of the designed activity with their peers. To explore the general interest of children in both the modes, we took the notes about the curiosity of children in both conditions just after finishing each session. From the perspective of the facilitator, the children showed more excitement and curiosity in the peer-tutor mode compared to the peer-learner mode. The facilitator explained that due to the role enactment almost all the children showed enthusiasm to play a role of a teacher. On contrary, in the peer-learner mode, the children acted as peers as no specific role was assigned to them and therefore were interested to do the activity but did not show similar excitement as in the peer-tutor mode. In addition, we noticed that a few children got confused when the facilitator exchanged their roles in the peer-tutor mode. To avoid this confusion in our future studies, either we should refrain the role reversal step or conduct the study with role reversal step in two sessions with a time duration gap.

Relevance of the writing activity: Regarding the relevance of the designed activity, we observed that the children were able to perform the writing activity with their peers as none of them quit the activity in between the study. For the writing task, we included the two Greek letters α and π among other English alphabet letters to test their transfer skills. Since, the children were not familiar of these letters, all of them found it difficult to recognise and copy these letters on their sheets and tablets.

The school teacher informed us that the children daily perform the writing activity in their classroom using paper sheets and pencil/crayons. Concerning writing, we observed that most of the children copy the letters with a sense of drawing the shape of the letter instead of writing the letter. This observation suggests that since the children belong to the reception class (children belong to 4-5 years of age; prior to first grade), they are in the process of learning letters and do not necessary aware of the shapes of all the letters in advance. In the study, we used paper sheets and the writing app on tablets as a writing tool , both of these included background support lines to help children in writing a letter. In the beginning of the study, the pattern of the background lines on the paper sheets included four equally spaced lines to write a letter. While performing the writing activity, most of the children did not follow the background lines. Therefore, in between the experiment, we changed the paper sheets with a different style of background lines; the design of the background supported lines included only three equally spaced lines (similar to the lines that children practice in their school). Despite the change in the paper sheets and prompts of the facilitator, most of the children did not consider the background lines while writing the letters. It might happen because the children are still at the onset of learning letters, and therefore, they did not pay attention to the lines. Before using the tablets, we preserved some time for the children to get used to the writing features of the writing application on the tablet. Regarding the writing performance on tablets, we noticed that after attending the practice session, they felt comfortable in writing on the tablet; however, they still ignored the background lines.

Note that the first research question regarding the understanding of the interaction modes and relevance of the writing activity is based on the facilitator's experience with children and general observations on the taped videos of the study. The observations validates our first hypothesis that the children were able to understand the designed interaction mode and perform the writing activity easily.

Exploration of handwriting errors: In the evaluation of handwriting errors, we explored

that the children produced 18 types of different errors, out of which they could recognise only five types of errors during the corrective feedback. We expected that due to the impact of the designed interaction modes, the children would be able to identify at least half of the errors. However, we did not find the expected results which suggest that we may need to review our protocol.

Exploration of communication modalities: Overall the results of the study regarding the communication modalities suggests that the children provided more minimal verbal feedback compared to other modalities such as the extended verbal feedback, demonstration through a pen or finger and nodding. We believe that it could happen because of three reasons. First, due to the children's young age they were not able to formulate their feedback extensively, and therefore, preferred the minimal verbal feedback and other non-verbal modalities. The second reason is that because of their ongoing development of writing skills, they could not perceive the particular errors and consequently provided the basic feedback such as nodding and minimal verbal feedback. The third explanation could be the *egocentric stage* (Piaget, 1997) as explained by Piaget, is common in four to seven year old children where they have difficulty to understand the things from other's perspective and believe that everyone else think the same as they do. Regarding the difference in communication modalities between the two interaction modes, the findings did not show enough evidence to support any of the modalities. As a result, our third hypothesis that the children in peer-learner mode would communicate more compared to the peer-tutor mode is not proved.

Children's learning gains: Concerning the results of children's learning, in spite of their improvement in both the interaction modes, we did not find significant differences neither between their pre- and post test scores nor in their learning gains. We believe that there could be a few explanations account for this result. One is *age*, we observed that all the children belong to 4 to 5 years of age and due to which they might not be prepared for handwriting tests. These results are aligned with Barbe and Lucas (1974) as the author suggested that the readiness phase of instruction in handwriting is important and writing instructions should not be given until a child masters nine geometrical shapes described in *Berry's Developmental Test of Visual-Motor Integration* (Berry, 1989). The other explanation could be the single-session study, the literature suggests that children show improvement in handwriting skills after practicing in multiple sessions. We believe that may be one session study was not sufficient to see the significant improvements and they might need more practice. Furthermore, the small sample size of the conducted study might be a reason of not obtaining the learning improvements. As a consequence, these results do not validate our fourth hypothesis that the peer-tutor mode would enhance more children's learning compared to the other mode.

4.4.1 Limitations and Lessons Learned

After analysing the overall results, we acknowledge several limitations of the study that can be helpful in our future research in designing better educational studies involving children. The first limitation is the *sample size* of the study. Occasionally, finding a school to conduct a study with young children can be critical due to several reasons such as bureaucratic problems, finding time in children's regular classroom schedule, number of children and so on. For our study, it was difficult to find a public school due to some bureaucratic reasons, and therefore, we conducted the current study in a private International school with 20 English speaking children in Geneva, Switzerland. As we wanted to test the designed activity with children who recently started learning shapes of letters, we selected the children of 4 to 5 years of age. As a consequence, we got the reception class which had only 20 children in total. We believe that due to the small sample size of the participants, it was critical to prove the above-mentioned hypothesis especially in comparing the effectiveness of the two interaction modes.

Besides, the other limitation we observed is the *children's age*. By analysing the video data and from the researcher's point of view, we realised that the children were immature in providing the corrective feedback on their peers' writing performance due to their young age. For the next studies, we will target a bit older children to explore their communication modalities in the assessment process using the peer-based learning methods.

Lastly, the third limitation is that the study was a *single session study* where children performed the writing activity for approximately 10 to 15 minutes. We believe that the improvement in handwriting might take multiple practice sessions and one session is not enough to see the children's learning gains.

4.4.2 Conclusions

This chapter presents our first exploratory study where we examined dyadic interaction of children in the presence of a human facilitator (Chandra et al., 2017a). For this, we tested the two interaction modes based on peer-assisted learning methods: peer-learning and peer-tutoring. In general, we observed that the children well accepted both modes of interaction and writing activity. In the study, we collected the children's handwritten letters and formed a database. We further analysed the letters in the database to find the common handwriting issues produced by the children. Finally, we classified the handwriting issues and built a taxonomy of writing errors. The results concerning the communication modalities and learning gains did not present sufficient evidence to differentiate the effectiveness of the two interaction modes. More specifically, we observed that the children were immature in providing corrective feedback on their peers' writing performance due to their young age. Since the results did not show the better interaction mode among the two, we further explored the two interaction modes in the next Chapters. The Co-Writer project aims to explore how a social robot can help children in acquiring handwriting skills. In the next chapter we investigate the impact of integrating a robot in the similar educational setting.

5 Impact of a Robot vs. Human Facilitator in Collaborative Writing

We have previously explored the dyadic interaction between children in the presence of a human facilitator in a collaborative writing activity. In this chapter, we present a study that examines the impact of integrating a robot vs. human facilitator in a scenario where a pair of children perform a similar collaborative writing activity. The study relies on the peer-tutoring learning approach; which boosts learning, provide clarity and enables responsibility in participants (Boud et al., 2001; Keppell et al., 2006). Further, we investigate children's responsibility towards their peers in the presence of each facilitator. Moreover, we examine children's interpersonal distance in terms of verbal and non-verbal communication with both facilitators.

5.1 Scope and Research Goals

Significant work on educational robotics adopt a collaborative setting where both learners and robots interact. In such settings, specific types of interactions (such as participants assessment on their peers) between learners are expected to occur. Yet, there is no guarantee that these interactions will actually occur. However, we can increase the probability of the occurrence of these interactions by setting up the initial conditions, by specifying the roles of participants in the scenario, or by controlling and monitoring the interactions (Dillenbourg, 1999b). The *peer-tutoring* has been shown to be an effective method to support student's learning. This approach allows students to prepare and teach lessons in their own way. In addition to preparation of lessons, the teaching process includes three aspects of learning interactions: structuring, taking responsibility, and reflecting. A study by Biswas et al. (2004b) shows that the students who teach acquire profound knowledge about the domain and are able to express their ideas more clearly than those who learn the same material by writing a summary. Biswas et al. (2005); Chase et al. (2009) further explored the protégé effect on students using the learning-by-teaching method (also called as peer-tutoring) where they use a teachable agent (virtual). The protégé effect is a result of the phenomenon when students make greater efforts to teach others to perform better rather than putting efforts for their own learning. They found that the students spent more time in learning and performed better when they taught the agent. Bargh and Schul (1980) concluded in their study that the participants who teach other participants about a passage scored more in a quiz comparing with those who did not teach. In the field of educational robotics, Tanaka and Matsuzoe (2012) used the NAO robot[1] as a care receiving interactive agent. In their work, children taught the robot using the peer-tutoring method and the results suggested that the care-receiving robot contributed to the enhancement of the children spontaneous learning and motivation. Similarly, Hood et al. (2015) also used NAO robot where children taught handwriting to the robot using the same method. With the intention of exploiting the benefits of the learning approach, we rely on the peer-tutoring (also called learning-by-teaching) approach in the current study.

Robots are used to play different roles in an education context, such as a tutor, an assistant and a learner. For example, Kanda et al. (2004b) used Robovie, a humanoid robot, as a social partner and peer tutor in a field trial. The results of the trial showed that robots could form relationships with children, and also that children may learn from robots as they learn from their peers. Similarly, several studies have used the peer-tutoring approach (Biswas et al., 2005; Roscoe and Chi, 2007), where a robot enacts as a peer learner rather than a teacher (Kanda et al., 2007; Tanaka and Kimura, 2009, 2010; Hood et al., 2015). Apart from the roles of a teacher or a learner (Deshmukh et al., 2013; Castellano et al., 2013), robots are also used as a human-teacher assistant, for example, Alemi et al. (2014) used the Nao robot as an assistant to a human-teacher in teaching English as a second language to Iranian students.

In the current study, by following the similar interaction scenario of the child-child study (the first study), we compare the dyadic interaction of children in the presence of a human adult vs. a robot; thus, we attributed the role to the robot and human adult as the *facilitator* .

Furthermore, when designing interactions with robots, one of the critical elements is *proxemics*; the amount of phychological and physical space that people feel necessary to set between themselves and others (Hall and Hall, 1969). Research in human proxemics has been extensively studied and models have been developed to explain human-robot behaviour in terms of verbal and non-verbal communication (Mumm and Mutlu, 2011). In the present work, we will use two models for the characterization of the *interpersonal distance* (psychological proximity) of children established with the robot and human facilitator, namely the *reciprocity* and the *compensation* models as described below: (see Chapter 2 for detailed description).

Reciprocity model

This model explains the psychological and interpersonal distance between people. According to this model, during an interaction, when one person decreases the distance (or increases closeness), the other reciprocates by increasing the closeness (Jourard and Friedman, 1970; Gouldner, 1960).

[1]Aldebaran robotics: `https://www.aldebaran.com/en`.

Compensation (or Equilibrium) Model

According to the *Compensation model* developed by (Argyle and Dean, 1965), there is an equilibrium for physical proximity and eye contact between two individuals. If this equilibrium is disturbed in one of its constituent dimensions, for example, by increasing physical proximity there will be complementary changes along the other dimensions.

5.1.1 Motivation and Contributions

In the peer-tutoring paradigm, interactions between learners can lead to more *responsibility* and *reflection* (Stone et al., 2013; Mynard and Almarzouqi, 2006; Medway and Lowe, 1980). For the purposes of the research work, we will focus on the notion of *responsibility* in human-robot interaction and explore it with a concrete scenario where two children (one acting as a *teacher* and another as a *learner*) interact with the help of a *facilitator*, which can be either a robot or a human. *Responsibility* in teaching relates the way a teacher responds in a particular moment to a particular student (Sherman, 2004). Additionally, a tutor tends to feel more responsible when the tutoring includes assessment in terms of immediate feedback to a learner's performance (Asghar, 2010). In the similar vein, the current study examines children's responsibility in terms of the verbal feedback given by the *teacher*-child to the *learner*-child over the latter's performance in writing, in the presence of a facilitator (a robot or a human).

Furthermore, psychological distancing in human-robot interaction is one of the important factors that facilitate interaction. Although some studies have explored physical distancing in HRI (Takayama and Pantofaru, 2009; Walters et al., 2005a), less attention has been given to the *interpersonal distancing*, specifically in child-robot interaction (Mumm and Mutlu, 2011). In the current study, we sought to provide a contribution to the HRI field by using the models of interpersonal distancing, *i.e.*the reciprocity and compensation models; to explore verbal and non-verbal cues in an educational context. Furthermore, we wanted to investigate how the presence of a robot facilitator would influence the interaction between children and how it may differ from the scenario where a human facilitator is present.

One of the limitations of the child-child study (the first study) was the age-group of the children, as they were immature to provide the corrective feedback on their peer's performance. Therefore, in the current study, we targeted children of six to eight years of age to further explore their feedback while following the similar interaction scenario of the previous study.

5.1.2 Research Questions and Hypothesis

The current study explored the impact of a robot vs. a human on children in an educational scenario based on the peer-tutoring approach. The scenario consists of a pair of children where one acts as a teacher and the other as a learner. And they perform a writing activity in the presence of the robot or human adult, as mentioned above, the robot and the human adult enact as a facilitator where they provide task instructions and prompts required during the study. The impact of the human adult and robot on children is measured related to children's corrective feedback, gaze, interpersonal distancing, responsibility and learning outcomes. Overall, the goal of this study concerns the investigation of children's responsibility given the assigned roles in a collaborative learning activity. In addition, we studied the children's models of interpersonal distancing that emerged in the presence of a human or robot facilitator during the interaction. Our research questions and hypotheses for the study are presented as follows:

- **Research Question 1:** The enactment of being a tutor brings self-responsibility in terms of providing feedback to a learner. Thus, we wanted to explore the children's responsibility towards their peers in both conditions. Our first research question is as follows: would tutor-children's responsibility towards the learner-children differ between the conditions? Which condition would evoke more responsibility?

  Hypothesis 1: We hypothesise that the children who plays a role of a teacher will express more responsibility in terms of giving feedback to their peers in a condition where the robot is present because they might take the robot as a non-authoritative figure and may feel responsible to critically respond on their peer's performance. On contrary, with the human-facilitator they may consider the facilitator as an authoritative figure (*e.g.*teacher) and might not give critical feedback.

- **Research Question 2:** Would children learning scores improve in both conditions? Would their learning gains differ in both the conditions?

  Hypothesis 2: Due to the proved benefits of the peer-tutoring learning method, we hypothesise that the children would benefit in both conditions in terms of their learning scores. In addition, as the facilitator (robot or human) provides equal task information to the children, the learning gains will not differ in both conditions.

5.2 Study 2- The Robot vs. Human Facilitator's Study

5.2.1 Participants

We conducted the study with 40 Portuguese speaking children in the age group 6 to 8 years (1^{st} and 2^{nd} grade) in 'Escola 31 de Janeiro'in Parede, Portugal. It followed the ethical norms of privacy and responsibility of HRI studies (Riek and Howard, 2014). Besides, only children who assented for the study and whose parents signed the consent form participated.

5.2.2 Materials

The materials used in the study consisted of two tactile tablets running Apple iOS with stylus installed with a custom writing application[2]. The writing application was specifically developed for the study with dual interactive feature. Also, we created 4 colorful cards, each

[2]We used the same application as in the previous study and was developed by my colleague.

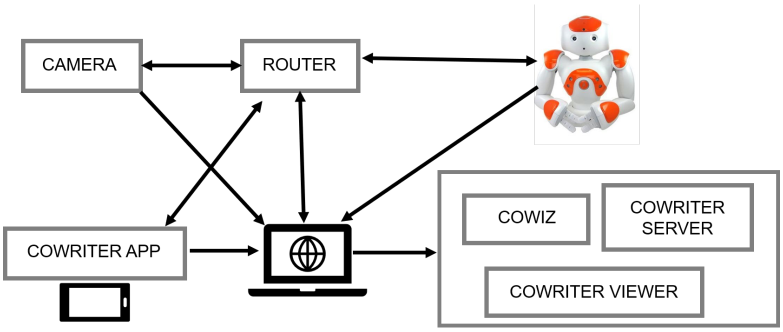


Figure 5.1 – Technical setup.

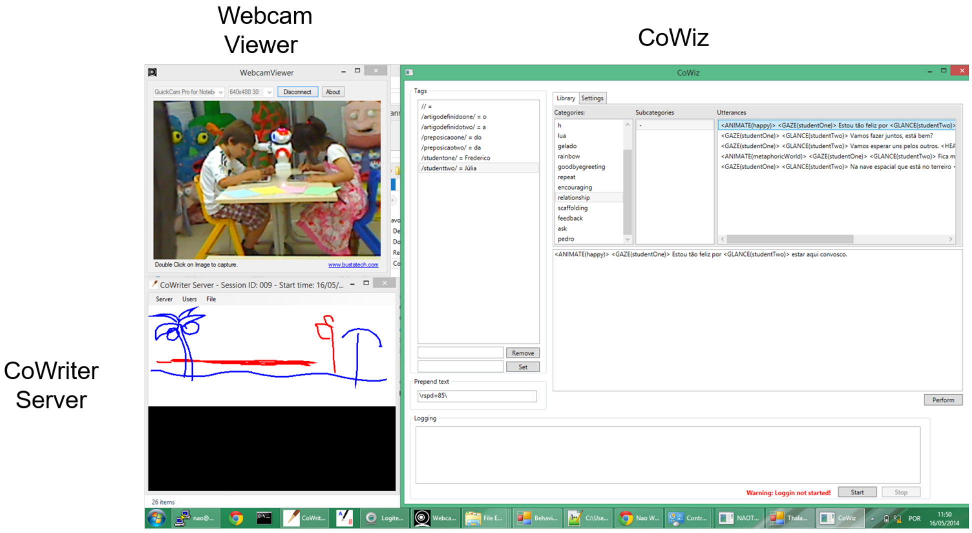


Figure 5.2 – WoZ interface.

written with a letter or word such as h, Lua [3] (moon), gelado (ice-cream), and Rainbow(see Appendix C). For the pre- and post-test we used a sheet with letters (j, D, K, y, W, t, α, and π)(see Appendix C). In terms of the technical setup, 3 video cameras, 2 microphones, a computer running MS Windows 8, a pair of headphones, 1 USB webcam and a NAO torso as the robot facilitator were used.

5.2.3 Platform

As shown in Figure 5.1, the cameras, tablets, computer and robot were connected to wireless router that functioned as the central access point. A Wizard-of-Oz (WoZ) interface application[4] is shown in Figure 5.2, which can be seen by the wizard on the computer screen during

[3] As the study was performed in a Portuguese school, the words, Lua(moon) and gelado(ice-cream) were presented in the Portuguese language.

[4] The CoWriterWiz and CoWriterServer application were developed by the other colleague who was involved in the research project.

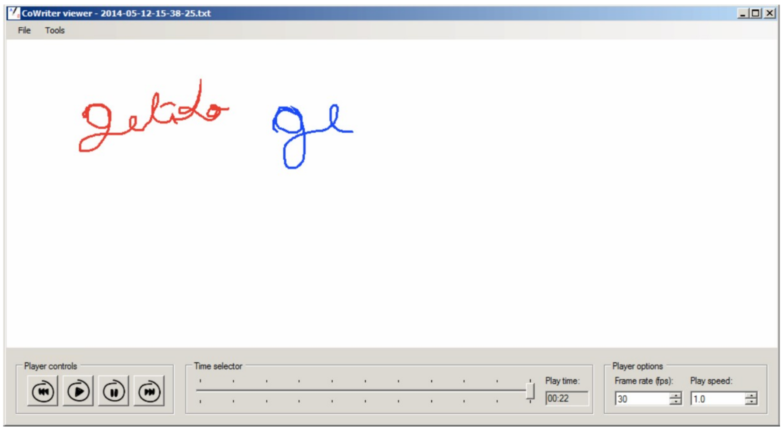


Figure 5.3 – CoWriter viewer application.

the experiment. The Nao robot and the WoZ interface application were connected through the high-level integration framework *Thalamus* (Ribeiro et al., 2014a,b), which was responsible to accommodating social robots and possibly to including virtual components such as multimedia applications. In addition, we used a semi-autonomous behavior planner named as *Skene* (Ribeiro et al., 2014b) to provide the robot's behavioral actions such as gazing, pointing, speech, gestures.

The WoZ interface consisted of four applications: 1) *CoWriterWiz (CoWiz)*; 2) *CoWriterServer*; 3) *CoWriterViewer*; and 4) *Webcam Viewer* as described below:

CoWiz: This application was developed to control the robot's behaviors(see Figure 5.2). It presented a list of categories and subcategories representing dialogue dimensions under which utterances were organised. This allows the Wizard to browse through the categories and subcategories to find appropriate utterances. A selected utterance could be played directly or changed manually before being sent for execution. For this purpose, a text-editable area was provided at the bottom of the interface. This allowed the Wizard to improvise utterances that had not been previously anticipated. The left part of the CoWiz app provided a list of replacable tags that could be filled by the Wizard before each session with information such as children's names. And these tags were previously introduced into the utterances to be replaced each time they were called. The dialogue utterances could also include non-verbal instructions such as gaze, glance, animate, point and headnod. The utterances were sent to Skene which deals with performing the non-verbal instructions at the correct moment based on the order they appeared in the utterance. This allowed the Wizard to control the verbal and non-verbal behavior at the same time. Skene also dealt with some semi-autonomous behaviors such as breaking-gaze with the children by glancing away, so that the Wizard did not have to control all the behaviors.

CoWriterServer: This application[4] was used to manage communications between the tablets in order to visualize and store the drawings of letters and words performed by children during the experiment in real-time. For writing activity, a writing app named *CoWriterApp* was designed and installed in tablets to provide a dual user interactive feature, which displays the

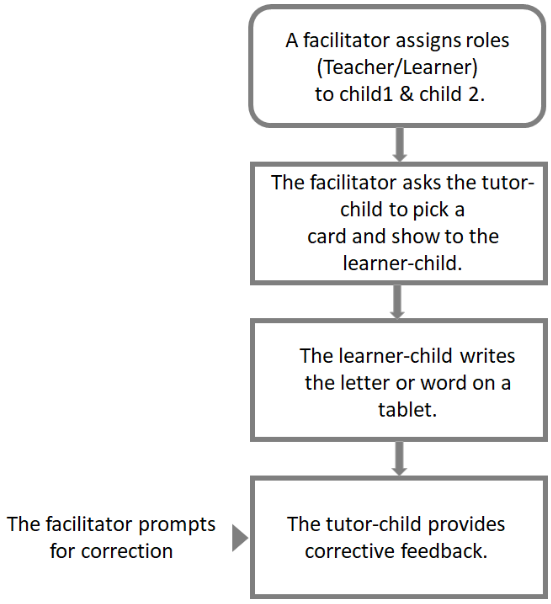


Figure 5.4 – Mode of Interaction: Peer-tutoring.

shapes being written on one tablet onto the other tablet. The app on each tablet displayed shapes with a different color to distinguish the writings of one child to the other (see Figure 5.3). This interactive capability allowed children to correct each other on their own tablet in real-time. In addition, it also has an eraser button, which a child could use to erase his/her writing. This application provided data that included the shapes drawn by the children and the time at which each point in the shapes were drawn. The application also allowed the real-time visualisation of the shapes allowing the Wizard to observe what each participant was drawing throughout the interaction (see Figure 5.2). The data of the interaction was saved automatically every time when one of the following events occurred: 1) one of the participants erased their drawing through the button; 2) every 5 minutes of interaction; and 3) a new session started.

CoWriterViewer: This was developed to perform offline visualisations of children's drawings from the tablets during each interaction and to export images and videos of the interactions. The application allows the observation of the shapes being drawn just like the subjects drew during each interaction. It also has the player like features to allow the user to play, pause, end, start the animation and change the speed and rate of the animation. The user could also export the current image of the animation and export image sequences, video files depicting the whole 'drawing' session to view in a common video player.

Webcam Viewer: This application was used to provide a real-time visualisation of the participant's behavior during the interaction. Hence, allowing the Wizard to understand the current tsate of the interaction between participants and the robot, and consequently allowing the Wizard to control the behaviors of the robot timely by seeing the behaviors of the participants (see Figure 5.2).

5.2.4 Conditions

To examine the impact of a robot versus a human facilitator, the study consists of a between-subjects design with two conditions: one in which a pair of children performs a collaborative learning activity with a *robot facilitator*, and another where the same activity is performed with a *human facilitator*. In both conditions, the learning-by-teaching method was used by assigning a different role to each child: either that of a *teacher* or a *learner*. The *teacher*-child was then asked by the facilitator to provide *corrective feedback* Bitchener (2008) on the performance of the *learner*-child.

In the study design, the dynamics between the participants (both children and the robot) is triadic but the interaction between the children is dyadic. Since the study was conducted with 6 to 8 years old children, the role of the facilitator was to support the interaction flow between children. In order to exploit the benefits of the learning-by-teaching method, we want to explore the dyadic interactions between the children in the presence of both a robot and a human facilitator. The validation of the study also includes the analysis of the learning gains in both conditions.

Since we were targeting children with 6 to 8 years of age, we designed the writing activity considering their grades (1^{st} and 2^{nd}) and writing skills. As mentioned above, we chose the learning-by-teaching paradigm and simultaneously attempted to design the activity that was simple to understand, engaging and playful. The interaction scenario followed the first study where a pair of children perform a collaborative writing activity with a facilitator. The role of the facilitator was to provide the task instructions and prompts to the children during the activity. The interaction between the children and the facilitator is described in Figure 5.4. The two conditions are explained as follows:

- **Condition 1:** A robot acts as a learning facilitator and interacts with the two children during a collaborative educational activity designed according to the learning-by-teaching method (one child plays the role of the teacher while the other the role of the learner).
- **Condition 2:** This condition is similar to Condition 1 but instead of employing a robot facilitator, we employed a human facilitator.

Both facilitators provide the same task information to the children. We designed the script of the interaction in advance and both facilitators followed the same script. For example, the sequence of the dialogues and the prompts(dialogues regarding the corrective feedback) were the same. For the robot's gestures, we prepared the animations before hand and the human facilitator followed the natural interaction behavior. In addition, none of the facilitators showed excess of social behavior.

5.2.5 Protocol

Figure 5.5 shows the classroom setup of the study. Each session was performed with a pair of children and a facilitator according to one of the conditions and lasted between 15-20 minutes.

Figure 5.5 – Classroom overview.

(a) (b)

Figure 5.6 – (a) Condition 1: children with the robot facilitator; (b) Condition 2: children with the human facilitator.

We used a Wizard-of-Oz (WoZ) procedure in which a robot is remotely controlled by a human, referred to as the *Wizard*, when interacting with research participants. The participants are unaware that the robot is being remotely controlled, and the method is commonly used within the field of HRI (Dahlbäck et al., 1993). In our study, a psychologist acts as the Wizard and present in the classroom (where the study took place) but hidden from the participants. Before initiating the study, the human facilitator went through a training phase to memorize the predefined script. Therefore, both the human and robot facilitator used the same script during the study. In the human condition, whenever a child asked questions to the facilitator, she gave neutral answers as to avoid discrepancies between the conditions. Condition 1 was performed with 24 children (12 pairs)(see Figure 5.6a) and the Condition 2 with 16 children (8 pairs)(see Figure 5.6b). All children performed a pre- and a post-test, *i.e.*before and after the learning activity with the facilitator. The study was thus organized in three main phases:

Phases 1 & 3: Pre- and post-test: In this phase a researcher asked the two children to individually copy the given letters (j, D, K, y, W, t, α and π) on a paper sheet (see Appendix C). This activity served as a pre-test and was repeated after Phase 2 thus serving also as a post-test.

Phase 2: Learning activity with the facilitator: After having completed the pre-test, the children were guided to the study setup in the same classroom and were instructed to sit around the table with the facilitator. The researcher explained that they were going to perform a collaborative writing activity on a tactile tablet with a robot/human facilitator. The researcher then left the room, leaving the children with the facilitator. The interaction pattern of the learning activity in both conditions of the study progressed as follows:

- **Welcome greeting:** The first step of the interaction pattern concerned the introduction of the facilitator and the children. Given the very young age of the children, this step was especially important in condition 1, as most children had never seen a robot before and needed some familiar ground to start the interaction.

- **Tutorial:** The second step concerned the explanation of the activity to the children by the facilitator. Following the explanation, the facilitator assigned two roles to the children: one child was instructed to play the role of a teacher and the other the role of a learner. Roles were randomly assigned by the researcher. Following the learning-by-teaching method of education, the *learner*-child wrote the letters and words on the tactile tablet, while the *teacher*-child was responsible to provide corrective feedback on the task performance of the *learner*-child in whatever ways were possible, *e.g.*by writing on the tablet a correction, or by verbally expressing it. During the writing activities, the facilitator ensured the educational interaction between the children would flow smoothly. After this tutorial part, some time was reserved for the children to draw freely on the tablet in order to make them familiar with the application dynamics. Moreover, the assigned roles of the children were not altered throughout the session to make the interaction simpler for them.

- **Peer activity:** The third step of the interaction pattern was dedicated to the learning activity between children and the facilitator. During the writing task, four different coloured cards with a different letter or words were placed on the table facing down. As the activity progressed, the facilitator asked the *teacher*-child to pick a card and show it to the *learner*-child so that he/she could write the letter or word on the tablet application. After the *learner*-child finished writing such letter/word, the *teacher*-child was instructed to provide corrective feedback. After that, the facilitator prompted the *teacher*-child to ensure that all corrections were provided. This process then repeated until all 4 coloured cards were picked. The cards were introduced with increased difficulty level, *i.e.*by increasing the word length. The last card to be picked was the word Rainbow as it represented the longest and unknown (English) word.

- **Goodbye greeting:** The activity was terminated by having the facilitator thank the children for their time.

5.2.6 Analysis

In order to analyse the interactions we performed video and audio analysis of all the sessions by coding and annotating verbal (corrective feedback) and non-verbal (Gaze) behaviours of both children and the facilitator. The annotations were performed with two independent coders using the ELAN multimedia annotation tool [5]. In addition, pre- and post-test sheets were also graded by the coders. In terms of the reliability of the participants' behaviours, Cohen's kappa showed 0.84 of agreement for verbal behavioura and 0.92 for the gaze behaviour, indicating a good agreement. The Welch Two-Sample t-test was further conducted to analyse both verbal behaviour and non-verbal of the facilitator and the children.

Regarding the pre- and post-test data, once again, two independent coders analysed each letter based on its legibility by comparing it to the correct sample of the letter (target lettercard that was displayed during the study). The coders rated each letter in the scale of 1 to 3 and the coding metric is given as follows:

1 = unreadable; if the letter is illegible and can not be recognised as a target letter.

2= readable; if the letter is legible but contains several errors such as missing sub-trajectory and alignment (present in the previous taxonomy).

3= identical; if the letter is legible, written similar to the the target letter and does not contain any errors.

In terms of the reliability of the participant's pre-/post-test scores, Cohen's kappa showed agreement values of 0.96, indicating a good agreement. We conducted the Sign test and Ma-Whitney test to analyse children's pre-/post-test scores and learning gains.

5.3 Findings

5.3.1 Responsibility in Teaching

Corrective feedback is the response regarding the corrections made by a child upon the performance of another child in the assessment process. Table 5.1 presents the definitions and examples of the types of annotated corrective feedback. In the study, we evaluated the children's feedback and classified them as either *minimal* or *extended* according to (Kahn Jr et al., 2012; Bitchener, 2008). Although most of the feedback between children was directed through the facilitator (prompts - given the several questions made during the activities), it is important to consider the dyadic interaction between children in which the feedback relates

[5] `https://tla.mpi.nl/tools/tla-tools/elan/`

Table 5.1 – Verbal Behaviour.

Verbal behaviour	Definition	Example
Corrective Feedback (minimal)	Minimal response related to the corrections of the letters and words.	Facilitator: *Is the shape of the letter correct?* *Teacher*-child: *Yes*
Corrective Feedback (extended)	Extended response related to the corrections of letters and words.	Facilitator: *Is the shape of the letter correct?* *Teacher*-child: *No, it's not. This part should be round.*

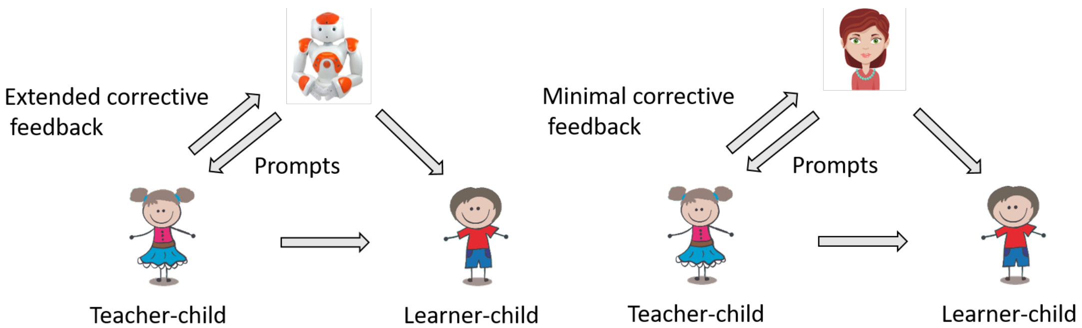


Figure 5.7 – Extended and minimal corrective feedback in the robot and human conditions.

the other child's performance. Therefore, we considered the corrective feedback provided by the *teacher*-child to the *learner*-child as a response through the facilitator. An example of interaction is given below.

> After learner-child finishes writing a word:
> Facilitator: *Do you think the word is written correctly?*
> Teacher-child: *No, I think it should be more curved here and written in the same size.*
> After the corrective feedback given by the *teacher*-child, *learner*-child addresses the corrections on the tablet.

The result of Welch's Two-sample t-test between the two study conditions suggests that the *teacher*-child gave more extended corrective feedback to the *learner*-child through the robot facilitator ($df = 20.373$, 95% CI$[-2.60, -0.29]$); $t = -2.6071$, $p = 0.01671$, $Mean$(Learner-child) = 0.15, $Mean$(Teacher-child) = 1.66 (see Figure 5.8b). On the other hand, we found that the *teacher*-child gave more minimal corrective feedback to the *learner*-child through the human facilitator ($df = 23.0$, 95% CI$[-2.3779970 - 0.1066184]$); $t = -2.2625$, $p = 0.03339$, $Mean$(Learner-child) = 0.30, $Mean$(Teacher-child) = 1.5 (see Figure 5.8a).

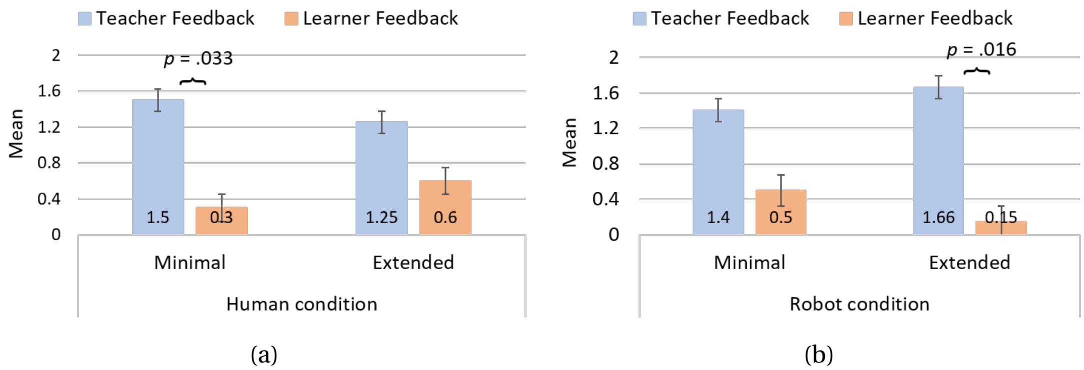


Figure 5.8 – Results of the corrective feedback between teacher-child and learner-child in the: (a) human; and (b) robot conditions.

Table 5.2 – Non-verbal Behaviour (Gaze).

Gaze Behaviour	**Definition**
Gaze at task	When children or the facilitator look at task, *e.g.*tablet, stylus, sheets.
Gaze at participants	When children look at human or robot facilitator. When the facilitator looks at children (teacher-child or learner-child). When children look at each other.
Gaze elsewhere	When participants look elsewhere.

Because the *teacher*-child was instructed to play the role of a teacher, we already expected that all *teacher*-children would provide more corrective feedback in comparison with the *learner*-children. Nevertheless, the interest of the results regarding corrective feedback lies on the type of the feedback (minimal or extended) that the *teacher*-children provided to the *learner*-children in both conditions (Figure 5.7).

In that respect, the *teacher*-children provided more of both types of feedback, particularly extended to the *learner*-children in the robot condition which suggests that the *teacher*-children felt more responsible over the performance of *learner*-children in the presence of the robot facilitator compare to the human facilitator (Figure 5.8b). These results support our first study hypothesis that the children feel more responsible in the presence of a robot facilitator. Further discussion is provided in Section 5.4.

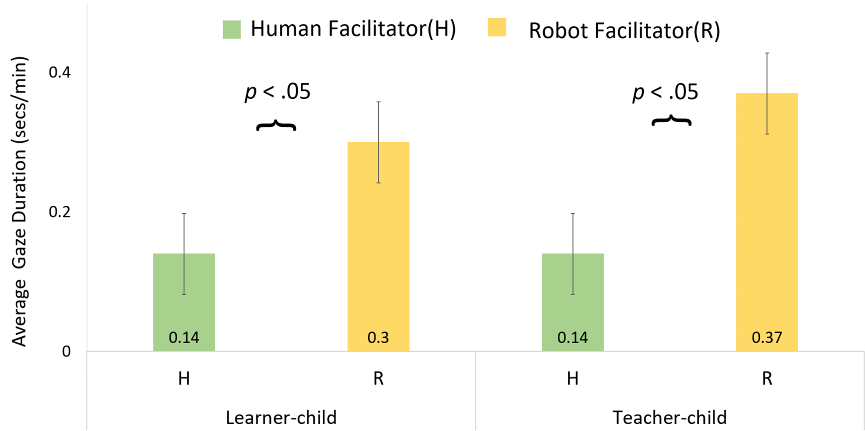


Figure 5.9 – Gaze duration of the facilitator (robot/human) to the *learner*- and the *teacher*-children.

5.3.2 Interpersonal Models of Interaction in Education

Interpersonal models of interaction were analysed by combining the results concerning the above-mentioned corrective feedback and following analysis of facilitator's gaze.

Gaze of the facilitator

The gaze behaviours of the robot and human facilitators towards the children were analysed in terms of gaze position and duration. Table 5.2 presents the annotated gaze positions. The eye-gaze model of the Nao robot was restricted due to its embodiment. The gaze behavior of the robot only includes movement of head and blinking of eyes, and hence, can not be used to perform eye gaze movements similar to human gaze behavior. For example, when the robot asked a question to a child, it would look at him/her for the required time by moving only its head instead of being able to perform gaze shifts with its eyes. In contrast, in the human condition there was no constraint for gazing at children, resulting in a natural gaze behaviour.

The results show that, in comparison with the human facilitator, the robot facilitator gazed for a longer time both to the *teacher*-child ($df = 17.88$, 95% CI$[-0.26, -0.18]$); $t = -11.2409$, $p = 1.547e^{-9}$, M(Human) = 0.14, M(Robot) = 0.37, and the *learner*-child ($df = 16.069$, 95% CI$[-0.20, -0.12]$); $t = -8.7743$, $p = 1.585e^{-7}$, M(Human) = 0.14, M(Robot) = 0.30. Figure 5.9 shows the average duration of the gaze of the facilitators to the children in gazing seconds per minute of interaction, normalized according to the length of each session. For instance, the human facilitator gazed 0.14sec/min to the *learner*-child while spending 0.86sec/min looking at the task or elsewhere. These results occur mainly due to the way the robot was programmed in the study.

Interpersonal distance

As mentioned before, we explored the interpersonal models emerged during the interaction between the participants. For this purpose, we computed the interpersonal distance between the children and the facilitator by relating the results of the facilitator's gaze and the children's corrective feedback. The gaze results of this analysis are depicted in Figure 5.9 and suggest that the robot facilitator looked longer while asking questions to both children, compared with the human facilitator. In addition, the *teacher*-children provided more extended corrective feedback to the *learner*-children through the robot facilitator (Figure 5.8b)—in this manner, the interaction between the robot and the *teacher*-child seems to follow the reciprocity model of interpersonal distancing. It suggest that gazes of the facilitator and corrective feedback of children are of reciprocal nature. On the other hand, the human facilitator looked for a shorter duration to both children and all *teacher*-children gave more minimal corrective feedback over the learner's performance through the human facilitator—as a result, the interaction between the human facilitator and *teacher*-child seems to follow the compensation model of interpersonal distancing. Overall, these results suggest that the different interpersonal models could emerge depending on the facilitator.

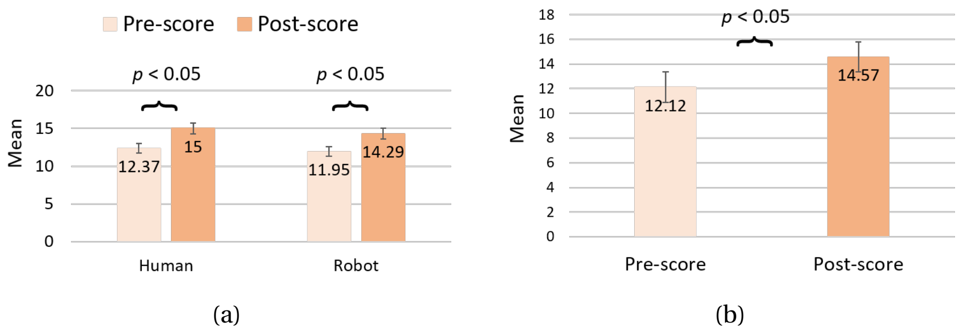


Figure 5.10 – Results of the pre- and post-test scores : (a) in human vs. robot condition; and (b) of all the children (combining both conditions).

Learning gains analysis

In order to analyze how the presence of robot or human facilitators affects the learning of children, we first measured their learning gains in each condition. Then, we compared their learning gains between the two conditions. Pre- and post-test sheets were graded by giving a score to each letter written by children in the sheets.

As shown in Figure 5.10a, the results of the Sign test suggest that there is a significant difference between pre- (mean = 11.95, median = 12) and post-test scores (mean = 14.29, median = 15) of the children in the robot condition, $Z = -3.8$, $p = .000$, effect size $(r) = -0.54$. Out of twenty-four children, nineteen elicited an improvement and five remained with no improvement (equal pre-post scores). Similarly, we also found significant differences between the pre- (mean = 12.37, median = 12)and post-test scores (mean = 15, median = 15) of the children in the human condition, $Z = -3.4$, $p = .001$, effect size $(r) = -0.60$. In this condition, out of sixteen children, fifteen showed positive improvement and one remained with no improvement. In addition, none of the child in both conditions got less post-test scores than the pre-test scores. Further, when we compared the pre- and post-test scores of the children combining the two conditions, we found that all the children performed significantly better in the post-test (mean = 14.57, median = 15) compared to the pre-test (mean = 12.12, median = 12), $Z = -5.12$, $p = .000$, effect size $(r) = -0.57$, see Figure 5.10b.

Moreover, regarding the learning gains, the results of Mann-Whitney test did not show difference between the robot (mean = 2.3, mean rank = 19.56) and human condition (mean = 2.6, mean rank = 21.91), $U = 169.5$, $z = -.63$, $p = .53$, effect size $(r) = -0.099$ (see Figure 5.11). **These results indicate that the children learnt more with the human facilitator compared to the robot facilitator, but the difference is not significant.** As such, these results do not validate our second hypothesis that the children's learning gains will not differ in the two conditions.

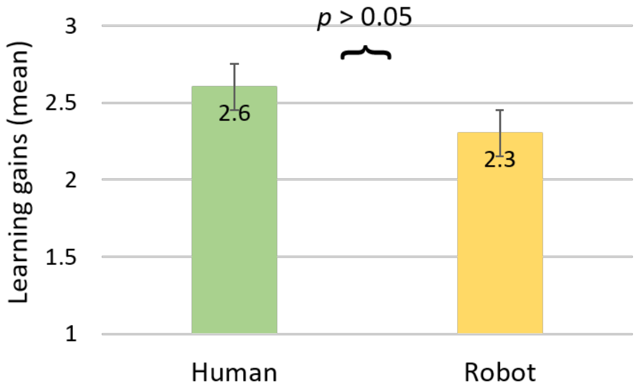


Figure 5.11 – Learning gains in human vs. robot facilitator condition.

5.3.3 Task Progression

In order to study whether the progression in the learning activity for both teacher- and *learner*-children was similar in the presence of a robot or human facilitator, we analysed the duration time of each task-step. The duration of each task-step was measured in the following manner:

- **Tutorial:** Duration measured from drawing start to the first coloured card was picked;
- **H, Lua, Gelado, Rainbow:** Duration measured whenever a card was picked until the next card was picked.

Additionally, the task-steps duration contained all the interactions, *e.g.*corrections, instructions by facilitator, etc. The average duration is depicted in Figure 5.12 showing the task

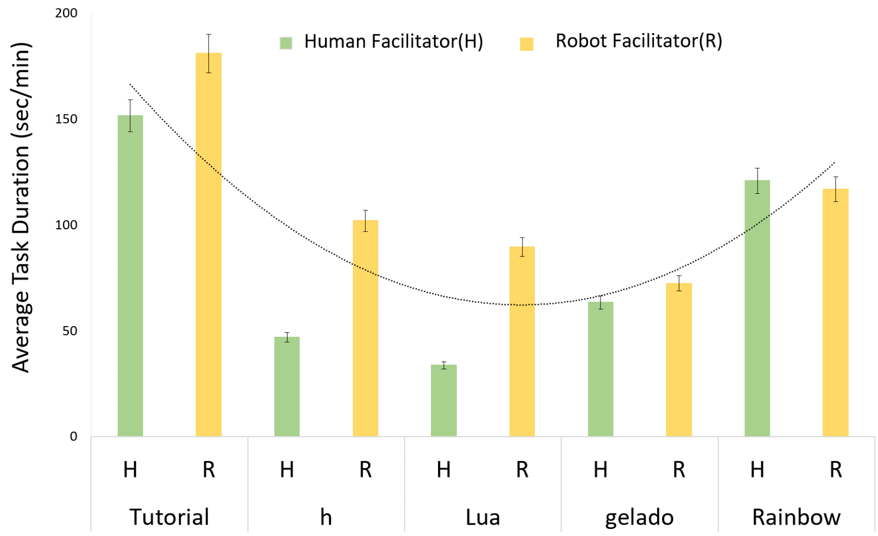


Figure 5.12 – Tasks duration across the study conditions.

approach of children in the presence of different facilitators. It also presents the relation between the task-step difficulty levels and the time spent finishing them. The results suggest that the task progression pattern with a robot facilitator was similar to the pattern with a human. Furthermore, it indicates that the children's approach to the overall task is the same irrespective of different facilitators. Moreover, Figure 5.12 shows there is a pattern in terms of the duration of task-step, suggesting a relation between each task-step difficulty level and the time spent on it, *i.e.*that children spent more time on the task-step related with more difficult levels.

5.4 Discussions and Conclusions

The goal of this study was to explore the child's *responsibility* in a collaborative learning activity using the learning-by-teaching method in the presence of either a robot or a human facilitator.

Responsibility: The results of the study suggest that the *teacher*-children felt more responsible over the *learner*-children's performance in the presence of robot facilitator. In this context, responsibility is concerned with the type of verbal feedback given by the *teacher*-child to the *learner*-child. Verbal feedback is an expression of responsibility that shows the *teacher*-child's engagement with the *learner*-child. Extended corrective feedback increases this engagement in comparison with the minimal corrective feedback as more information is provided to the *learner*-child on his/her performance. As a result of our study, *teacher*-children expressed more responsibility in the presence of the robot as he/she provided more extended corrective feedback.

Children's learning: Children's learning is one of prime the expectation of conducting an educational study in order to explore the impact of the study on their learning outcomes. In our study, we also anticipated their learning improvements; however, we hypothesised that the learning gains will not differ in both conditions. The results of the learning scores shows that the children significantly improved in the presence of both facilitators: human and robot. This may suggest that itself the designed writing activity was effective irrespective of the type of the facilitator. We believe that the obtained results may be due to the impact of the peer-tutoring learning method; where the enactment of a teacher and a learner influenced children's learning. As a consequence, **irrespective of the source of the task instructions: robot or human adult; the children performed better in the post-test.** Therefore, the results did not show significant difference in the learning gains between the robot and human condition, revealing a similar learning pattern in both conditions.

Interpersonal Models of Interaction: The emergence of different interpersonal models was also studied during a collaborative learning activity in the presence of different facilitators. In that respect, the results suggest that by having a robot facilitator, a *reciprocity model* of interaction emerged Hall and Hall (1969); Mumm and Mutlu (2011), thus showing the presence of reciprocity and closeness between the children and the robot facilitator. The reciprocity also indicated an increased verbal behaviour (extended corrective feedback) by the children as a response to the robot's increased gaze behaviour. On the other hand, by having a human facilitator, a *compensation model* of interaction emerged, indicating an increase in the children's verbal behaviour (minimal corrective feedback) related with human's decreased gaze behaviour Hall and Hall (1969); Mumm and Mutlu (2011). Establishing and maintaining the appropriate interpersonal distance may increase the fluidity in interactions with the robot Mumm and Mutlu (2011). In that respect, the interpersonal models emerged in this study will support the design of more rich behaviors of robots in educational scenarios.

5.4.1 Limitations

We recognise a few limitations of the study. First of all, in our study we had unequal sample size of participants between the conditions. The condition with the robot facilitator had 24 children while the human facilitator condition had sixteen children. Before conducting the study in the school, we did not get all the consent forms. We collected some of the forms while running the study, consequently, we could not assign equal number of participants in each condition. However, for the analysis of the data, we chose the statistical tests which took care of the unequal sample size data and did not affect the results.

The literature suggests that the when a tutor provides extensive corrective feedback, it provides clarity of his/her domain knowledge and enables knowledge construction. As such, the second limitation is that we did not explore how children's corrective feedback affected other aspects of interaction and their learning. In addition, the type of the feedback is important as it may elevate children's responsibility towards their peers. But the current study lacks this exploration.

To understand profoundly the aspects of an educational activity that may affect children's learning and interaction behavior, it becomes important to explore the children's perception. The other limitation of the study is that we did not investigate children's perception towards the robot and the designed activity.

5.4.2 Conclusions

The chapter presents a study that specifically explores the influence of integrating a robot vs. human facilitator on children in an educational scenario (Chandra et al., 2015). The scenario consists of a pair of children performing a collaborative writing activity based on the peer-tutoring approach in the presence of the facilitator. The role of the facilitator is to provide the task instructions and prompts to the children during the study. More specifically, the study investigates the children's responsibility towards their peers, their interpersonal distance with the facilitator and their learning gains in the given scenario.

One of the finding concerning responsibility shows that the children provided more extended corrective feedback to their peers in the presence of the robot facilitator compared to the human facilitator; and therefore, felt more responsible towards their peers. Although, the study did not explore the effect of children's responsibility on their social and learning behavior; nevertheless, this finding suggests that the inclusion of robots in an educational system is beneficial as it can augment responsibility in students.

The findings of the interpersonal distance revealed that the children interact differently with the robot than the human adult. Particularly, with the robot facilitator they seem to follow reciprocity model and with the human facilitator, they tend to follow the compensation model. These results may help other researchers to design the child-robot interaction studies considering the reciprocal model of interpersonal distancing.

Additionally, the findings of the learning gains revealed that the children learned significantly in the presence of the human and robot facilitator. These results suggest that the educational activities which are of repetitive kind and demand extra time from a a school teacher especially in one to one learning, can incorporate a robot as a tool. Moreover, the obtained results of the study pose questions suitable for further investigation. For example, what would be the results if the peer-learning method is applied in the similar scenario? Would children's interaction and learning behavior differ if the peer-learning and peer-tutoring approach is employed integrating a robot? and how would children's social behavior emerge in these scenarios?. In the next chapter, we address such questions to investigate further the impact of incorporating a robot in an educational scenario.

6 Peer Assessment and Self-Disclosure in the Presence of a Social Robot

Peer assessment is defined as *an arrangement in which individuals consider the amount, level, value, worth, quality, or outcomes of learning of peers of similar status* (Topping, 1998). In this chapter, we present a study that explores children's assessment behavior towards their peers during a collaborative writing activity. More specifically, we investigate how they assess their peers in two specific group learning situations: *peer-tutoring* and *peer-learning*. Previously, we have investigated children's learning and interaction behavior in the two learning situations in the presence of a human facilitator; however, the present study still focus on the two learning methods but examines children's behavior in the presence of a robotic facilitator. Additionally, we explore and compare children's self disclosure towards the facilitator and their learning gains in both learning situations.

Concerning handwriting errors, in the child-child study (first study) we have explored children's handwriting in an educational learning scenario and presented a taxonomy of writing errors. To further investigate in this direction, we would revise the previous build taxonomy based on handwriting errors analysed in the last and the current study.

6.1 Scope and Research Goals

Research in education has long established how children mutually influence and support each other's learning trajectories, eventually leading to the development and widespread use of learning methods based on peer activities. Different methods of learning have been explored to foster childhood education and researchers are seeking new approaches to improve them. One of such approaches is directed towards research in educational robotics, showing its significance in several fields such as design, mathematics, among others Johnson (2003b). In designing an educational scenario, robots have been introduced playing diverse roles with children to support learning. Some researchers have used the peer-assisted learning methods like *peer-tutoring* and *peer-learning* involving an interaction with robots. For example, Kanda et al. (2004b), used Robovie, a humanoid robot, as an English peer-tutor for Japanese students. The results of this study showed that the robot could form relationships with children and also encouraged some of them to improve their English. Furthermore, the EMOTE project[1] aims to address the role of empathy in educational robots, using a multidisciplinary approach (Jones et al., 2015). In this project, a robotic tutor with empathetic qualities is used to assist and engage learners in several topics such as sustainability and map-reading (Sequeira et al., 2016; Castellano et al., 2013). In the same line, the Second Language Tutoring using Social Robots (L2TOR) project[2] aims to design a child-friendly robot, which will be used to teach preschool children a second language by interacting with them in their social and referential world (Belpaeme et al., 2015a).

Self-disclosure is the act of verbally disclosing personal information about oneself to another, including feeling, thought and experience, and is considered as a key in the growth of close relationships Collins and Miller (1994); Dindia et al. (2002). In peer-tutoring method, one of the pedagogical advantages for the tutee is self-disclosure among other advantages like participative learning, immediate feedback, etc. (Topping, 1996). Furthermore, within HRI some research has examined the self-disclosure behavior of people towards a robot. Mumm et al. Mumm and Mutlu (2011) found that the people who disliked the robot also disclosed less to it. In the context of our research, self-disclosure is defined as children's verbal revelation of their choices regarding general social questions such as - favorite flavor of ice-cream, rainbow treasure etc.(see Appendix C). The choice of the questions is based on their prevalence, task activity and aptness with respect to children's age-group. In this work, we want to explore how the *peer-tutoring* and *peer-learning* methods could influence the self-disclosure of children to the robot facilitator. In particular, we would like to answer the question: *"Is children's self-disclosure to the robot influenced by the role they play according to the peer-tutoring and peer-learning methods?"*

6.1.1 Motivation & Contribution

The *CoWriter project*[3] addresses the question of how a robot could help children in the acquisition of handwriting skills. In addition, it also explores different child-robot interaction modes to maximize children's learning gains. Regarding handwriting skills, it has been shown in literature that handwriting difficulties vary according to children's age (Berninger and Graham, 1998). Handwriting legibility tends to improve over time and reaches a plateau at the age of 8 or 9 (Karlsdottir and Stefansson, 2002; Bonney, 1992). We have seen previously the types of handwriting errors young children produce; however, it would be interesting to explore the handwriting issues with older children.

Concerning modes of interaction, we began our research using the two peer-assisted learning paradigms; peer-learning and peer-tutoring (learning-by-teaching). Regarding the peer-tutoring approach, we previously addressed the subject of children's responsibility towards their peers in the presence of a robot. The scenario involved two children performing a collab-

[1] www.emote-project.eu
[2] www.l2tor.eu
[3] http://chili.epfl.ch/cowriter

orative learning activity with either a human or a robot facilitator. Within the scenario, one child plays a role of a teacher and the other of a learner. The results suggest that the child acting as a teacher feels more responsible towards his/her peer when the facilitator is a robot compared to the human (Chandra et al., 2015).

Moving forward in this direction, we therefore conducted the present study only in the presence of a robotic facilitator. The current work aims to provide a contribution in the human-robot interaction field by employing both peer-assisted learning methods, *i.e.*the peer-tutoring and peer-learning, and comparing children's assessment behavior and their self-disclosure in an educational context.

In this chapter, we use the peer-tutoring and the peer-learning methods as a way to understand how children assess their peers in the presence of a robot during a collaborative writing activity. Although there has been a plethora of research on the peer-learning methods and peer-tutoring methods, less attention has been paid on how these methods can impact children's behavior towards their peers in a learning scenario where a robot is present. In other words, we want to discover whether their peer-assessment behavior is influenced by the role they are assigned to. As we have seen in the child-child study, the 4-6 years old children were incapable to provide corrective feedback to their peers. As a result, in the current study we targeted children of 6 to 8 years of age to explore how peer interactions affect the self-disclosure of children towards the robot and children's corrective feedback towards their peers.

6.1.2 Research Questions and Hypothesis

In the context of Co-writer project, exploring children's handwriting errors is one of the crucial steps in the research. The research questions related to the exploration of handwriting errors include:

- Which types of common handwriting errors children produce?
- Can handwriting errors be classified?
- Do these errors vary according to their age?

We attempted to answer the first two questions in 3rd Chapter, where we have presented classification of handwriting errors based on 4 to 5 years old children. However, in order to answer the third question it becomes necessary to examine the handwriting of older children. Thus, one of the research goals of the the current study is to further explore the handwriting errors of 6 to 8 years old children. The other goals of the study concerns the assessment of children's behavior on their peers and their self-disclosure in the presence of a robot facilitator while performing a collaborative activity. The current study explores the impact of a peer-learning vs. a peer-tutoring approach on children in an educational scenario. The scenario is similar to the 2nd study and consists of a pair of children performs the collaborative writing activity in the presence of a robotic facilitator. The current study does not employ human facilitator. In this context, the research questions and the hypothesis of the experiment are presented as follows:

- **Research Question 1:** What type of corrective feedback (minimal or extended) would children provide in each condition? Does this feedback differ across the conditions?

  Hypothesis 1: We hypothesize that corrective feedback is higher and extensive in the peer-tutoring condition as one child (tutor), who plays a role of teacher, has an explicit position of responsibility Keppell et al. (2006). Therefore, we expect the tutor-child to provide more and extended corrective feedback to the tutee-child compared to the peer-learning condition, where no roles are assigned to children (resulting in a balanced distribution of responsibility and position).

- **Research Question 2:** Would the self-disclosure by children to the robot facilitator in the peer-tutoring condition be higher in comparison to the peer-learning condition?

  Hypothesis 2: Given the characteristics of the peer-tutoring method, we hypothesize that self-disclosure by the tutee-child is higher in the peer-tutoring condition when compared to the peer-learning condition. As shown in past research resorting to the peer-tutoring method, one of the pedagogical advantages for the tutee is an immediate feedback with corresponding higher self-disclosure Topping (1996).

- **Research Question 3:** Would children's learning gains differ across the conditions? Which of the two conditions would effect more children's learning gain?

  Hypothesis 3: We hypothesize that both conditions would increase children's learning gains. However, based on the hypothesis of the first research question, we expect the children in the peer-tutoring condition would have higher learning gains compared to the peer-learning condition as more corrective feedback provided by the children would lead higher learning gains Black and Wiliam (1998).

6.2 Study 3- The Peer-tutoring vs. Peer-learning Study

The current study shares a number of similarities with the previous study. For example, we conducted both studies in the same school one after another. Besides, both studies share same material, same technical platform , similar interaction scenario and similar study protocols. However, the research goals of both studies are entirely different. Although the studies share a number of resources, for the reading purpose we will repeat some study descriptions in this chapter.

6.2.1 Participants

We conducted the study in 'Escola 31 de Janeiro ' in Parede, Portugal. 40 Portuguese-speaking children in the age group of 6 to 8 years (1^{st} and 2^{nd} grade) participated in the experiment.

Only children who assented and whose parents signed the consent form participated in the experiment. The experiment followed the ethical norms of privacy and responsibility of HRI studies (Riek and Howard, 2014).

6.2.2 Materials

The material in the experiment is similar to the second study. It included two tactile tablets with stylus, one for each child, installed with a writing app developed specifically for the experiment. Regarding the writing activity involved in the experiment, we created four colorful cards written with a letter/word as h, Lua(moon) and gelado(ice-cream) were written in the Portuguese language and Rainbow was written in the English language (see Appendix C). Each of the cards were introduced with an increased difficulty level as provided by the inscribed word length. The last card had the word Rainbow inscribed as it represented the longest and most unfamiliar word (since Portuguese speaking children are not expected to know this English word). For the pre- and post-tests we used a sheet with some letters (j, D, K, y, W, t, α, and π)(see Appendix C). The last two letters (α and π) were included to level the expertise of children (since none of the children are expected to know these Greek letters). In terms of the technical setup, this consisted of 3 video cameras, 2 microphones and a Nao robot (only torso part). The selection of the material and experimental protocol was finalized with the help of the schoolteachers.

6.2.3 Platform

We used the same WoZ interface and server application that we used in the previous study (See Chapter 5, section 5.2.3). These were used to manage communications between the tablets in order to visualize and store the drawings of letters and words performed by children during the experiment in real-time. We used the *Thalamus* (Ribeiro et al., 2014a) high-level integration framework and *Skene*, semi-autonomous behavior planner to provide the interaction between the Nao robot and the WoZ interface application. As the collaborative activity involved writing, we used the same writing app with dual-user interactive feature. This interactive capability allowed children to correct each other on their own tablet in real-time.

6.2.4 Conditions

Our current study consists of a between-subjects design with two conditions: *peer-tutoring condition* and *peer-learning condition*. Both conditions were performed in the presence of a robot facilitator whose role was to support the interaction flow between children, in particular by asking them to assess their peer's performance by providing *corrective feedback* (Bitchener, 2008). We further describe the conditions as follows:

- ***Condition 1- Peer-tutoring:*** A robot acts as a learning facilitator and interacts with a pair of children during a collaborative learning activity designed according to the

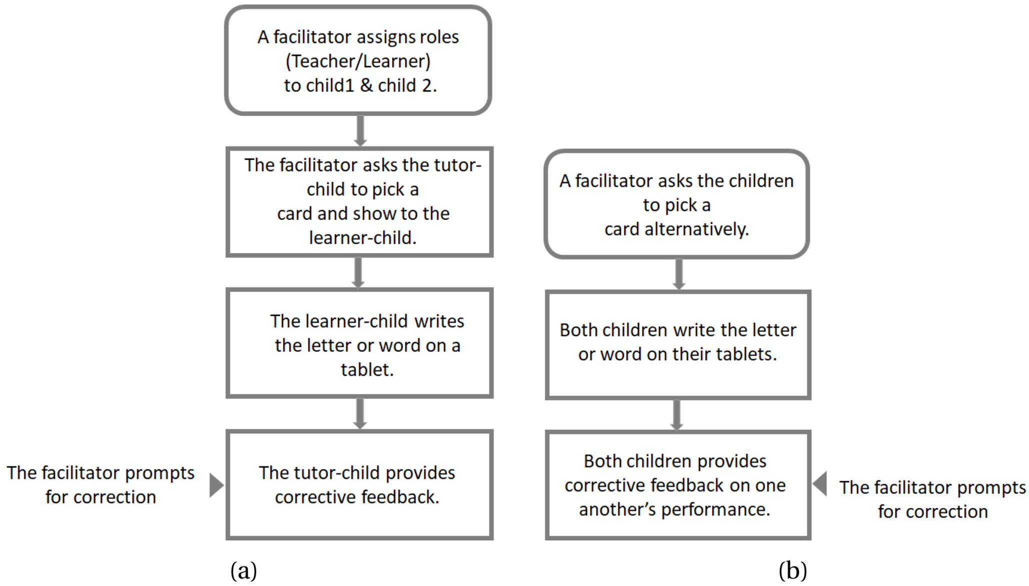


Figure 6.1 – Protocol for both conditions: (a) Peer-tutoring; (b) Peer-learning.

Figure 6.2 – Children interacting with a robot in peer-learning and peer-tutoring condition.

peer-tutoring method, in which one child plays the role of the teacher, while the other plays the role of the learner.

- ***Condition 2- Peer-learning:*** This condition is similar to Condition 1 but instead of the peer-tutoring method, the learning activity was designed according to the peer-learning method, meaning that no roles were assigned to the children and therefore both were considered as teachers and learners.

6.2.5 Protocol

Figure 6.2 depicts the classroom setup of the study. Each session was performed with a pair of children and a robot according to one of the conditions and lasted about 15-20 minutes. Condition 1 (peer-tutoring) was performed with 24 children (12 pairs) and the Condition 2 (peer-learning) with 16 children (8 pairs). Due to the ongoing submission of the consent forms during the whole study, we were not able to assure a balanced number of participants in both conditions. We used the WoZ approach Dahlbäck et al. (1993) to remotely control the robot's behavior. In our study, a psychologist acting as the Wizard was present in the classroom where the study took place but hidden from the participants. During the introduction of the experiment, a researcher would explain to the participants that they are going to write some letters on a paper and then on tactile tablet in the presence of a robot. All the participants were informed that if they do not wish to continue the learning activity, they could stop but no participant left during the experiment. The experiment followed these steps:

1) **Pre-test:** In this phase, a researcher asked the two children to individually copy the given letters (j, D, K, y, W, t, α and π) on a paper sheet.

2) **Learning activity with the robot:** After completing the pre-test, the children were guided to the experiment set-up room and were instructed to sit around the table where the robot facilitator was already placed. The researcher explained that they were going to perform a collaborative writing activity on a tablet with the robot. The researcher then left the room, leaving the children solely with the robotic facilitator. The interaction pattern of the learning activity in both conditions of the study progressed as follows:

- **Welcome greeting:** The interaction started with the introduction of the robot and the children. As most of the children had never seen a robot before, this step was important to provide some familiar ground to initiate the interaction.

- **Tutorial:** In the second step, the robot explained the writing activity and the features of the writing app. Next, some time was reserved for the children to draw freely on the tablet to get familiar with the writing app.

- **Collaborative learning activity:** The third step of the interaction pattern was dedicated to the learning activity. First, the robot explained the writing task to the children and assigned roles to them according to the conditions (peer-tutoring or peer-learning). In the peer-tutoring condition, one child, selected at random, was instructed to play the role of a teacher and the other the role of a learner. For the writing task, four different colored cards with a different letter or word were placed on the table facing down (see Figure 6.2). In the peer-tutoring condition, the robot asked the tutor-child to pick a card and show it to the learner-child so that he/she could write the letter or word on the tablet application. Following the peer-tutoring method, the learner-child wrote the letters and words on the tablet, while the tutor-child was responsible to provide corrective feedback on the writing performance in whatever ways were possible, *e.g.*by writing a correction on the tablet, or by verbally expressing it. After the learner-child finished writing such letter/word, the robot prompted the tutor-child to ensure that all corrections were provided. This process was repeated until all four colored cards were picked. Furthermore, the assigned roles of the children were not altered in this condition to make the interaction simpler for them.

In the peer-learning condition, no roles were assigned to the children and the robot alternatively asked one of the children to pick a card. Both were instructed to write a letter/word on the tablet. Following the principles of the *reciprocal peer-learning* method Boud et al. (2001), after writing both children were asked to provide corrective feedback on the other's task performance. Again, the process was repeated for all the four cards. In this condition, although the robot did not explicitly assign any role to the children, implicitly both children behaved as teachers as well as learners. In both conditions, each card was introduced with an increasing difficulty level as provided by the inscribed word length. The last card had the word Rainbow inscribed as it represented the longest and more unfamiliar word. On every finished card, the robot asked both the children one social question related to the respective word to keep them engaged in the activity. In order to avoid the cases where the children would ask social questions back to the robot, it would always provide its answer regardless of being questioned by the children. This also ensured that the educational interaction between the children would flow smoothly.

- **Goodbye greeting:** In this last step of interaction, the robot thanked the children for their time.

3) **Post-test** After finishing the interaction with the robot, children were guided to the same room where they performed the pre-test. The pre-test activity was repeated and thus also served as a post-test.

Regarding the verbal interactions among the children and the robot in all the sessions, we noticed that during the tutorial period, most of the children discussed features of the writing app. During the learning activity period, children corrected each other only when the robot prompted them to do so. Sometimes, they asked queries to the robot, related to the ongoing task. Since the robot's behavior was controlled by the researcher, it would repeat the task instructions again.

6.2.6 Analysis

With the purpose of examining the interactions during the experiments, we performed video and audio analysis of all the sessions by coding and annotating the verbal behaviors (corrective feedback, self disclosure) of both children. Written form of feedback by children were not analyzed, as sometimes children were able to verbally correct their peers more efficiently compared to written form. The annotations were performed with two independent coders using the ELAN multimedia annotation tool[4]. Regarding the reliability of the participant's behavior, the Cohen's kappa showed .92 of agreement for the verbal behaviors. First, data from the verbal behavior and pre-/post-test scores were tested for normal distribution using the Shapiro-Wilk normality test.

Regarding the pre- and post-test data, once again, two independent coders analysed each letter based on its legibility by comparing it to the correct sample of the letter (target lettercard that was displayed during the study). The coders rated each letter in the scale of 1 to 3 and the coding metric is given as follows:

1 = unreadable; if the letter is illegible and can not be recognised as a target letter.

2= readable; if the letter is legible but contains several errors such as missing sub-trajectory and alignment (present in the previous taxonomy).

3= identical; if the letter is legible, written similar to the the target letter and does not contain any errors.

In terms of the reliability of the participant's pre-/post-test scores. , Cohen's kappa showed agreement values of .80, indicating a good agreement. The hypothesis that the data comes from a normal distribution was not confirmed, hence we analyzed the data using the non-parametric Exact Wilcoxon rank-sum (Mann-Whitney U) test which was also appropriate for the unequal sample size data.

To analyse the handwriting errors in the letters, we collected the data from the paper sheets as well as from the tablets. The data were analysed by two independent coders, who examined each sample and classified based on various factors such as the shapes of the trajectory and sub-trajectory, the number of strokes, and the alignment. Furthermore, a taxonomy of writing issues was built depending on the classification. In terms of the reliability of a participant's writing errors, Cohen's kappa showed agreement values of .65 indicating a good agreement.

6.3 Findings

6.3.1 Corrective Feedback

Corrective feedback is the verbal response related to the corrections provided by a child on the performance of another child. Table 6.1 presents the types and examples of annotated corrective feedback. The corrective feedback given by children was considered as being either as *minimal* or *extended* (Kahn Jr et al., 2012; Bitchener, 2008). Note that the study was designed in a way that the dynamics between the participants is *triadic*, but the interaction between

[4] `https://tla.mpi.nl/tools/tla-tools/elan/`

Table 6.1 – Verbal Behaviour.

Verbal behaviour	Definition	Example
Corrective Feedback (minimal)	Minimal response related to the corrections of the letters and words.	**robot**: *Do you think that the written letter is similar to the one in the target card?* **tutor-child**: *Yes*
Corrective Feedback (extended)	Extended response related to the corrections of letters and words.	**robot**: *Do you think that the written letter is similar to the one in the target card?* **tutor-child**: *No, it's not. The shape is not correct. It should be extended and rounded.*
Self Disclosure (minimal)	Minimal response related to the social questions asked by robot.	**robot**: *What is your favorite flavor of Icecream?* **child**: *Chocolate*
Self Disclosure (extended)	Extended response related to the social questions asked by the robot.	**robot**: *What is your favorite flavor of Icecream?* **child**: *Chocolate! I love it! What is yours?*

the children is *dyadic*. This means that although children provide corrective feedback as a direct response to the robotic facilitator (the robot prompts students for corrective feedback), the feedback is implicitly directed at the other child but through the robot. Therefore, during the annotation we considered as corrective feedback provided by one child to the other child through the robot. In the peer tutoring condition, although the tutor-child was responsible to give feedback on the performance of the learner-child, many times during interaction the latter gave feedback regarding the corrections. In other words, the learner-children in the peer-tutoring condition provided response back to the teacher-children's corrective feedback (Figure 6.3a and 6.3b). For annotation purposes, we considered such cases as corrective feedback by the learner-child over his/her own performance.

In order to assess whether the roles assigned to the children have an impact on their assessment behavior in the presence of a robot, we first compared the feedback of all children in the peer learner condition with the tutor-children in the peer-tutor condition. Then, we compared the feedback of all children in the peer learner condition with the learner-children in the peer-tutor condition.

The result of the Man-Whitney U test suggested that all the learner children in the peer-tutor condition gave significantly more extended feedback to their peers (Mean = .75, Mdn = .50)

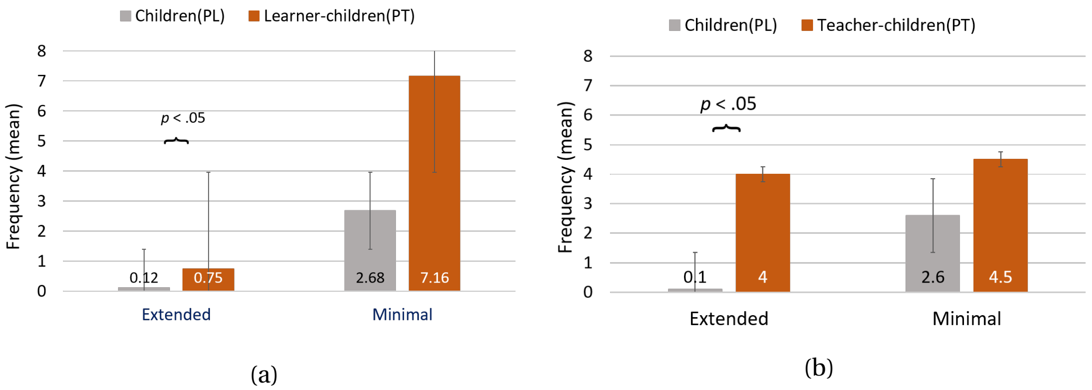


Figure 6.3 – Results of the corrective feedback between: (a) all the children in the peer-learning condition and the learner-children in the peer-tutoring condition; (b) all the children in the peer-learning condition and the tutor-children in the peer-tutoring condition.

in comparison to all the children in the peer-learner condition (Mean = 0.12, Mdn = 0.0), $U = 57$, $p < 0.05$, $r = .43$, as depicted in Figure 6.3a. In addition, the results showed that all the tutor-children in the peer-tutor condition gave significantly more extended corrective feedback to their peers (Mean = 4, Mdn = 2.5) in comparison to all the children in the peer-learner condition (Mean = .1, Mdn = 0.0), $U = 21$, $p < .001$, $r = .73$, as seen in Figure 6.3b. We did not find significant difference in children's minimal corrective feedback between the two conditions. These results validate our first hypothesis that corrective feedback is higher in the peer-tutor condition. We further discuss these results in Section 6.4.

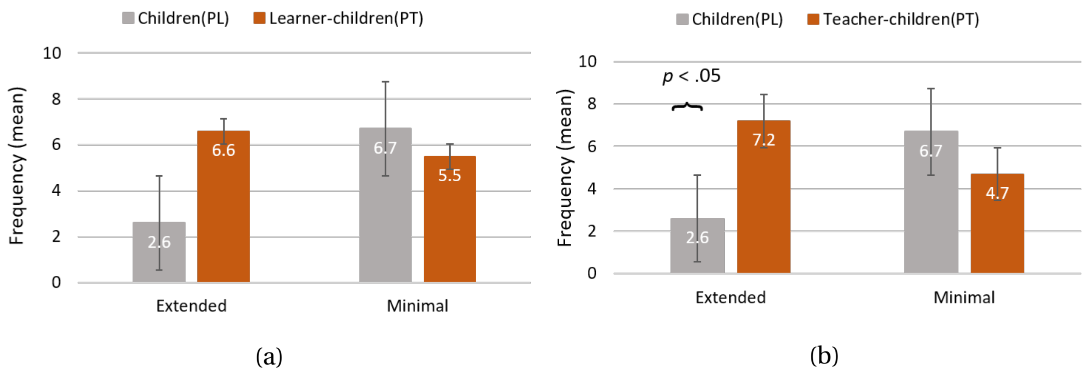


Figure 6.4 – Results of the self-disclosure between: (a) all children in the peer-learning condition & the learner-children in the peer-tutoring condition; (b) all children in the peer-learning condition & the tutor-children in the peer-tutoring condition.

6.3.2 Self-disclosure

During the interaction between the children and the facilitator, after finishing each letter or word, the robot-facilitator asked a social question related to the letter or word to the children (refer Appendix C) . For example, after finishing the word 'Lua' (moon), the robot asked - How many moons are there in the sky? We analysed children's feedback to those social questions and classified them either minimal or extended. Table 6.1 presents the definition and the examples of the social questions and answers provided during the study.

With the purpose of examining the effect of the two conditions, we first compared the self-disclosure of all children in the peer-learning condition with the tutor-children in the peer-tutoring condition. Then, we compared the self-disclosure of all children in the peer-learning condition with the learner-children in the peer-tutoring condition. The results showed that all the learner-children in the peer-tutoring condition gave significantly more extended self-disclosure to the robot (Mean = 6.6, Mdn = 6.5) compared to the children in the peer-learning condition (Mean = 2.6, Mdn = 2.0), $U = 46.5$, $p < .05$, $r = .44$, as illustrated in Figure 6.4a. Also, all the tutor-children in the peer-tutoring condition disclosed significantly more in terms of extended self-disclosure (Mean = 7.2, Mdn = 6.0) compared to the children in the peer-learning condition (Mean = 2.6, Mdn = 2.0), $U = 34.5$, $p < .05$, $r = .54$, as seen in Figure 6.4b . We did not find significant difference in children's minimal self-disclosure between the two conditions. These results support our second hypothesis, that is self-disclosure by children is higher in the peer-tutoring condition compared to the peer-learning condition.

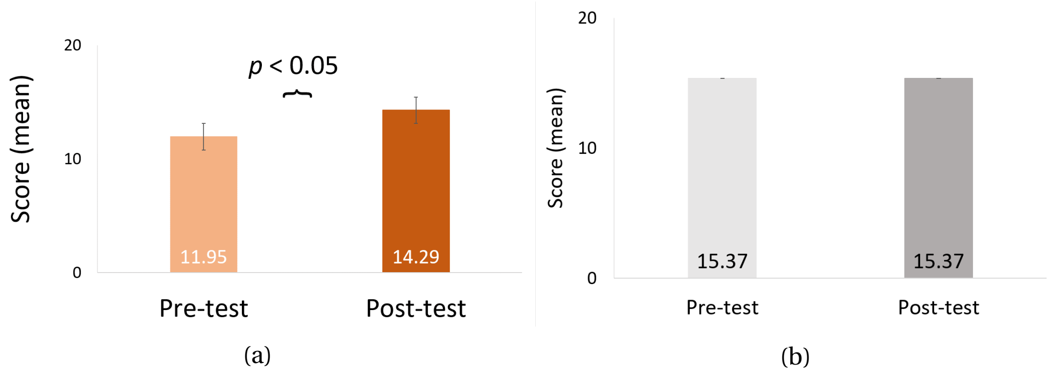


Figure 6.5 – Results of the pre- and post-test score of all children in the: (a) peer-tutoring condition; (b) peer-learning condition.

6.3.3 Learning Gains

To explore the impact of the two methods on the children's learning involving the interaction with a robot, we compared their pre- and post-test individual scores for each condition. As depicted in Figure 6.5a, the results in the peer-tutoring condition showed a significant improvement in children's learning gains in the post-test (Mean = 14.29, Mdn = 15.0) as compared to the pre-test (Mean = 11.95, Mdn = 12.0), $U = 131.5$, $p < .001$, $r = .47$. However, no difference was found in pre- and post-test scores in the peer-learning condition, as seen in Figure 6.5b. Since, the pre- and post-test scores were equal, we could not compare the children's learning gains between the two conditions.

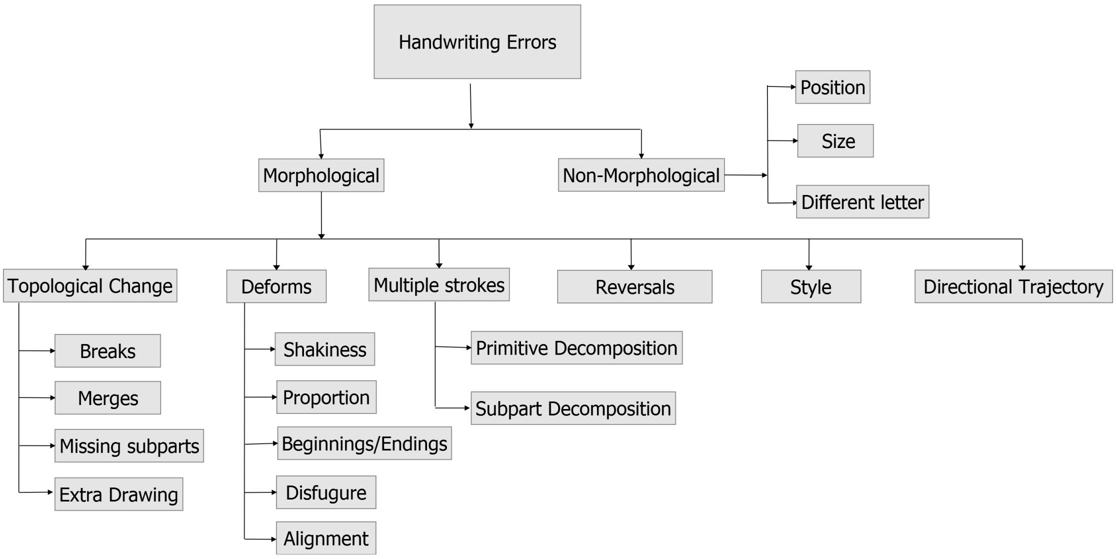


Figure 6.6 – Taxonomy of writing errors.

6.3.4 Taxonomy of Writing Errors

After analysing the incorrect letters from the collected database of children of 6 to 8 years of age, we revised the previous built taxonomy (discussed in Chapter 3^{rd}) to incorporate modifications based on the second and current study. Note that the classification of writing errors is based on the English alphabet, including both uppercase and lowercase letters. As shown in Figure 6.6, the error tree is classified into seventeen types of handwriting errors. Moreover, the classification included different writing styles, for example, manuscript and cursive.

6.3.4.1 Revision of writing Errors

We classified the writing errors into two broad categories: morphological and non-morphological. These categories are further divided into subcategories (see Figure 6.6).

Morphology is defined as the study of the shapes of letters. The writing issues that show a change in the morphology of a letter belong to this category and are further divided into 6 subcategories: *topology changes, deforms, multiple strokes, reversals, directional trajectory,* and *style*. We further describe the writing errors as follows:

1- Topology change: Topology [5] is related to the properties of shapes that are preserved under continuous deformations, for example, bending and shrinking without breaking or merging. The writing issues that show a change in the topology of a letter belong to this category. This category contains four more subcategories explained below:

[5] https://en.wikipedia.org/wiki/Topology

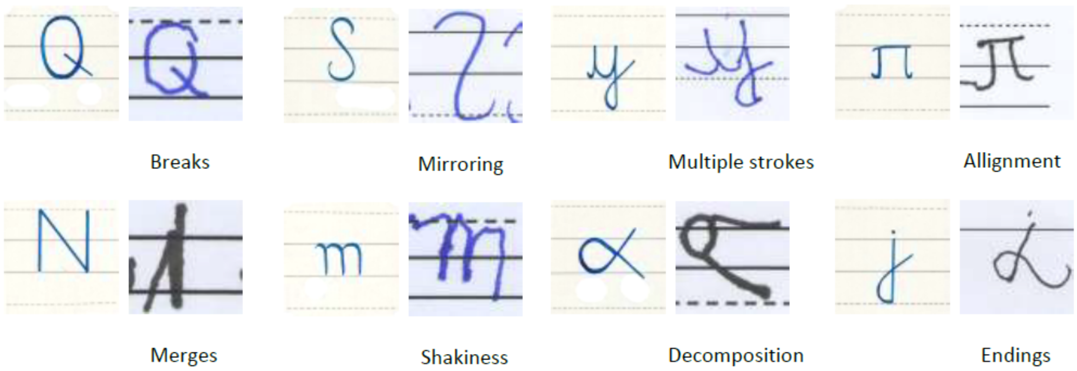


Figure 6.7 – Children's handwritten letters corresponding to the errors. The correct samples of letters are shown on the left side of each letter.

- **Breaks**: Any discontinuity in the shape of a letter can be observed as a 'hole' in the letter. The writing errors that contains breaks or holes belong to this category (see Figure 6.7).

- **Merges**: When a sub-part of a letter is glued to another sub-part of the same letter, it creates a merging error in the letter (see Figure 6.7).

- **Missing Sub-parts**: Only those letters that have more than one stroke can have this error. A missing stroke in a letter creates this type of error.

- **Extra drawing**: This type of error refers to when an additional stroke is added (not necessarily touching the letter) to make a letter decorative or exaggerated. However, this is not considered to be a major error, as it generally adds artistic value to a letter.

2- Deforms: When a letter shows any malformation or deformation in the shape of the letter while maintaining the topology of the letter, the error belongs to this category. The deformations can be present in a sub-part of the letter (locally) or in all parts of the letter (globally). This category is further divided into 5 subcategories, discussed below:

- ***Shakiness***: This type of error occurs when a letter shows a visible jerk in its trajectory. (see Figure6.7).

- **Proportion**- This type of error occurs when a letter shows an asymmetry or disproportion in its shape, *e.g.*shrinking or stretching in any direction.

- **Beginnings/Endings:**
  This issue is when then beginning or ending is extended (in the shape of a curve or a straight line). This type of error is different from the *extra drawing* error, as it only exaggerates the extensions. This error is further divided into two additional categories,

detailed below.

Playful: When a letter shows a decorative extension and the child who formed this letter is aware of the extension, then the error belongs to this category.
Non-playful: When a letter shows extensions (not decorative) and a child does not have knowledge of forming the extensions, then the error belongs to this category. However, it is difficult to identify this issue by looking at the final images of letters. It can be easily seen during the formation of a letter.

- **Distortion:** This is a general category of errors that do not follow any specific patterns. This type may include, for example, wide, curvy, and snake-style distortions in the shapes of letter and sometimes leads to fully distorted shapes resulting in illegible letters.

- **Alignment:** This refers to the misalignment or rotation of a letter through some angle (see Figure6.7).

3- Multiple strokes: When a letter is formed by decomposing it into parts, this type of error is created (see Figure 6.7). If the parts are well joined in the final image of the letter, then it is difficult to visualise this error; however, during the formation of a letter, this issue can be easily observed. In addition, the error may or may not change the topology of the letter and can be present locally or globally. This category contains two subcategories, detailed below:

- **Primitive Decomposition:** This type of issue is when a letter is formed by decomposing it into basic shapes, for example, circles and horizontal/vertical lines (see Figure 6.7). In the first study, we observed this error mostly in beginners, and it may occur due to the lack of knowledge about shapes. For example, when writing the letter $alpha$, a few children decomposed it into a circle and straight lines, as the letter was unfamiliar to them (see Figure6.7).

- **Sub-part Decomposition:** This issue refers to when a letter is formed by decomposing a single stroke into several strokes. This is different from the above error, as in this case, the decomposed strokes do not resemble basic shapes such as a circle. Here, a circle can possibly be made with several small strokes.

4- Reversals: This error refers to when a subpart or a full letter is reversed in any of the four directions, left, right, top, or bottom; then, a reversed image is created. This does not affect the topology of the letter.

5- Direction of trajectory: This writing error can only be observed during the formation of a letter, as it concerns the direction of the trajectory of the letter. This issue does not produce a change in the topology of the letter and can be present locally or globally.

6- Style: This issue refers to when a letter is formed with a different style (cursive or manuscript) instead of the required style. However, this is a minor issue and can be present locally or globally. The topology may or may not be changed.

Non-morphological: errors do not produce a change in the shape of a letter and therefore are not related to the morphology of a letter. In addition, this error does not affect the topology of the letter. This category is divided into three additional subcategories, discussed below.

1- Position: This issue refers to the correct placement of a letter with respect to base/reference lines present on a writing base where the letter is drawn.

2- Size: As the name suggests, this issue is related to the size of a letter with respect to reference lines or the size of other letters present on the same writing surface.

3- Different letter: This error is related to the misinterpretation of a letter. For example, in both studies, we found two letters, α and π, were misinterpreted as the letters “a” and “r” or “u”, respectively. Initially, we did not include this issue in the tree because we thought that this error might occur due to the introduction of unknown letters to the children. However, in the second study, we found that two children misinterpreted the letters “W” and “j” as “U" and “G", respectively, which shows that this error may occur, although not often.

Modifications in the Taxonomy:

The above writing issues were explored by analysing the letter images as well as by observing the formation of letters during the studies. The classification is based on considering the change in shape of the letters and patterns of the writing errors. We revised the built taxonomy and modified it by adding and merging some writing issues. Here we list the different modifications done in the previous taxonomy as follows:

- We modify the name of the major categories of the handwriting errors as *morphological* and *non-morphological.*
- The writing error named *alignment* is moved to the *Deforms* category.
- The writing errors, *decomposition* and *multiple strokes* are merged.
- The errors named *Different letter* and *Directional trajectory* are added in the revisions.

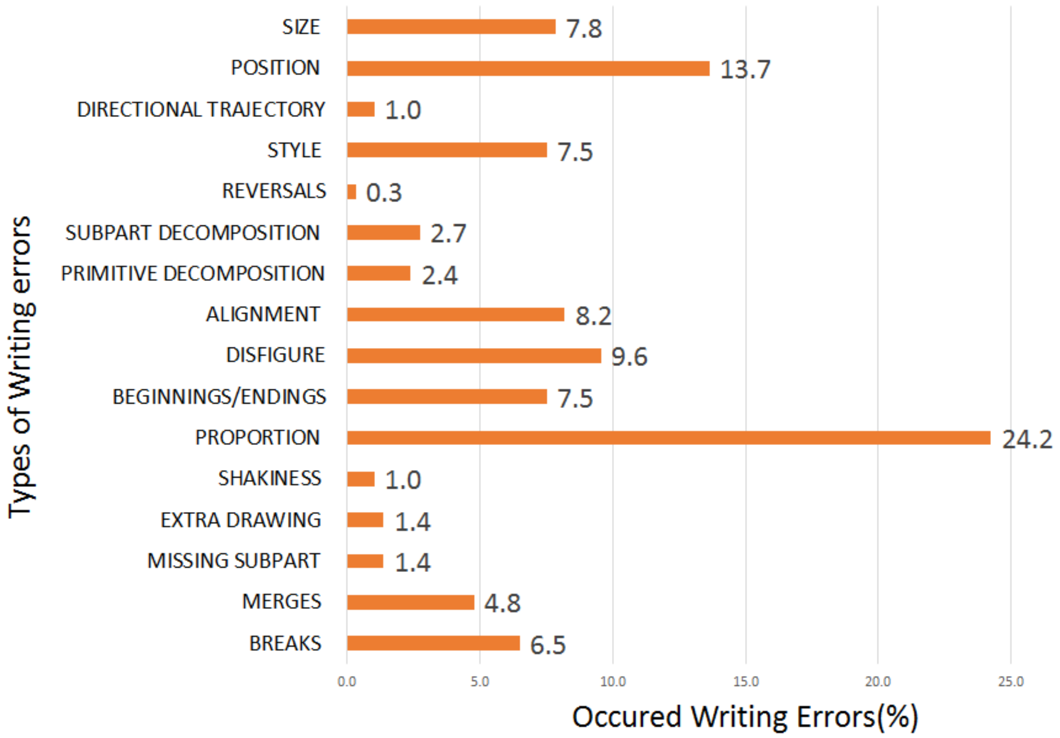


Figure 6.8 – Percentage of handwriting errors produced by children during the study.

- The name of the writing error is changed from the *Mirroring* to *Reversals*.

Children's handwriting has been studied and associated with at least two factors: *legibility* and *speed* (Berninger and Graham, 1998; Karlsdottir and Stefansson, 2002). Our research is mainly focused on the legibility factor. In all the three studies, we included two Greek letters α and π, in addition to the English alphabet, As the children were unfamiliar with these letters, we used the letters to check their expertise in the pre- and post tests. Although, the exploration of writing errors was based on only English alphabet, we believe it may also apply to the letters of different languages; however, future investigation is needed to verify this.

Regarding the occurrence of the writing errors between the first and the last two studies, we observed that a few writing errors, such as shakiness, missing subpart and extra drawing, seemed to be less frequent in the last two studies (see Figure 6.8). The other errors remained prevalent in all the studies. The frequencies of the errors in the second and third study are shown in Figure 6.8. In addition, a few samples of the handwritten letters from the last two studies are presented in Figure 6.9. Altogether, wee present samples of children's handwriting errors in the age-group of 4-8 years for most of the handwriting issues in Appendix C.

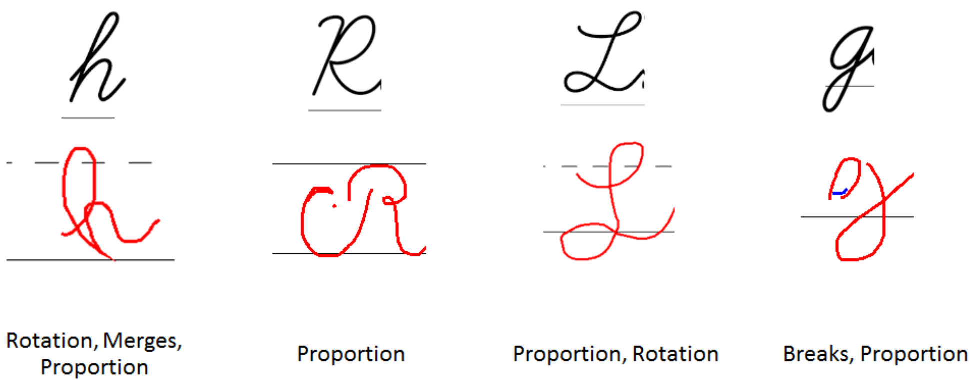


Figure 6.9 – Sample of letters (top row) with samples of children's handwriting errors (bottom row).

6.4 Discussion and Conclusions

6.4.1 Corrective feedback

Overall, the results of the current study regarding corrective feedback suggest that in the peer-tutoring condition, children who played a role of teacher gave more extended feedback compared to the children in the peer-learning condition with no assigned role. Therefore, these results show that the assessment behavior was affected by the role of tutor-child, who had a responsibility to provide feedback (corrections) to the learner-child. In addition, learner-children in the peer-tutoring condition also provided more extended self-corrective feedback compared to the children in the peer-learning condition. This result suggests that the more corrective feedback they got from the peer-teacher, the more they responded. Furthermore, the relevance of the results lies in the type of feedback provided by the children—both tutor and learner children gave more extended feedback, meaning that they provided more extensive feedback with deepened corrections, which in turn supports the effectiveness of the roles in the peer-tutoring scenario.

6.4.2 Self-disclosure

In relation to self-disclosure, our results show that the teacher and learner children in the peer-tutoring condition disclosed more compared to the children in the peer-learning condition. These results are consistent with findings previously reported in Topping (1996). Nonetheless, the peer-tutoring method not only benefited the tutee but also the tutor as the tutor-children disclosed more compared to the children in the peer-learning condition. This suggests that self-disclosure may also depend on the context of the learning scenario—the roles played by the children, depending on the peer-assisted learning method, may elevate their self-disclosure to the robot.

6.4.3 Learning Gains Combined with the Corrective Feedback

The results of the peer-tutoring condition regarding corrective feedback combined with the learning gains are consistent with Black & William Black and Wiliam (1998), who concluded that *"the provision of challenging assignments and extensive feedback lead to greater student engagement and higher achievement"*. Although, we could not compare the learning gains of the children between the two conditions, we can still compare their feedback and pre- and post-test scores between the conditions. The results show that all the children in the peer-tutoring condition gave more extended feedback compared to the children in the peer-learning condition. This suggests that providing extensive feedback might have led to increase in children's post-test scores in peer-tutoring condition, while in the peer-learning condition, the children's post-test scores remain constant to their pre-test scores.

We believe that there could be a few reasons why the children did not improve in the peer-learning condition: First, the children's pre-test scores in the peer-learning condition were higher than the children in the peer-tutoring condition. To achieve 20 points (maximum score), the children might need multiple sessions instead of a single session. The other reason could be the small sample size (16 participants) of participants in the peer-learning condition. Therefore, a long term study with more participants may be required to compare peer-learning and peer-tutoring methods.

6.4.4 Taxonomy of Writing Errors

The taxonomy of writing errors is built on English alphabet and based on writing errors produced by children of 4-8 years of age. It is worth noting that the writing errors defined in the taxonomy may benefit both teachers and students. Generally, if a student struggles in forming a letter, s/he practices it by writing it several times, which may involve the correction of random writing errors in the same letter. However, one of the key advantages of using the taxonomy is in helping a child with one particular writing error at a time. In addition, the proposed taxonomy can be used to evaluate children's handwriting skills in a more structured way. To improve handwriting, researchers may develop an educational scenario dedicated to a particular writing issue or similar writing issues present in the taxonomy. However, incorporating all the handwriting issues for one educational activity seems to be challenging, as writing errors differ with respect to the levels of handwriting and motor-cognitive skills. In addition, this would also increase the cognitive load on a child.

Besides, the writing errors presented in the taxonomy can be further exploited to improve children's writing skills by using a digital medium. However, to synthesise the errors we would need an algorithm suitable for handling different types of errors. In the next chapter, we will implement a set of errors digitally to enhance children's handwriting performance.

6.4.5 Limitations

We acknowledge a few limitations of the current study in which some of them are similar to the second study (discussed in 4th Chapter). For example, *unequal sample size*, due to the ongoing submission of the children's consent form we could not allocate equal number of participants in both conditions. To avoid the discrepancies in the reliability of the results, we used the appropriate statistical test to analyse the data that took care of unequal sample size.

Conducting a study in one school often brings small number of participants because of various reasons such as availability issues due to children's daily classroom schedule, exam period, holidays and so on. And choosing multiple schools for a study may lead to other inaccuracies in the results such as use of different writing styles(*e.g.*cursive, manuscript) in schools, duration of daily writing activities and so on. As a consequence, for the current study, we chose one school where we got 40 children in total. The obtained results are based on this sample size (40 children) and may not be generalise to a large population.

One of the limitations of the study belongs to the design of the peer-tutoring condition. In the study, we compared the children's assessment between peer-tutoring and peer-learning condition. In the peer-learning condition, both children provided corrective feedback to each other while in the peer-tutoring condition, only tutor child provided feedback to the learner-child. In this condition, we did not reverse the roles of children to prevent children's confusion about the roles (as observed in the first study) and to make the activity simpler. Therefore, before conducting the experiment, we anticipated that we would get more corrective feedback in the peer-learning condition than the peer-tutoring condition. However, we did not get the expected results; the findings significantly showed more number of feedback in the peer-tutoring condition compared to the peer-learning condition. We believe that not including the role-reversal step might have affected the results of children's corrective feedback but only in terms of more significant figures.

Moreover, the study lacks the investigation of how children's corrective feedback and social disclosure have affected their other aspects such as social and behavior interactions with their peers. In addition, the study did not explore children's perception of the activity and the robot. These results could help us to understand deeply how children's experience can influence their learning outcomes.

6.4.6 Conclusions

In this chapter we have studied the assessment behavior of children on their peers by using two peer-based learning methods, namely peer-learning and peer-tutoring, in the presence of a robot acting as an interaction facilitator (Chandra et al., 2016). The results of the experiment suggest that the role played by a child in a peer-tutoring scenario can boost the corrective feedback provided on his/her peer. We also showed how self-disclosure of children to the robot can vary according to the peer-assisted learning method used. In that regard, our results show that the attribution of roles makes children disclose more information to the robot. In addition, we found children in the peer-tutoring condition improved while in the peer-learning condition showed constant performance (between the pre-and post-test scores). These results may help other human-robot interaction studies in the design of learning scenarios for children involving the interaction with a robot.

Moreover, the chapter presents the taxonomy of writing errors in letters based on children of four to eight years of age. The presented taxonomy of the writing errors provides a deep understanding of common handwriting issues for letters of the English alphabet (Uppercase and Lowercase). We believe that the taxonomy extends the existing literature, as it contains a few writing issues, for example *multiple strokes and breaks*, that have not been explored previously. Moreover, the classification in the taxonomy may provide a new understanding of writing errors.

Until this chapter, regarding child-robot interactions we have investigated the two modes of interactions with the integration of a robot in the the role of a facilitator. The employment of the robot seems to be positive for children in terms of learning , assessment and social-disclosure. Certainly, these conclusions pose other questions suitable for further investigation. For example, how would child-robot interaction affect children's learning if a robot plays a role of a peer-learner? How would these interactions occur in multi-session studies? As mentioned before about the children's perception of the robot, how would children perceive robot's in the similar learning scenarios? In the next chapter, we address some of these questions and explore more in this direction by performing multi-session studies.

7 Development of an Educational Co-Writer Robotic Peer

In the preceding chapters, we have explored the child-robot interaction scenarios where the learning and teaching transactions happen between two children, and the presence of the robot is to facilitate the interaction between them. In this chapter, we present an educational system where the learning transaction occurs between a robot and a child in one-to-one interactions. For designing the system, we developed an autonomous social robot that provides an educational setting for a child to improve his/her handwriting skills. This one-to-one scenario is based on the peer-tutoring learning method, where the child acts as a tutor and the robot acts as a learner. In Section 7.1, we describe the motivation behind developing the system. Afterwards, in Section 7.2, we outline different design variables of the system such as interaction design, handwriting errors, algorithms and overall system architecture. Finally, we discuss the conclusions and implementation of the developed system in subsequent studies in Section 7.3.

7.1 Research Goals

7.1.1 Motivation and Contribution

One of the research goals of the *Co-writer* project is to examine different modes of child-robot interactions that better support acquisition of handwriting skills. Moving forward in this direction, we explore an educational scenario where a child and robot establish one-to-one learning interactions. Yet, instead of attributing a role of a facilitator to the robot (as in the previous studies), we want to examine the impact of a social robot that participates in the direct learning interactions with the child. To address this vision, we have build a system that provides an educational setting to investigate three aspects as follows:

- to determine which modes of child-robot interaction would better support acquisition of handwriting skills;
- to understand how children would perceive the behaviour and abilities of the robot

using these modes of interactions;

- to handle different handwriting issues, which differ from child to child according to age, cognitive and motor capabilities.

Combining all the above-mentioned aspects, we developed an autonomous social robot that provides an educational scenario for children to improve their handwriting skills. Concerning the modes of interaction, our last two studies showed interesting findings. For example, the results of our second study (Chapter 5) using the *peer-tutoring* method revealed that a tutor-child felt more responsible towards their peers in the presence of a robot facilitator contrary to a human facilitator (Chandra et al., 2015). And our third study (Chapter 6) with *peer-assisted* learning methods, we have shown that the *peer-tutoring* (also known as learning-by-teaching) situation can lead to significantly more corrective feedback provided by the children to another and self-disclosure to the robot compared with a peer-learning situation (Chandra et al., 2016). Since, the results of these two studies favored the peer-tutoring approach and the positive influence of the robot on children, the current system presented in this chapter relies on the *peer-tutoring* method in which the child acts as a 'tutor' and helps the learner-robot improve its handwriting skills.

Since child-robot interaction is inherently social (Salter et al., 2008), it becomes crucial to investigate different aspects of the social relationship between robots and children. The aspects related to robot's behavior and abilities may alter the children's learning gains, engagement, and perception (Deshmukh et al., 2016; Kennedy et al., 2015b). Thus, with regard to the second aspect, we aimed to understand how children perceive the robotic agent educationally and socially. More specifically, we wanted to assess children's perceptions in terms of the social robot's behaviour taken into account its abilities and role through the developed system.

Handwriting is a complex blend of motor and cognition skills. Ineffective motor skills are difficult to change, so it is important to sharpen the skills from the beginning (Sassoon et al., 1986; Medwell and Wray, 2008). Ineffective skills often lead to different handwriting errors in the formation of letters which is our third investigated aspect. Researchers have used these errors to detect early signs of handwriting problems, to improve the handwriting instruction practices, and to develop handwriting readiness tests. Based on the database of our previous three studies, we built a taxonomy of writing errors of children between the age of 4-9 years. Further, we test a set of errors in the current developed system.

Recent studies have also explored the learning-by-teaching method to improve children's writing capabilities (Hood et al., 2015; Matsuzoe and Tanaka, 2012). Shizuko et al. performed a study using the method to enhance children's knowledge of English words, in which children drew some shapes associated with the words. The results suggested that the tele-operated robot capable of learning helped children learn unknown English words for the shapes (Matsuzoe and Tanaka, 2012). Following a similar line of work, this chapter makes two contributions: first, by the creation of an autonomous social robot designed to provide a learning scenario in which a child learns by teaching the robot, in a natural setting, by sitting next to each other; and second, by testing a set of writing errors from the taxonomy in an educational scenario whereby a child corrects the writing errors produced by a learner-robot. Thus, we tested the system by conducting two longitudinal studies to explore children's learning and their perception's towards the robotic agent. We present the studies in the next chapter (Chapter 8). In the next section, we describe the developed system.

7.2 An Autonomous Robot that Learns from a Child

7.2.1 Interaction Design

The main idea is for a child to sit side-by-side with a robot and teach it how to write! Figure 7.1 shows a general interaction setup of the designed system. This one-to-one child-robot interaction scenario involves a child sitting side-by-side with an autonomous Nao robot. We choose the side-by-side spatial arrangement between the child and the robot to provide both of them physical space to write on the same touch-screen. This arrangement resembles a common one-to-one tutoring seating arrangement where a student and a teacher sit next to each other. Particularly, when tutoring requires writing, this arrangement provides a natural and comfortable setting and apt for both the student and the child. For example, they both can use verbal and non-verbal behaviors easily such as verbal feedback, gaze and gestures and yet perform the task by sharing the common note-book (or the touch-screen).

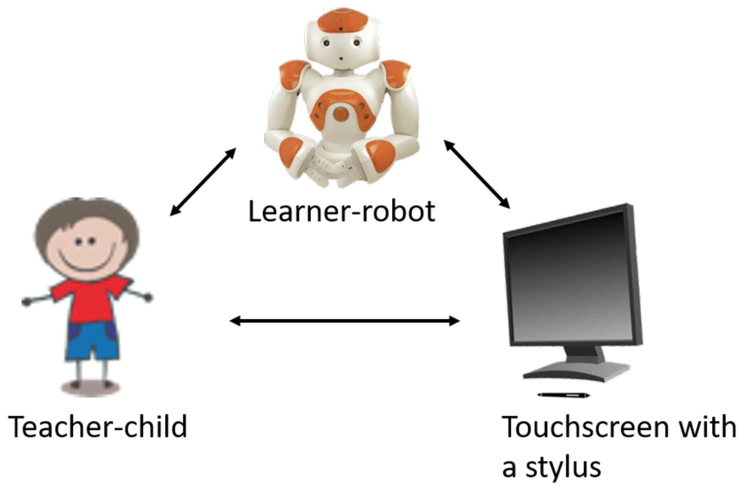


Figure 7.1 – Child-robot interaction setup.

Additionally, the interaction scenario is based on peer-tutoring approach (often known as the 'learning-by-teaching' method) where the robot acts as a learner and the child acts as a tutor. For the handwriting purpose, there is a touchscreen with a customised application and stylus to write letters. In the scenario, the learner-robot writes a deformed letter on the screen and asks the teacher-child to correct it. The teacher-child then corrects the letter and demonstrates a sample of the same letter by writing on the other side of the screen. After getting the correction from the child, the robot asks the child to press a button to correct other letters (detailed explanation is provide in Section 7.2.3).

Since the child is aware of his/her role as a teacher, the tutor-child performs the corrections on the learner-robot's input in a flawless manner. The turn-taking occurs when the robot prompts the child once the correction and demonstration of the letter is finished. The robot uses sentences such as 'could you show me the correct shape of this letter?' or 'let's move to another letter for correction by pressing this button'. Thus, in our interaction design, we attempt to blend both social and pedagogical aspects in the context of handwriting.

7.2.2 Interactive Embodied Learning Agent using a Nao Humanoid Robot

To develop a learner agent that is capable to engage a child in a collaborative writing activity, we have set up capabilities of the robot to interact and perform interactive turn taking. As mentioned before, we have used Aldebaran's Nao humanoid robot due to its commercial affordability, approachable design (Gouaillier et al., 2008) and suitability for close interactions with children.

(a) (b)

Figure 7.2 – Nao robot writing a letter: (a) back view; (b)side view.

During the writing activity, the robot first exhibits its handwriting skills by writing a letter, then it asks the child to correct it, see Figure 7.2a. As the role of the child is a teacher, s/he performs the correction and demonstrates the correct version of the letter on the screen (Figure 7.2b). This learning-by-teaching paradigm between the child and the robot demands engagement and interactive turn-taking in a seamless manner. Thus, precise information of the state of the child such as correction, demonstration is necessary for the robot's interaction in the proposed application. The development of different components for the child-robot interaction in the writing application is described in the following sections.

7.2.3 Writing Application

To display the robot's writing and child's correction on the same screen, we developed a specific application, named *co-writer application* for the collaborative writing activity. The

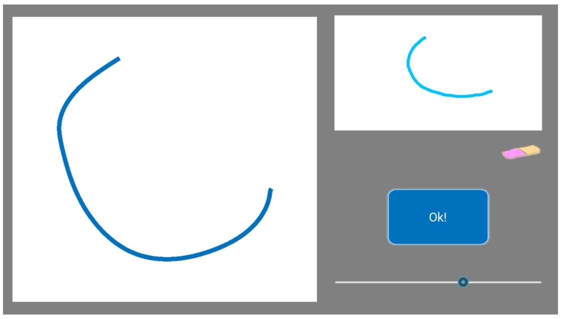


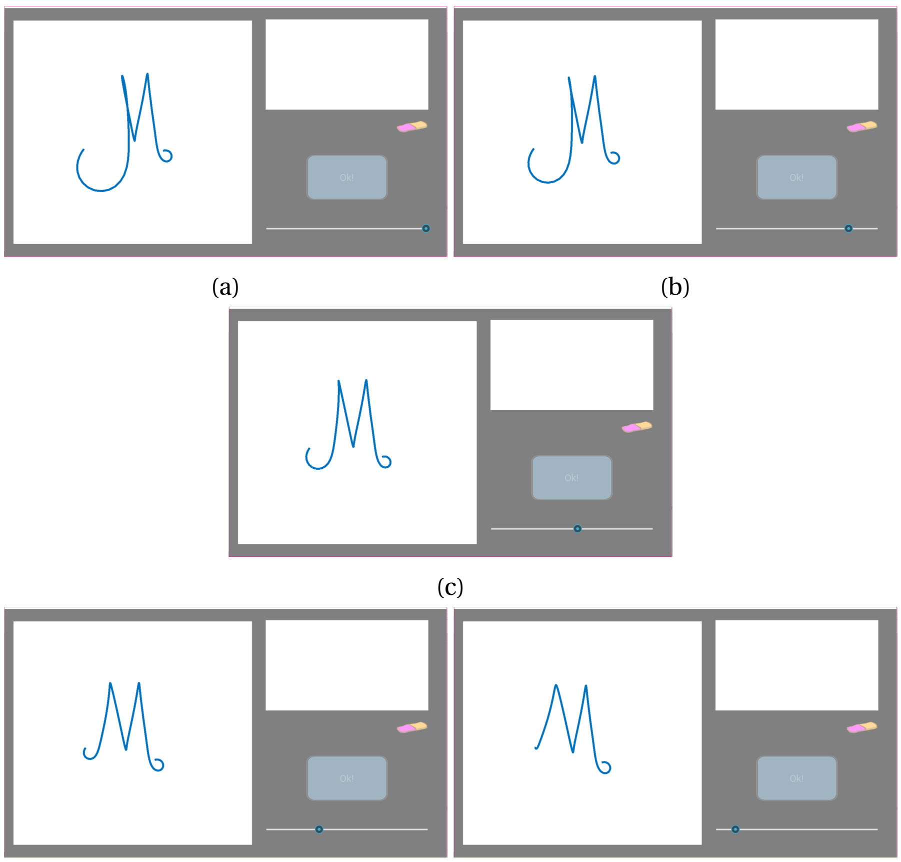
Figure 7.3 – Co-writer application interface.

application provides the interactive capability to the teacher-child to correct the shapes of deformed letters written by the learner-robot. As shown in Figure 7.3, the application interface includes a screen showing a large white box for the robot to write (left side of the screen), a small white box (right side) for the child to write in, a small button for erasing the shapes, a blue button to move to the next screen and a slider to perform the corrections. By using these interactive features of the application, the child could provide the overall corrective-feedback on the robot's writing performance.

The right side of the interface includes two distinct features, a small white box and the slider. The small white box is designed to allow the child to demonstrate the correct version of the letter written by the robot on the large white box. While, the slider shown is designed to provide the capability for the child to verify different variations in the shape of the letter. Since the slider is linked to different parameters of the letter trajectory (described in Section 7.2.7), the movement in the slider produced a change in the algorithm parameters resulting in a change in the letter's shape. For example, Figure 7.4 illustrates the variations of proportion issue in the letter *M* through the movement of the slider (from right to left). For all the letters, middle position of the slider is the position where the correct shape of the letter is displayed and the extreme positions of the slider show contrast distortion in the shape. Integrating the slider and small white box in the interface is motivated by two reasons described below:

- By moving the slider, the child is able to see a range of deformities (related to only one issue such as proportion) inside the letter that helps the child to find a position in the slider that displays the best possible letter. Although movement of the slider does not boost their motor skills but may augment their cognition skills.
- As the small white box allows the child to demonstrate the letter, it also reveals the child's knowledge about the shape of the letter. By writing the correct version of the letter, the child would enforce his/her current knowledge of the letter's shape. Additionally, it would also boost the child's motor skills.

Besides integrating the three application tasks from the child's side such as correction, demonstration and moving forward to another letter; the tasks display status and follow a specific order in which the child can use them. For example, when the robot finishes writing, it asks the



(a) (b) (c) (d) (e)

Figure 7.4 – A set of letters with varying degree (top to bottom) of rotation, proportion and alignment issues. The letters g,z,k shows the proportion issue and the letters W and d shows the breaks issue. The deformities can be generated by changing one or more parameters of a specific component of the letter.

child to correct the letter by moving the slider. At this point only the slider feature is enabled and the other two features (such as the small white box, 'ok' button) are disabled. After the correction process, the robot prompts the child to demonstrate the letter in the small white box, at this point, the box get's enabled and the button is still in a disable status. However, when the demonstration is over, the button get's enabled for notifying the child to move to another letter. Between each task application, some time is reserved for the child to finish the corrections and demonstrations according to his/her pace of performing the task. The correction through the slider is performed before the demonstration so that the child can provide the demonstration based on the corrections on the robot's letter. Additionally, this ordering also ensures that children perform all the application tasks in a simple and clear manner for the rest of letters. Moreover, the application is connected to the robot through a high-level integration framework (described in the following section) to notify the current state of the writing activity.

Besides developing the *co-writer application*, we developed the second application, called *tutorial application* that contains the same interactive features as in the former application. This application is used for children to provide familiarity's of the application features (such as writing using a stylus, using the slider) in advance before interacting with the robot in the collaborative writing activity. Both the applications are written in Python and run as a full-screen application on a touch-screen(see Figure 7.2a).

7.2.4 System Architecture

For developing the interactive embodied learning agent using the Nao robot, we used a high-level integration framework, called *Thalamus*. It can accommodate social robots while giving a generic and flexible capabilities to include physical and virtual components such as multimedia applications running on a touch-screen (Ribeiro et al., 2014b). In our scenario, the Display Screen Module and the robot are connected through Thalamus. As Thalamus relies on the concepts of asynchronous messaging middle-ware, it provides plug-and-play modules functionality and does not follow any layer structure.

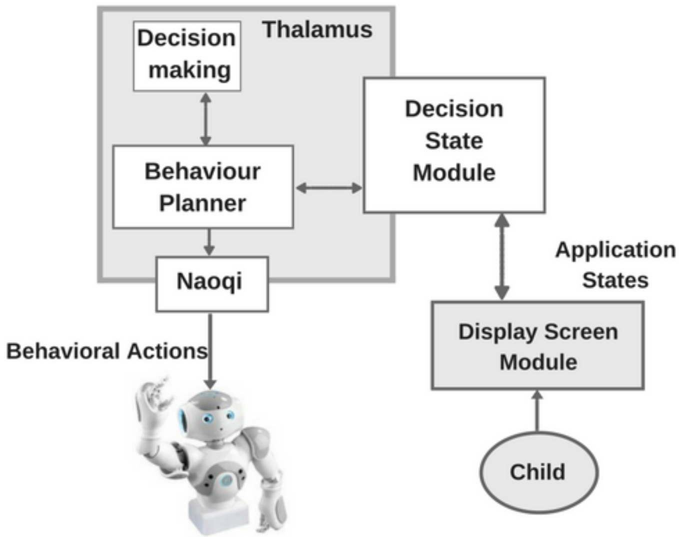


Figure 7.5 – System architecture.

The Thalamus Master is the main node that centralizes all communication that runs between different Thalamus Modules. Each module can subscribe and publish both Actions and Perceptions. In our designed system, figure 7.5 shows the overall system architecture, which was distributed in several thalamus modules: a *Display Screen Module* contained the co-writer application including all algorithms, letter trajectories, a *Decision State Module*, a *Behavior Planner*, the Naoqi API (provided by the Aldebaran) with the Nao robot. Each module acts as an independent module and equipped with a designated role in the behavior of the learning agent. Moreover, the Thalamus provides several other advantages such as it does not require installation on the host system, provides graphical interface to view modules and Thalamus agents, portability and convenience.

In order to provide the robot's behavioral actions such as gazing, pointing, speech and gestures, we used a semi-autonomous behaviour planner called *Skene* (Ribeiro et al., 2014b, 2016). The behaviour planner translates high-level behaviour description language (skene utterances) and perception information (e.g. target locations) originated at the decision-making level into a schedule of atomic behavior actions (e.g. speech, gazing, gesture) to be performed by lower levels. The use of the planner allowed the learning agent to communicate with the child in a social and natural way.

The *Decision State Module* is developed in C# and acts as a brain to communicate with the rest of the system modules such as Thalamus, Skene and Noaqi API. The essential functionality of the module is to inform the robot about the current states of the co-writer application through the Thalamus. Each interactive feature (letter screen, button, small writing box, slider; see Figure 7.3) in the co-writer application refers to a state. When the child interacts with any of these states, this module determines the action for the robot to perform. The decisions include whether to perform an action, the type of the action and when the action should be performed.

The robot's actions cover waiting, performing gestures without interacting with the child, and interacting with the child using gestures and dialogues. By receiving the action (according to the current state), the robot would know the current working status of the child. For example, if the child is correcting a letter through the slider and has not written the letter yet, the robot will be aware of which letter is under the correction process and which other actions are yet to be performed by the child and thus interact accordingly with the child.

To provide timely interaction, the Decision State Module checks the application state and adds the waiting timer in behavioural actions for the robot to react. Because we wanted all the children to perform a correction on the same number of letters, we partially facilitated the children to work at their own pace depending on the application state. For example, when the child finishes the correction of a letter, s/he can move to another letter without waiting, and when the robot is writing a letter, the child must wait until the robot finishes writing and for the correction process. Moreover, if the application state changes quickly depending on the child's speed, the system will cancel the behavioural actions of the robot to provide timely interaction between the child and the robot. Hence, the robot performs autonomously in an interaction with the child.

For the hand-drawing movement of the robot on the touch screen, simulated handwriting is used to provide the appearance of smoother shapes of letters. The robot used its finger to draw letters on the screen instead of using a pen. It writes letters in air so that they appear on screen; however, the robot's handwriting movement must match the appearance of the points in the letter's trajectory on the screen. The synchronization between the robot's hand movement and the simulated appearance of the letter is necessary to capture the engagement of the participants and to exhibit that the robot is actually writing. The hand-drawing movements of the robot were animated for writing all the letters on the screen and timely synchronised with the co-writer application (when the letter appears point-by-point on the screen).

We positioned the touch-screen in a vertical position due to two reasons: first, the vertical position allows the robot and the child participant to share the screen together in a side-by-side sitting arrangement while using the maximum space; second, this position of the screen is commonly used in schools (see Figure 7.5).

As described above that the writing application is written in Python and the rest of the system relies on C# language. To provide the communication between the two, we used XML-RPC server, a Remote Procedure Call method that sends data between the python and C# applications. More specifically, using the server, the current state of the interactive features in the writing application (on Python side) is notified by the Decision State Module (on C# side).

Thus, by integrating all the components discussed above, we are able to develop an educational tool suitable for children to enhance their handwriting skills using the peer-tutoring approach.

7.2.5 Robot's Role and Behavior

In the child-robot interaction described above, the robot initiates the interaction with the child and introduces itself as a learner and wants to improve its handwriting skills. Consequently, it asks the child for help to correct its handwritten letters. In this close interaction, the robot performs the role of a learner; and simultaneously a role of a facilitator. From the peer-tutoring viewpoint, the robot acts as a student which shows its writing skills to the tutor-child and prompts for correction. And from the viewpoint of designed activity, the robot facilitates the child to perform different actions such as correction, demonstration and move forward from letter to another by using simple dialogues. Both these roles are linked to the social and task related behaviors employed in the robot.

As shown in the Table 7.1, the verbal behavior of the robot are classified into two types of dialogues: *social* and *task* dialogues. The robot uses the social dialogues at a few places during interaction such as when it introduces itself to the child:

> *"Hello, I am Michael. I am happy to see you here. You know I have been learning the shapes of letters of Portuguese alphabet. I am liking it, but there is one problem. The problem is that when I write a letter, its shape is not correct. I was thinking that if you could help me to correct some shapes of letters. Let's start! "*

Besides, the dialogues related to introduction greetings and handwriting problem, it asks questions two or three times related to the letters. The examples of these questions are shown in the Table 7.1(Number 2 and 3). Overall, these dialogues were included in robot's verbal behavior to maintain the child's engagement throughout the interaction. The task-related dialogues are only related to the writing application features (such as slider, eraser, box) and the shapes of the letters.

Table 7.1 – Robot's dialogues in the task-related and social aspects.

Aspects	Examples of Robot's Dialogues
Social	1. Hello, I am Michael. How are you today? 2. You corrected letter 'B', do you know any animal's name which starts with this letter? 3. Sumo(juice) starts with letter 'S'. Which is your favorite flavor of sumo? 4. Thanks a lot! Today you helped me a lot! See you next week!
Task-related	1. Please, correct the letter by moving the slider. 2. Let's move to another letter! 3. You may press button 'ok'. 4. After you corrected this letter, it looks much better!

7.2.6 Synthesising Deformed Letters

Since we used the peer-tutoring approach where the learner-robot demonstrates a deformed letter to the tutor-child, we expect that the process of correcting and demonstrating letters would enhance the child's handwriting skills. Therefore, generating the deformed letters for the robot and demonstrating the correct letter (from the child side) are the key points in the system. As we have studied in the previous chapters, while writing children produce a variety of letter errors which also depends on their age and level of writing skills.

(a) (b) (c)

Figure 7.6 – Handwriting issues used for generating the deformed letters: (a) Proportion; (b) Breaks; (c) Alignment.

In literature, the most common handwriting issues faced by children are related to overall neatness, letter formation, and alignment Graham et al. (2008, 2001). In addition, the results of our previous studies have shown that the errors such as *proportion*, *alignment* and *breaks* were among the most produced errors among *position*, *size*, *style* etc. Thus, in the designed system, instead of generating random deformations in the letters, we targeted only three common handwriting issues *proportion*, *breaks* and *alignment* and are described below:

- **Proportion**: the issue relates to distortion in a letter and can be present either in a sub-part (locally) or in the whole letter's trajectory (globally). One of the example of such is shown in Figure 7.6a where the sub-part (the first part of the trajectory of the letter) is not in proportion with respect to the rest of the trajectory. In our previous studies, this issue has shown the highest frequency and produced by majority of children.

- **Breaks**: the issue arises when there is a 'hole'present in the letter's trajectory, resulting in a discontinuous shape. The example of a letter contains this type of issue is shown in Figure 7.6b. Based on our previous research, this issue has not shown the highest frequency; however, is prevalent in majority of students.

- **Alignment**: the issue relates to nonalignment of the letter, for example, rotation of the letter at some angle (Figure 7.6c). Again, the issue is widespread among children's handwriting issues.

7.2.7 Algorithm:

For handling the *proportion* and the *breaks* issues in the generated errors, we use an algorithm proposed in (Yin et al., 2016) that incorporates human movement inspired features and generalises the synthesis to generate poor or good written samples of a letter. In addition, it estimates motion parameters associated with stroke deformities in an imitation learning problem. For testing purposes, we created a data set $\mathscr{D}$ of letters in advance and used the algorithm to generate the deformed letters based on children's handwriting errors collected in previous studies (Chandra et al., 2015, 2016, 2017a) described in Chapter 3, 4 and 5.

Algorithm 1 Learning with curvature-based features for modelling handwriting motion

Require: $\mathscr{D} = \{\varsigma_i\}, M$
Ensure: $\mathscr{D}^m_{k=1:K_m}, \hat{\boldsymbol{\theta}}^m_k = \{\mu_f{}^m, \Sigma_f{}^m\}, m = 1, ..., M$
  $\mathscr{D}^m_{k=1:K_m} \leftarrow$ Partitioning($\mathscr{D}, M$) ▷ Build locally similar dataset $\mathscr{D}$ through partitioning
  for all m in 1:M **do**
    $\mu_\varsigma{}^m, \Sigma_\varsigma{}^m \leftarrow \underset{\boldsymbol{\theta}}{\text{argmax}} \sum_{i=1}^{|\mathscr{D}^m_k|} \log \mathscr{N}(\varsigma^*_i | \boldsymbol{\theta})$
    $\mu_f{}^m \leftarrow$ RXZERO($\mu_\varsigma{}^m$)
    $\Sigma_f{}^m \leftarrow J(\mu^m_\varsigma)^T \Sigma^m_\varsigma J(\mu^m_\varsigma)$
  end for

The input of the algorithm is a planar handwriting data set $\mathscr{D}$, see Algorithm 1. For generating similar instances of a letter from the dataset, the Gaussian statistics of trajectories are extracted. The parameters received from the statistics are further converted to a curvature-based representation with nonlinear feature embedding. The mean of the trajectory $\mu^m_f = \{A_j, z^j_0, \mu_j, \sigma_j, \alpha^j_s, \alpha^j_e\}_{j=1:N}$ is obtained by an RXZero process (O'Reilly and Plamondon, 2009), which effectively solves a nonlinear optimization to match the trajectories through Equation (7.1) and (7.2). The two equations determine the stroke velocity $|v|$ and the path angular direction ϕ_f on the time phase z and are sufficient to reconstruct letter trajectories. The covariances are transformed through local linear projections, with $J(\cdot)$ denoting the Jacobian of the reconstruction. It is easy to find that some of the extracted parameters are correlated to the motion path in an explicit manner.

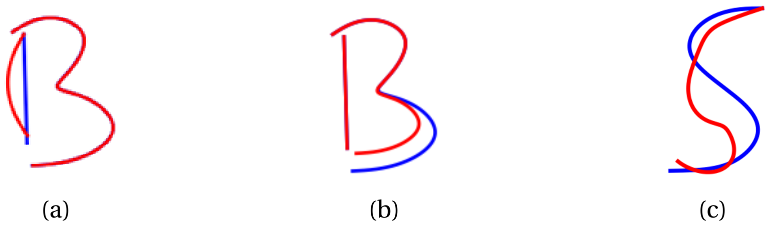


Figure 7.7 – The blue trajectory denotes the letter input to the algorithm while the red denotes the output. The letter ‘S’(c) shows the *proportion*; the letter ‘B’(b) represents the *break* and the letter ‘B’(a) represents the *proportion* and *break* handwriting issues.

$$|v(z)| = \sum_{j=1}^{N} \frac{A_j}{\sqrt{2\pi}\sigma_j (z - z_o^j)} \exp(-\frac{(\ln(z - z_0^j) - \mu_j)^2}{2\sigma_j^2}) \tag{7.1}$$

$$\phi_j(z) = \alpha_s^j + \frac{\alpha_e^j - \alpha_s^j}{2}(1 + \mathrm{erf}(\frac{\ln(z - z_0^j) - \mu_j}{2\sigma_j})) \tag{7.2}$$

For instance, in Equation 7.1, A, z0, μ and σ are the parameters that regulate the velocity profile |v|. A_j is proportional to the velocity magnitude such that the size of specific letter components can be modulated without influencing the other components. Equation 7.2 shows that α_s^j and α_e^j anchor the start and end angular position with erf(·) denoting a Gaussian error function. Hence, the two parameters allow the stroke orientation or the curvature to be adjusted; see Figure 7.7. The introduction of the phase variable z allows to evaluate the trajectory on a uniform interval z ∈ [0; 1].

First, the algorithm recognises different strokes present in a letter and then for each stroke, the algorithm generates a number of components. For each component there exist a set of parameters such as A, z0, μ and σ. For generating an issue (such as proportion) in a letter, one or more parameters of the letter’s trajectory can be changed in a specific component of the letter to produce variations. For example, the letters g, z, W, d and k illustrates the capability of the algorithm by varying its parameters to produce a range of proportion and break issues (see Figure 7.8). For the *alignment* issue, we developed another algorithm to produce the rotation effect with different angles, see letter b in Figure 7.8. The input of the algorithm is again the handwriting data set $\mathcal{D}$ and the input angle. In addition, the algorithm is capable of recognising the strokes of a letter and aligning the letter with a specific input angle. Overall, both algorithms generate a full letter and capable of improving or deforming the shape of the letter. Figure 7.8 shows a set of letters exhibiting different models of *proportion*, *alignment* and *breaks* issues. The choice of using the first algorithm is motivated by two reasons: first, it has the power to synthesize and learn the multiple-mode motion trajectories, with the integration of rapid extraction and representation. Second, we wanted to generate deformed letters for the robot that closely resembles children’s handwriting. As a result, this provides a digital approach to control the letter deformities, hence allowing the robot agent to exhibit a

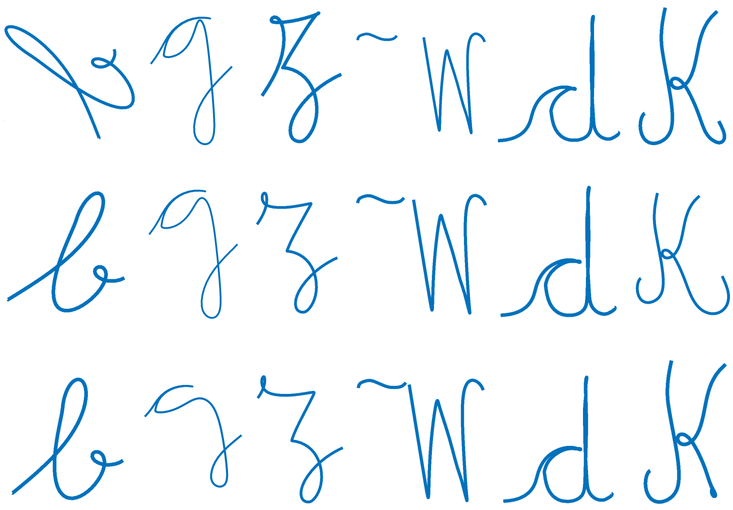


Figure 7.8 – A set of letters with varying degree of rotation, proportion and alignment issues are shown from high to low in a top to bottom manner. The letters g,z,k shows the proportion issue and the letters W and d shows the breaks issue. The deformities can be generated by changing one or more parameters of a specific component of the letter.

spectrum of levels of handwriting skills.

7.3 Discussion and Conclusions

This chapter presents three important contributions to the work (Chandra et al., 2017a, 2018): (1) the development of autonomous social robot; (2) the generation of a set of common writing errors by the robot; and (3) an overall system as a test for further investigation of peer learning mode.

7.3.1 The Autonomous Social Behavior of the Robot

We were able to build a system that incorporates an autonomous social behavior in the robot. Indeed, this will have some impact in numerous ways compared to our previous studies where the Wizard-of-Oz approach is traditionally used. In the developed system, the wizard is not needed and yet the scenario is such that the robot engages a child in a collaborative writing activity. The robot is continuously aware of the ongoing state of the child's task performance and is able to facilitate the interaction throughout the session. In addition, due to this awareness, the robot creates an environment where it timely prompts, ask questions and provides feedback to the child. This capability infuse the belief for the child that the robot is intelligent. Considering the robot's social behavior (verbal and non-verbal), the welcome and goodbye greetings, introduction where it seeks help regarding handwriting, prompts, social questions along with the ability to physically write on the screen and show the timely gestures such as head-movement, gazing and pointing allows the robot to captivate the child's attention in a social, yet natural way.

Besides, all these advantages, the current system still requires some advancements in a few aspects. For example, although the system is technically autonomous, it follows the restricted scenario presented in Section 7.2.2. It needs to be extended in substantial ways where it can be applicable under different protocols and different scenarios. For example, it can be modified to incorporate other learning interactions such as peer-learning scenario where no specific role is attributed to the participants and both acts as learners. Although, due to the knowledge of the task status, the robot is capable of providing timely responses during the interaction with the child; still, it is incapable of doing the two-way conversations with the child and hence limits the fully autonomous behavior. Moreover, the system used offline models of the letter trajectories, and the Nao robot used an animated handwriting movement while writing.

7.3.2 Inclusion of a Set of Errors in the System

The writing errors presented in the Chapter 6 and here included in synthetic generation of errors may benefit students. Commonly, when a child struggles in forming a particular letter, the handwriting instructor (a teacher or parents) ask them to repeatedly write the letter until the letter's shape becomes identical to the correct sample; this process involves correction of several types of errors in the letter simultaneously. Consequently, it may or may not improve the child's writing but takes a significant amount of time. On the contrary, when the instructor is aware of the errors that the child produces during writing, this knowledge can make the whole process of learning shapes simpler and clearer. In the work described here, we created a system that is able to generate three types of errors, such as *proportion*, *breaks*, and *alignment*. There are two reasons for this approach: first, they have been shown as the most common errors in literature and our past studies; second, we believe introducing more than three errors may clutter child's mind in understanding and perceiving the difference between the three errors; and consequently increase the cognition load. The implementation of the errors in the system may provide the opportunity to the children to pay attention on the robot's writing errors which is actually based on their own writing errors. By correcting the errors and demonstrating the letter, may expose children to reflect on their own writing errors. Thus, this learning-by-teaching approach may help them to enhance their own writing skills in an unusual and effective way. Currently, the system has a capability to generate three types of errors but it can be extended and modified by including other types of writing errors. This inclusion may require different algorithms in addition to the algorithms presented in this article.

7.3.3 System for Further Exploration

As mentioned above, the developed system does not require more than one experimenter to supervise it; and subsequently, eliminates the need of being present as a facilitator during the interaction or remotely watch the child-robot interaction in real experimental settings. Although, the system setup is easy and does not require advanced technical knowledge; however, necessitates an adult with basic knowledge of handling the computers to run it. Thus, we believe that the current system can be used in the schools to enhance children's handwriting skills.

We developed the system with the intention to test it for a set of research questions: apt for enhancing children's handwriting skills; apt for exploring children's perception of the robot; and would it be possible to use the system for multi-session studies? One of the prominent reason to develop any technology is provide well-being to its users. And when it come to educational child-robot interaction, one of the major expectation for the researchers is to anticipate whether the overall interaction would lead to children's learning gains or not. In the context of our research, it is important to develop a system which can prove to be useful for children's learning specifically handwriting skills. Thus, our research question is to investigate whether the developed system can be effective for children in the acquisition of handwriting skill.

Our other research interest is to explore children's perception of the robot's capabilities and behavior. In our system, children are the real users and therefore, it becomes important to investigate their perceptions of the robotic agent in the existing learning-by-teaching scenario. This curiosity leads to a number of questions such as: how would they perceive the robot's social behavior and its capabilities? Would their perception affect learning gains?

One of the relevant and challenging aspect in HRI, specifically in child-robot interaction scenarios is to design the system to maintain children's engagement and interest for a sustained amount of duration. Through our developed system, we seek whether the system is apt of performing multi-session child-robot interactions. For instance, would children be able to continue interact with robot over one session? Additionally, a systematic review of handwriting intervention studies concluded that a minimum of two handwriting spaced practice sessions per week and at least 20 sessions are required to deliver effective results in children's handwriting (Graham et al., 2000; Hoy et al., 2011). Therefore, by relying on the conclusions of the above-mentioned reviews, we plan to test the system with multi-sessions studies in order to examine children's learning gains over the sessions. Moreover, we also want to seek whether children's perceptions of the robot would change over time?

With the above-mentioned research questions, we conduct two multi-session studies with children in a school setting environment. The studies are further detailed in the next chapter.

8 Children's Learning and Perceptions of a Social Robot

In the preceding chapter, we described an educational system where we developed an autonomous social behavior of the robot that was designed to enhance children's handwriting skills. Exploiting the benefits of the *learning-by-teaching* method, the system provides a scenario in which a child acts as a teacher and corrects the handwriting difficulties of the robotic agent which acts as a learner. In this chapter, we validate the developed system by conducting two multi-session studies in school-settings. In Section 8.1, we first describe the research goals of the studies, including the motivation and contributions. Further, we describe our 4th study in Section 8.2. The study consists of multi-sessions; compare two contrasting competencies in the robot: 'learning' vs. 'non-learning'. In this study, we investigate children's learning gains and their perceptions towards the social robot throughout the sessions. Inspired by the results of this study, we conducted another similar study while integrating the learned lessons of the previous study. We further detail our 5th study in Section 8.3. Similar to the 4th study, the 5th study follows the same child-robot interaction scenario and includes multi-sessions; but, compares three varied competencies of the robot: 'continuous-learning'; 'non-learning' and 'personalised-learning'. Further, in Section 8.4, we provide insights of both studies and highlight the similarity and differences in the findings. Finally we wrap up the chapter by briefly describing the overall conclusions and limitations.

8.1 Scope and Research Goals

Social robots are being used to create better educational scenarios, thereby fostering children's learning. In the preceding chapter, we describe an autonomous social robot that was designed to enhance children's handwriting skills. Exploiting the benefits of the *peer-tutoring* method, the system provides a scenario in which a child acts as a teacher and corrects the handwriting difficulties of the robotic agent. To explore the children's perception towards this social robot and the effect on their learning, we have conducted two multi-session studies with children. The motivation behind these studies and the contributions of the studies are discussed in the next section.

8.1.1 Motivation and Contribution

Over the past several years, robots have been introduced into educational contexts seeking different ways of fostering engagement in learning activities. A significant part of the work in educational robotics utilises robots as tutors; however, some researchers have started using the robots as tutees based on the peer-assisted educational method named as *learning-by-teaching* or *peer tutoring* (Kanda et al., 2004b; Biswas et al., 2004b). Besides academic benefits of the method, it is also believed to engage and motivate students (Tanaka and Matsuzoe, 2012; Rohrbeck et al., 2003). For example, Kanda et al. (2004b), used Robovie, a humanoid robot, as an English peer-tutor for Japanese childrenand concluded that the robot encouraged some of the children to improve their English and form relationships with them. Similarly, Hood et al. also found that the Nao robot[1] could improve children's writing skills and engage them successfully (Hood et al., 2015). However, *how do the children perceive these robots? How do these perceptions change over multi-session interactions?* Children's perception towards a robotic agent is related to several aspects such as the robot's role, physical or nonphysical behaviour, and appearance and indeed seems to be relevant in child-robot interactions (Kahn Jr et al., 2012; Okita et al., 2005; Beran et al., 2011; Woods, 2006; Hyun et al., 2008). Since child-robot interaction is inherently social (Salter et al., 2008), it becomes crucial to investigate different aspects of the social relationship between robots and children. In fact, Beran et al. (2011) asked questions about a robot to 198 children and found that a significant proportion of children were able to ascribe behavioural, cognitive characteristics to the robot. Similarly, (Kennedy et al., 2015b) conducted a study where a social vs. asocial robot (Nao robot) taught prime numbers to children of 7 to 8 years of age. After the interaction, the children were asked to attribute a role to the robot out of 8 available options (brother or sister, classmate, stranger, relative , friend, parent, teacher, and neighbour). The results showed that the children consistently perceived the tutor-robot as a friend. Although there has been significant research on children's perception of robots, less attention has been paid to how children perceive the abilities of a robot in educational scenarios in multi-session studies and how their perceptions change over time.

One of the aims of peer-tutoring method is to maximise the learning gains of students. In our developed system (described in 7^{th} Chapter), we exploit this method with the goal of answering a question: *how would the learning capabilities of a tutee impact the learning of a tutor?* Therefore, in our current studies, we design a child-robot scenario, where a child acts as a *teacher (tutor)* and a robot acts as a *learner (tutee).* The use of a robot allows us to manipulate its capabilities and behaviour in a controlled way. To have a clear differentiation in the learning capabilities, we have chosen contrasting competencies of the learner-robot in both studies. Furthermore, the peer-tutoring approach is also explored based on *Role Theory* (Sarbin, 1966). According to the role theory, the enactment of a role such as a teacher or a learner affects the behaviour, attitudes and perceptions of the participants consistent with role expectations (Bierman and Furman, 1981). Tutor-children attribute prestige, authority,

[1] Aldebaran robotics: `https://www.aldebaran.com/en`

self-esteem (Allen, 1976) and their perceived *self-efficacy* towards tutoring and this has also been associated with academic achievement (Bandura, 1977; Zimmerman, 2000; Bandura, 1986). Besides, the performance of the tutee may also affect tutor's attributions towards the tutee (Allen and Feldman, 1974).

As previously mentioned, we developed a robot with autonomous social behaviour that provides an educational scenario for children to improve their handwriting skills. The effect of feedback in assessment process becomes most powerful when it addresses faulty interpretations (Hattie and Timperley, 2007). Thus, we used corrective feedback (Bitchener, 2008) as a peer assessment approach, where the tutor-child gives feedback on the learner-robot's handwriting. Further, we aimed to understand how children perceive the agent's behaviour and capabilities since they can impact the child-robot learning interaction. Aspects such as children‘s learning gains, engagement, and perception may be altered (Deshmukh et al., 2016; Kennedy et al., 2015b). Past research has shown that multiple sessions of handwriting practice are required to improve children's handwriting skills (Hoy et al., 2011). Also in the context of child-robot studies, it was shown that the children tend to change their attitude towards a social robot over time (Kanda et al., 2004b). Thus, we tested the system by conducting two multi-session studies.

8.2 Study 4: The Learning vs. Non-Learning Study

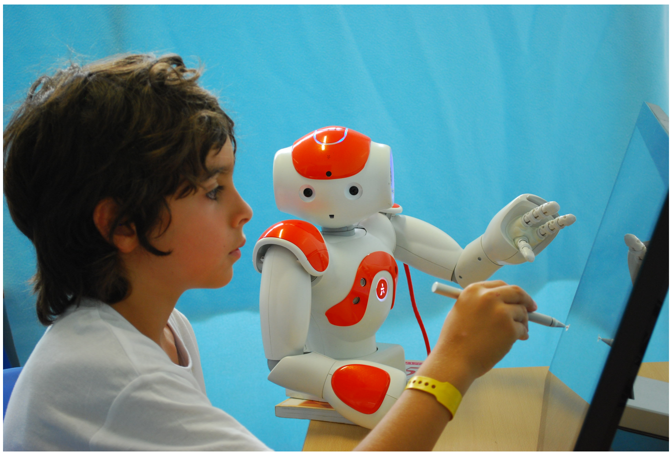


Figure 8.1 – A robot explains its handwriting problems and seeks help from the child.

8.2.1 Research Questions and Hypothesis

The current study explores the children's learning and their perceptions of the robot in an educational scenario based on one-to-one peer tutoring approach. The scenario involves a tutor-child and a learner-robot performing a collaborative learning activity. As mentioned before, the robot seeks help from the children to improve its handwriting skills while facilitating the task (see Figure 8.1). However, the robot exhibits two contrasting competencies; one where the robot shows improvements, and the other where it does not learn (detailed in Section 8.2.5). Overall, the goal of the study is to explore children's learning and perceptions over time. We state the research questions and hypotheses as follows:

- **Research Question 1:** Can the children respond differently to the robot's contrasting learning capabilities (related to the robot's overall performance, writing capability and handwriting improvement)?

  Hypothesis 1: Because the robot shows two contrasting competencies, we hypothesise that the children would be able to recognise the learning capabilities of the robot in each condition.

- **Research Question 2:** Would children in the learning condition consider themselves a better teacher than in the non-learning condition?

  Hypothesis 2: In the study, children's perceived self-efficacy towards tutoring the robot means how good children consider themselves as a 'teacher'. Thus, we hypothesised that by the end of the study, the children in the learning condition would perceive themselves better teachers compared to the other condition because they may believe that their teaching abilities improved the robot's writing skills.

- **Research Question 3:** Would the two different competencies (learning and non-learning) of the robot affect the children's perceived likability and friendliness towards it?

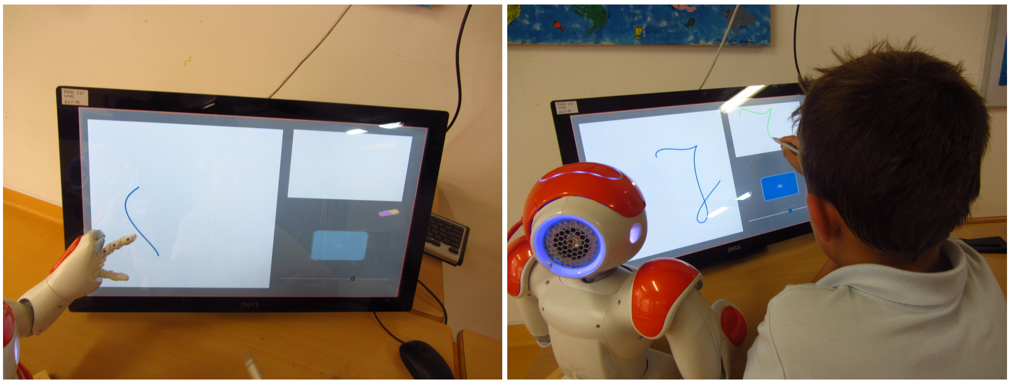
  Hypothesis 3: We hypothesise that if the children could differentiate the two competencies, they would like the robot more in the learning condition because they would have more positive interactions with the robot.

- **Research Question 4:** Would the two competencies affect children's learning gains? Which competency would affect more?

  Hypothesis 4: We hypothesise that the children would benefit in both conditions regarding handwriting skills. However, the children in the learning condition may benefit more by seeing the robot's continuous improvement.

8.2.2 Participants

We conducted the study in "Colégio da Fonte" in Porto Salvo, Portugal. Twenty-five children participated from the 7- to 9-year-old age group (1^{st} and 2^{nd} grade) over a period of 1 month. Thirteen children (M=7.92; SD= 0.82; 5 male and 8 female) participated in the *learning condition*, and 12 children (M=8.08; SD=.75 years old; 7 male and 5 female) participated in the *non-learning condition*. Only children who assented and whose parents signed a consent form participated in the study.



(a) (b)

Figure 8.2 – Experimental setup: (a) when a robot writes on the screen; (b) when a child provides correction.

8.2.3 Materials

The material in the study included a computer with a touchscreen, stylus, tablet (for pre- and post-test), video camera, microphone and Nao robot (only torso part). As shown in the past research, several letters in the English alphabet (lowercase - (b, q, d, k, g, p, z, u, j, n, a), uppercase - (K, Y, Z, W, R, M, F, D)) are problematic for primary grade children (Graham et al., 2001, 2008); we targeted letters from this category only (see Appendix E). For each interaction, we prepared a different set of deformed letters, avoiding the conflict of using the same letters with the same handwriting issues. We conducted the study in a local private school, “Colégio da Fonte" in Porto Salvo, Portugal.

8.2.4 Interaction Design

Our experimental setup involves a child sitting side-by-side with an autonomous Nao robot and a touchscreen used by both to write: the learner-robot writes a deformed letter on the screen (Figure 8.2a) and asks the teacher-child to correct it (Figure 8.2b). The teacher-child then corrects the letter and demonstrates a sample of the same letter by writing on the other side of the screen. In our design, the turn-taking occurs when the robot prompts the child for correction once it finishes writing (using sentences like ‘could you show me the correct shape of this letter?’) and when the child presses a button on the screen after finishing the correction.

To test the system in schools, we contacted and visited two schools in advance and found that the children use the similar vertical interactive digital screen in their classroom for writing purposes. Thus, we believe that the children are familiar with writing on the vertical screen and the overall spatial arrangement between them, the robot and the screen would be suitable for them.

8.2.5 Conditions

Our study consists of a between-subjects design with two conditions: *learning* & *non-learning*. In the study design, the interaction between the child and the robot is dyadic where the learner-robot seeks help from the tutor-child to correct the shape of the letters drawn by it. For example, the robot writes a letter on the screen and asks the child to correct it. For correction, the child performs two tasks: first, s/he corrects the shape of the letter through the slider; and second, demonstrates the letter on the touch-screen. The robot's letter and child's corrections correspond to one letter and are performed in the same space on the touch-screen (see details in Chapter 7). Each child interacted with the robot four times with an interaction gap of 4-5 days. The two conditions are describe as follows:

- **Learning:** In this condition, the robot shows progress between the sessions. In the first session, it writes poor shapes of letters and by the end of the last session, it writes the letters all most with correct shapes. More specifically, it is actually becoming competent in learning how to write and shows advancement in its writing skills independent of the performance of the tutor-child.
- **Non-Learning:** In the non-learning condition, the robot shows the consistent performance throughout the sessions. In the first session, it writes deformed letters and continues to write poor shapes of letters by the end of the final session. To be more specific, it does not learn.

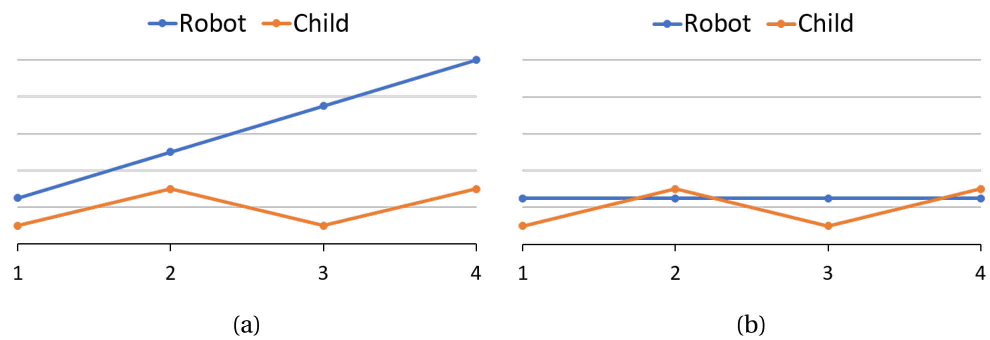


Figure 8.3 – Robot's learning progression in terms of writing skills and grades in the: (a) learning-condition; (b) and non-learning condition.

In both conditions, the robot showed the same social behavior despite exhibiting different competencies. As shown in Figure 8.3, the robot's progress is graphically shown in the learning and non-learning conditions. In both conditions, the robot initiates with the same level of writing skills and grades.

8.2.6 Protocol

The children were randomly assigned to one of the two conditions to perform the collaborative writing activity with the robot. Each session was performed with a child and a robot and lasted approximately 13-15 minutes. The study was set up in a computer classroom in the school, and the children were comfortable with the classroom settings. The robot was named *Michael* to provide friendly interaction. During the introduction of the study, the researcher explained to the participants that they were going to interact with the robot 4 times (once per week) for the writing activity because the robot needed help in improving its handwriting skills. The researcher also explained the role of the robot as a learner and the participants' role as a teacher. Moreover, the participants were also informed that if they did not wish to continue, they could leave the study anytime they wanted. However, no participant left the study in between. The study was organized into following steps:

Tutorial: in this step, a researcher would bring a child into the classroom and explain the features of the tutorial application. The child then performed the tutorial activity on the monitor in the presence of the researcher. This step was crucial because all participants were young and needed the understanding to use the application. All children performed this step only before the first interaction.

Pre-test: the researcher would ask the child to perform the pre-test on the tablet. The pre-test application is developed to test the child's knowledge about the shape of a letter. This knowledge was examined based on two legibility factors: first, how well they could recognise the most correct shape of the letter; second how well they could demonstrate the letter by rewriting it. Thus, 3 different shapes of the same letter were displayed on the screen, and the children had to choose the most correct letter and write it on the same screen. The process was repeated for the remaining 8 letters.

Teaching activity with the robot: this phase involved the child-robot interaction. The researcher would bring the child into the classroom and leave him/her alone with the robot.

- **Welcome greeting:** the robot greeted the child and expressed its writing difficulties while showing its poor grades (fictitious grades it received from its fictitious teacher). This step was important to create an environment in which the child would find the robot in need of help.

- **Correction period:** the robot wrote a letter on the screen and asked the child to correct it by using a slider (see Figure 8.2a). After that, the robot asked the child to demonstrate the same letter in the small white box (right side) (Figure 8.2b). After finishing the correction and writing, the child advanced to the next screen and repeated the process for the remaining 15 letters.

- **Goodbye greeting:** after the correction period was completed, the robot would thank the child for the help. Moreover, the robot also informed the child that it would practice these letters until the next interaction.

Post-test: the researcher would ask the children to perform a post-test, identical to the pre-test.

Interview Questions: after finishing the teaching activity with the robot, the researcher would perform an interview with the child by asking a few questions for 5-6 min. As shown in Table 8.4 and 8.2, the questions were divided into five categories and were based on categorical and 5-point Likert scale respectively. The questions were specifically designed and based on different aspects such as on the role assignment theory (Kennedy et al., 2015b)(2nd category, Table 8.4); study's research questions (1st category, Table 8.4; 3rd and 4th category, Table 8.2); and Godspeed questionnaire (5th category, Table 8.2). Before interviewing the children, the researcher would emphasise that honest answers are important for the robot's learning, and the answers would not be disclosed to the robot. Then, the researcher would present the questions to the children on a sheet of paper in a child-friendly manner (see questionnaire in Appendix E). For example, for the question 'How many stars would you like to give for Michael's overall performance?'(3rd category, Table 8.2), the values of the Likert scale (1,2,3,4,5) were represented with stars (*, **, ***, ****, *****).

In addition, Table 2 describes the % of children (right side of the questions) who gave either 4 or 5 points on the scale. For the analysis purpose, we considered the Likert scale values as scores given by the children. The high scores discussed in the result section represents the combined scores of 4th and 5th point in the Likert scale. Furthermore, these questions were asked at three-time intervals, immediately after the second, third and fourth interactions with the robot.

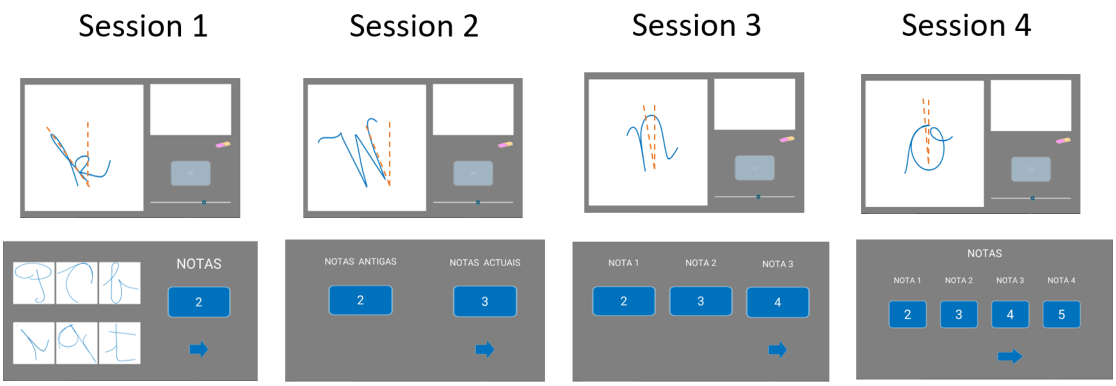


Figure 8.4 – Improvement in robot's written letters (top) and grades (bottom) in the four sessions in the learning condition.

8.2.6.1 Learning vs. Non-learning capability:

In the learning condition, the robot would show its progression in two ways: by writing the improved letter and by showing improved grades (fictitious). The robot would inform the children that these grades it got from its professor. Figure 8.4 shows the screen shots of the writing application, for example, the letters shown contains the rotation error. The red dotted

Table 8.1 – Percentage of children who answered questions in 1st category after each session.

Robot's grades (1st category)†	Options	L & NL(%)
Q1. Have you observed Michael's grades? How well did it score?	Yes/No, score(value)	100
Q2. Was the grades improving or not?	Improved/Not Improved	100

*Learning(L), Non-Learning(NL); †Based on study's research questions.

lines on the letters were not shown to the children and are only displayed here to show a decrement in the rotation error. The robot's handwriting ability and grades would improve at a constant rate from low to high. It would show the grades as: session1, grade = 2/5; . . . session4, grade = 5/5. In the non-learning condition, the robot would display consistently unimproved letters and constant grades throughout the sessions (session 1 to 4, grade = 2/5). We chose the two parameters (the handwriting and the grades) to show the robot's performance explicitly to the children. The robot would show its grades at the beginning of each session and then perform the writing activity. Besides, the robot showed same social behaviour and interaction in both conditions.

8.2.7 Analysis

We collected the data from the questionnaires and logs of the tablets. The results of the Shapiro-Wilk test did not show the normal distribution of the data, so we analysed the data by using the non-parametric tests. For evaluating all the questions related to the perceived robot's capabilities (Table 8.2, 3rd category) and learning gains, we used the Mann-Whitney U test. For analysing the questions related to the children's self-evaluation towards tutoring (Table 8.2, 4th category) and their perceived impressions of the robot (Table 8.2, 5th category), we present the results in terms of correlations. For comparing the pre-and post-test scores, we used the Sign test. And finally, for analysing the questions concerning perceived role of the robot (Table 8.4, 2nd category), we used the Chi-square test. In addition, we also discussed the results concerning percentages. In the following sections, we present the results in the order of the above-mentioned research questions.

8.2.8 Findings

8.2.8.1 Robot's Grades

The questions assessed in the 1st category correspond to the children's awareness of the robot's grades (Table 8.1). We found that all children were aware of the robot's grades in terms of the score (Q1) and the improvement made (Q2) since they answered both questions accurately according to each condition. The result suggests that the children indeed paid attention to the robot's grades and learning skills during the interaction and were aware of this knowledge while answering the other questions.

Figure 8.5 – Results of the children's perceived scores of the robot in both conditions: (a) writing capability scores after the third interaction; (b) writing capability and overall performance scores after the fourth interaction.

8.2.8.2 Children's Perceived Capabilities of the Robot

The presented questions in the 3rd category such as Q1 (overall performance), Q2 (writing capability) and Q3 (improvement) correspond directly to the robot's learning capabilities (see Table 8.2, 3rd category). Despite showing no differences after the first two interactions with the robot, over repeated interactions, the perception of two of these capabilities showed significant differences over time. For example, after the second interaction, the results of the Man-Whitney test showed no significant difference between the learning (mean rank = 9.44) and the non-learning condition (mean rank = 7.56), $p > .05$. However, after the third interaction, children in the learning condition (mean rank = 16.42, mean = 4.69) gave significantly higher *writing capability scores* to the robot compared to the non-learning condition (mean rank = 7.86, mean = 3.45), $U = 20.5$, $z = 86.5$, $p = .002$ (see Figure 8.5a).

Furthermore, after the last (fourth) interaction, *overall performance* scores and *writing capability scores* both showed significant results. Children in the learning condition (mean rank = 16.58, mean = 4.77) gave significantly higher *overall performance* scores to the robot compared to the non-learning condition (mean rank = 7.68, mean = 3.73), $U = 18.5$, $z = -3.366$, $p = .001$. Besides, for the *writing capability*, they (mean rank = 15.65, mean = 4.69) gave higher scores to the robot compared to the non-learning condition (mean rank = 8.77, mean = 3.55), $U = 30.50$, $z = -2.67$, $p = .015$ (Figure 8.5b). The results suggest that the children noticed the difference in the robot's capabilities regarding its writing capability and the overall performance only after the third and final interactions. Regarding the improvement in the robot's handwriting (Q3), we did not find any significant difference between the two conditions, which is interesting given that in one of the conditions, the robot was not learning. Indeed, after the last interaction, most of the children in both conditions (learning - 92%, non-learning - 75%) provided high scores to the robot's handwriting improvement (see Table 8.2, 3rd category).

Table 8.2 – Percentage of children who gave high scores to the robot for the questions in the third, fourth and fifth category after the last interaction.

Children's perceived capabilities of the robot (3rd category)†	L(%)	NL(%)
Q1. How many stars would you like to give for Michael's overall performance?	85	67
Q2. How many stars would you like to give for Michael's writing capabilities?	92	58
Q3. Do you think Michael's handwriting is improving?	92	75
Children's self-evaluation towards tutoring (4th category)†	**L(%)**	**NL(%)**
Q1. Do you like teaching Michael?	100	92
Q2. Would you like to teach Michael in the future?	92	92
Q3. How good were you as a Michael's teacher?	92	92
Children's perceived impression of the robot (5th category) (Bartneck et al., 2009)	**L(%)**	**NL(%)**
Q1. What grade would you like to give for Michael's intelligence?	100	67
Q2. Do you like Michael?	100	92
Q3. Do you find Michael friendly? How much?	100	92

*Learning(L), Non-Learning(NL); †Based on study's research questions; The % of children (right side) who chose either 4 or 5 points on the Likert scale; The scale values are considered as scores in the analysis; High scores: combined scores of fourth and fifth point in the 5-point Likert scale (1st-point = Lowest, 5th-point = highest).

This result suggests that 75% of the children in the non-learning condition, being aware of the robot's fictitious grades (these grades were not improving in the non-learning condition) believed that the robot's handwriting was improving (although it was not). We believe this may be due to two reasons: first, the children actually thought that the robot was improving, because they were teaching it; and second, as we introduced different set of letters in each session, the children might have found difficult to track the improvement in robot's letters. Thus, the hypothesis that the children would be able to perceive the difference in the robot's learning capabilities is only partially proved.

8.2.8.3 Children's Self-efficacy Towards Tutoring

One aim of the *learning-by-teaching* method is to motivate learners to teach, leading to a rewarding feeling as the tutee improves and learns. To assess this feeling, we evaluated children's perceived self-efficacy towards tutoring. Perceived self-efficacy is defined as "*people's judgement of their capabilities to execute actions required to attain designated types of performance*" (Bandura, 1986). In the context of our study, it is defined as the children's self-perception of their capability of tutoring the robot. To measure this, we have included a specific question-Q3 (Table 8.2, 4th category) that the children answered after each interaction with the robot. The other questions in this category correspond to the children's current and future likeness towards tutoring the robot (Table 8.2, 4th category). Despite the differences in competencies of the robot, in all questions, we found no significant difference between the two conditions

Table 8.3 – Correlations between perceived intelligence and the other capabilities in the learning and non-learning condition.

Learning condition	Perceived Intelligence
Perceived likeness	rs(13) = .77, p = .00
Perceived overall performance	rs(13) = .77, p = .00
Likeness towards tutoring	rs(13) = .67, p = .01
Likeness towards future tutoring	rs(13) = .67, p = .01
Non-learning condition	**Perceived Intelligence**
Perceived overall performance	rs(11) = .68, p = .02
Future teaching	rs(11) = .67, p = .02
Handwriting Improvement	rs(11) = .65, p = .02

at any point. Besides, after the last (4th) interaction, we found some strong correlations in both conditions. In the learning condition, we found two strong correlations: one between the perceived writing capability of the robot and the children's fondness towards teaching the robot, $rs(11) = .736$, $p = .004$; and the other between the perceived writing capability of the robot and the grades children gave themselves for tutoring, $rs(11) = .693$, $p = .009$. In the non-learning condition, 92% of the children gave high scores to all questions (Table8.2, 4^{th} category) with strong correlations between the children's willingness towards future tutoring and the robot's capability to help others ($rs(11) = .69$, $p = .01$), the robot learned from the children ($rs(11) = .695$, $p = .01$) and improvement in the robot's handwriting ($rs(11) = .72$, $p = .01$). This suggests that the children want to teach the robot in the future despite of being aware of the robot's incapacity to learn. Our third hypothesis that the children in the learning condition would consider themselves better teachers compared with the non-learning condition was thus not proved.

8.2.8.4 Children's Perceived Impressions of the Robot

The questions in this category are inspired by the Godspeed questionnaire (Bartneck et al., 2009) and correspond to children's perceived intelligence, likability and friendliness towards the robot, see Table 8.2 (5^{th} category). Regarding all questions, no significant differences were found between the conditions. We observed after the last interaction that more than 92% of the children gave high scores for the fondness and friendliness scale (see Table 8.2 (5^{th} category, Q2-Q3)). In addition, in the learning condition, we found a correlation between the likability and the overall performance, $rs(13) = .567$, $p = .043$, and in the non-learning condition, between the friendliness and the overall performance, $rs(11) = .606$, $p = .04$. The results suggest that the children's social behaviour such as fondness towards the robot did not show to be affected by its writing capabilities. Regarding the perceived intelligence, 100% of the children in the learning condition and 67% in the non-learning condition gave high scores (see Table 8.2, 5^{th} category, Q1).

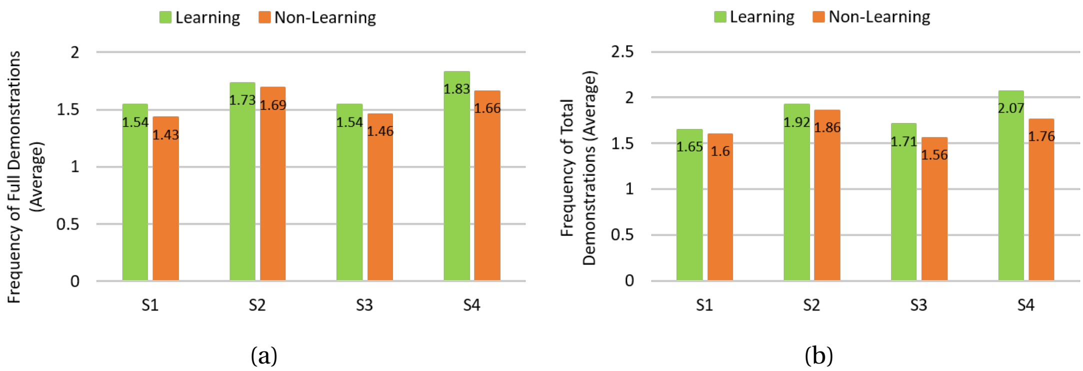


Figure 8.6 – Children's demonstrations of letters in the four sessions in both conditions: (a) full letter demonstrations; (b) full and half letter demonstrations.

Furthermore, in both conditions, we found multiple strong correlations. The results show that after the last interaction in the learning condition, all the children found the robot intelligent which can be directly related to the robot's learning progression. However, it was more interesting to see the other capabilities of the robot due to which the children perceive the robot to be intelligent. As shown in Table 8.3, the children in both condition perceived the robot's intelligence because of different perceived abilities. These capabilities differ in each condition, for the learning condition there were strong correlations found between the children's perceived intelligence and perceived likeness, robot's overall performance, likeness towards tutoring and future tutoring (see Table 8.3). In the non-learning condition, there were correlations found between the children's perceived intelligence and perceived overall performance of the robot, likeness towards future teaching and handwriting improvement of the robot (see Table 8.3) Thus, our third hypothesis is not proved because we did not find a significant difference between the two conditions.

8.2.8.5 Children's Demonstrations of Letters

The teaching activity with the robot included fifteen letters in total. For each robot's written letter, the children provided correction using the slider and written demonstration. As more number of demonstrations lead to more practice of writing letters and can be associated to the children's learning gains, we analysed children's written demonstrations for each letter in all the four sessions comparing the two conditions. We observed that sometimes the children provided more than one demonstration for a letter and the demonstrations contained both full and half letter trajectories (incomplete shape). The half letter demonstrations represents a trajectory of a letter which is not fully drawn. For example, a child starts writing a letter and meanwhile s/he finds the shape of the letter incorrect, then s/he erases the incomplete written trajectory and rewrites the letter again. We analysed full number of demonstrations and total number of demonstrations (full and half) separately. We first present the results of demonstrations comparing the sessions within each condition. Then, we look at the results comparing the conditions.

Within conditions: Figure 8.6a shows the average number of full demonstrations of the letters in the two conditions. And Figure 8.6b shows the total demonstrations (including the full and half letters). As shown in both figures, the number of demonstrations given by the children in the learning condition are greater than the non-learning conditions throughout the four sessions, but the results of the Friedman test did not show any significant difference between the sessions in each condition (see Figure 8.6a and 8.6b).

Nevertheless, it is interesting to see the pattern of demonstrations in the learning- and non-learning condition (Figure 8.6a and 8.6b). In both conditions and for both full and total number of demonstrations, they follow the same wave pattern: the numbers first increase from Session 1 to Session 2, then they decrease in Session 3 and they further increase in Session 4. It can be seen that the third session impacted the children differently from the other sessions in both conditions.

Between conditions: we further analysed the number of demonstrations between the conditions in each session. The results did not show any significant difference in any of the sessions. However it is interesting to see that the learning behavior of the robot influenced children in such a way that they gave slightly higher demonstrations to the learning robot compared to the non-learning robot across all the sessions in both conditions.

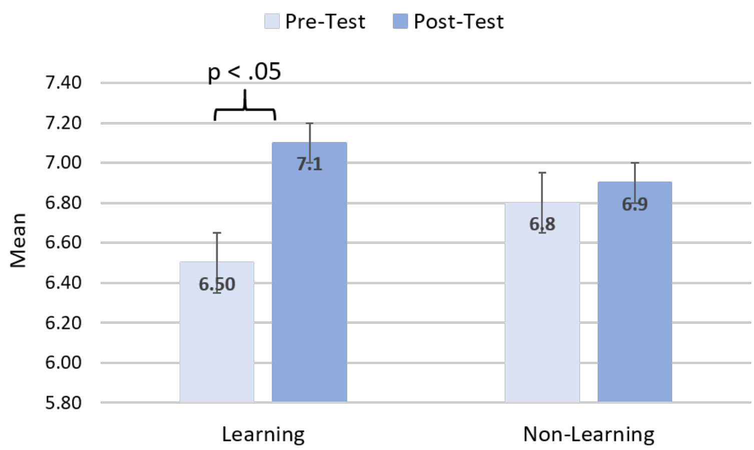


Figure 8.7 – Pre- and post-test scores in the learning and non-learning condition.

8.2.8.6 Children's Learning Gains

The pre- and post-test consisted of 9 letters (see Section 8.2.6, pre-test). For every letter, the child was asked to perform two actions on a tablet: (1) *letter selection*- to select the best-shaped letter among 3 presented samples. Five points were given to the correct letter and 0 points for the incorrect letter; and (2) *letter writing*- to write the correct sample of the letter. Two independent coders analysed each letter by comparing it with the correct sample of the letter. The coders rated each letter based on its legibility in the scale of 1 to 5: 1 = unreadable; 2 = difficult to read; 3 = readable with multiple errors such as shakiness, missing stroke; 4 = readable with one error, and 5 = readable with no error. The reliability of the scores using the

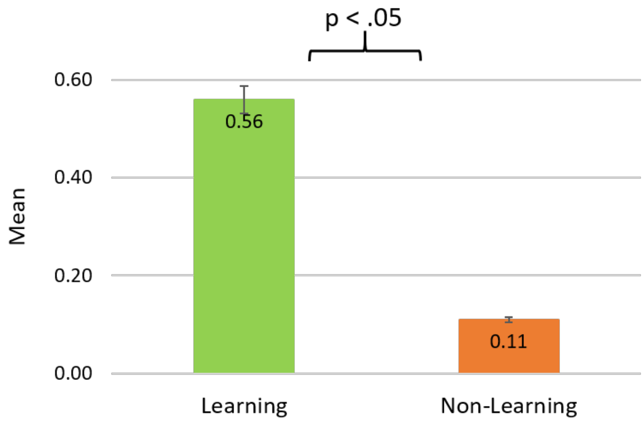


Figure 8.8 – Learning gains in the learning and non-learning condition.

Cohen's kappa showed good agreement between the two coders, $\kappa = .75$, $p < .05$. We scaled the above action scores to match the data range and obtained the averaged combined score. Children's post-test scores were relatively compared with their pre-test scores and grouped by the condition. As shown in Figure 8.7, the results of the Sign test suggest that the children in the learning condition showed significant improvement between pre- (mean = 6.5, median = 6.7) and post-test scores (mean = 7.1, median = 7.2), $Z = -2.8$, $p = .004$, effect size (r) = −0.55. Out of 13 children, 10 elicited an improvement and 3 remained with no improvement (equal pre-post scores). On contrary, all the children in the non-learning condition showed improvement but no significant difference was observed $p > .05$, effect size (r) = −0.088.

Table 8.4 – Interview questions in second category.

Children's Perceived role of the robot (2^{nd} category) (Kennedy et al., 2015b)	Options
Q1. What do you think Michael writes like a?	Child (younger than you) your friend (same age) your parents you/your teacher
Q2. How do you consider Michael as a?	Brother/Classmate Stranger/Relative Friend/Parent/Teacher

Moreover, we analysed the interaction effect between the two conditions and two time-points (pre-test and post-test) on their learning. As such, a two-way repeated measures ANOVA was run to determine the effect of the two conditions over time (4-week period between the pre- and post-test) on children's scores. Analysis of the studentized residuals showed that there was normality, as assessed by the Shapiro-Wilk test of normality and no outliers, as assessed

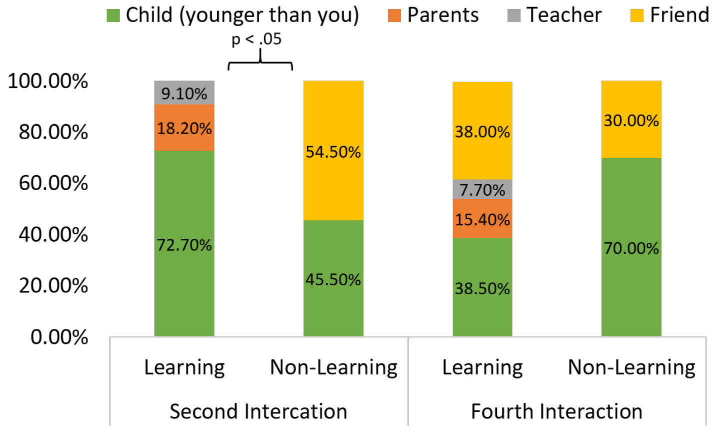


Figure 8.9 – Perceived robot's role in terms of writing capability by children after the second and fourth interactions.

by no studentized residuals greater than ± 3 standard deviations. There was no statistically significant two-way interaction between conditions and time (pre and post), F(1, 23) = 2.93, p = .10. The main effect of time showed that there was a statistically significant difference in scores between the two time points, F(1, 23) = 6.82, p =.016. In addition, the main effect of conditions did not show significant differences. This suggests that the children in both conditions improved their scores with time and the effect of conditions on their learning was not same as the affect of the time points. We further discuss these findings in Section 8.4.4.1.

We further performed Mann-Whitney test to analyse if there are differences in children's learning gains between the two conditions. The findings showed significantly higher learning gains (normalised) in the learning condition (mean = .56, mean rank = 15.96) compared to the non-learning condition (mean = .11, mean rank = 9.7), $U = 39.5$, $z = -2.1$, $p = .035$, effect size (r) = −0.42 (see Figure 8.8). These results validate our fourth hypothesis that the children would benefit more in the learning condition compared with the non-learning condition.

8.2.8.7 Children's Perceived Role of the Robot

The questions under this category correspond to the perceived role of the robot by the children regarding its writing capability and the social relationship, and only Q1 (2^{nd} category, Table 8.4) showed a significant result over time. After the second interaction, we found a statistically significant association between the roles assigned by the children to the robot between the two conditions, $\chi^2(4) = 11.60$, $p < .021$ (see Figure 8.9). In the learning condition, after the second interaction, 72.7% of the children perceived the robot as a *younger child*, and no child perceived the robot as a *friend*; however, after the last interaction, an equal number of the children perceived the robot as a *friend* and a *younger child* (see Figure 8.9). In the non-learning condition, after the second interaction, 54.5% of the children perceived the robot as a *friend*, and 45.5% of the children perceived it as a *younger child*. Nevertheless, after the last interaction, 70% of the children perceived the robot as a *younger child*, while 30% of the children perceived it as a friend (see Figure 8.9). After the third interaction, no significant association was found between the roles assigned in both conditions, $\chi^2(4) = 3.5$, $p > .05$.

These results in the learning condition suggest that the increase in the perception of the robot as a friend may be due to its continuous learning, allowing the children to see it as a peer. In the non-learning condition, the increase in the perception of the robot as a younger child is due to the robot's proof of poor learning.

8.2.9 Discussions and Conclusions

The results provided partial support for the first hypothesis. By the end of the last interaction, the children were able to differentiate the two out of the three robot's competencies. We did not find support for the second hypothesis that expected children to like more the learning robot compared to the non-learning robot. Also, the third hypothesis was not proved as the children's self-efficacy towards tutoring did not show the significant difference between the conditions. However, the children showed more improvement with the learning robot compared to the non-learning robot, hence, providing support to our fourth hypothesis.

Effect of multi-session study on children's perception: *"longitudinal studies are extremely useful to investigate changes in user behaviour and experiences over time." (Leite et al., 2013)*, In fact, children tend to change their attitude and behaviour towards a social robot over time in multi-session studies (Kanda et al., 2004b; Salter et al., 2004; Gockley et al., 2005). In the current work, conducting a longitudinal study with 4 consecutive sessions was a key factor in finding some of the most relevant outcomes, because some aspects became significant only over time. The findings of children's perception regarding the robot's *writing capability, overall performance* and *role* changed after the second and third interactions which could not be possible to explore in a single session study. In addition, we observed a few unexpected but relevant outcomes such as children's perceived likability, friendliness and intelligence towards the robot was not affected by its learning capabilities.

Children's role and self-efficacy: after the last interaction, more than 92% of children in both conditions liked tutoring the robot, wanted to teach the robot in the future and, in fact, rated themselves as good teachers (see Table 8.2, 4th category). The results of children's self-efficacy towards tutoring are consistent with Bierman and Furman (1981) findings who concluded that children, when acting as a tutor, tend to form positive attitudes regarding the perceived competence on the task. In our study, the fact of 'being a teacher' influenced all the children in the way they evaluated themselves as teachers. As a result, we did not find any difference between the two conditions. Moreover, Allen and Feldman (1974) also found similar results in a peer tutoring scenario and concluded that the differential performance of tutees did not affect tutor's self-evaluation of their teaching. The studies of Berninger and Allen involved students (human); however, the findings of the current study gives some evidence that similar effects can also be present in human-robot interaction studies.

Link between children's perceptions of the robot and their learning gains: In the process of teaching, the performance of a tutee may affect tutor's attribution about the tutee (Allen and Feldman, 1974; Strain, 1981). Due to the two contrasting competencies of the robot *i.e. learning* *and non-learning*, the children perceived the robot differently. Despite obtaining similar pre-test scores, $p > .05$, effect size $(r) = -0.076$, the children in the learning condition improved significantly compared with the non-learning condition. We believe that the children's role and overall perceptions towards the robot such as perceived robot's capabilities, role, social behaviour and self-efficacy towards tutoring are not only linked (Allen and Feldman, 1974) but also influenced their learning outcomes. We speculate that there could be at least two variables: *motivation* and *knowledge construction* that may account for more learning in the learning condition. The children in both conditions were aware of the robot's writing capability, overall performance and grades(as we found a significant difference in their perception after the third and fourth interaction). In the learning condition, due to the continuous improvement of the tutee-robot in each consecutive session, the tutor-children might have experienced it as a rewarding feeling because they could see the results of their teaching efforts. Consequently, they put extra efforts as they gave more number of written demonstrations and attention on the robots writing which eventually improved their learning. Also, the corrective feedback which they provided during tutoring propelled through motivation encouraged them to heed in writing the letters. In fact, Topping (1996) described that the act of tutoring involves the construction of new knowledge and improvement in self-concept . On the contrary, the children with the non-learning robot lacked enough motivation. In spite of their ongoing efforts, in each consecutive interaction, they found the robot is struggling to acquire the handwriting skills, performance and better grades. And therefore, they might not have put extra efforts (less number of written demonstrations compared to the learning condition) and attention which consequently improved their handwriting skills but insignificantly. Since the robot was not learning, they could not construct new knowledge efficiently and instead attended to the corrections in the same way.

8.2.9.1 Lessons Learned

After reviewing the results of the study, we identify a few shortcomings in the design of the study that may affected the discussed results. We present three lessons learned as follows:

The robot in the learning condition was improving its grades and writing skills between the sessions and not during a session. In other words, the level of deformation in the robot's writing was constant throughout each session. We believe if the robot would improve within and between the sessions, the impact of robot's continuous-learning may enhance children's perceptions and their learning. Thus, for the next study we would add this learning element within as well as between the sessions.

The robot shows the improvements in two ways: one, by improving the shape of the letters it wrote; and second, by displaying the better grades (fictitious). However, displaying the grades directly to the children might have affected their perception towards the robot's behavior and capabilities. In our next study, we would remove the explicit display of robot's grades and would explore children's perception solely based on its writing performance.

In the non-learning condition, one of the results was that despite knowing the grades of the robot, the children did not perceive the robot's lack of learning. We believe it might happen because within the same session, fifteen different were displayed containing the three types of errors in a random order. And therefore, it might have been difficult for children to perceive clearly if the robot's writing was improving or not. Hence, in our next study, we will group the letters by type of errors and also repeat some letters to show the explicit improvement of the shape of the letters.

8.2.9.2 Conclusions

In the presented study, we describe a social robot that autonomously interacts with children to foster their handwriting skills. Two versions of the robot were developed: one that actually improves its performance and the other that does not change its capability of writing. Using an algorithm that incorporates human-inspired movements we could reproduce childlike errors in the writing and improve them over the weeks of interaction. We tested the system by conducting a longitudinal study with 4 sessions in a school and found that the children's writing skills improved more with the learning robot compared to the non-learning robot.

Additionally, we explored the children's perception towards the 'learning' vs. 'non-learning' capabilities in the robot and the effect of these perceptions on their learning. The results revealed that the children were able to perceive the robot's actual learning abilities only after the third and fourth interactions but were unable to perceive the improvements in robot's writing. The children considered themselves as good teachers regardless of the robot's different competencies. Moreover, the robot's different learning competencies did not affect children's perceptions of the robot such as friendliness, fondness and intelligence. Overall, these results suggest that conducting the multi-session study proved to be relevant in the exploration of children's learning and their perceptions.

8.3 Study 5: Multi-learning Study

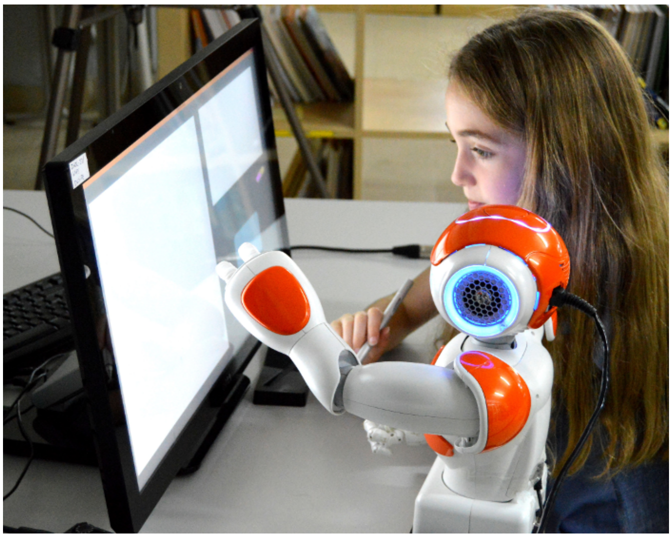


Figure 8.10 – Experimental setup.

8.3.1 Research Questions

This study explores the similar research questions presented in the former study: '*What would be the affect of varied learning competencies of the robot on children's learning and perception*'. The study follows same child-robot interaction and experimental set-up; however, slightly differs in its protocol based on the learned lessons of the former study (Study 4). In the current study design, the learner-robot seeks help from the tutor-child to correct the shapes of a set of letters and exhibits three different competencies as study conditions: *continuous-learning*- where it continuously improves; *non-learning*- where it does not learn through the interaction; and *personalised-learning*- where it adapts its learning with respect to the child's progress. Once again, our aim is to investigate the impact of the robot's competencies on children's learning and their perception of the robot over multiple sessions of interactions. The research questions and hypotheses of the study are as follows:

- **Research Question 1:** Would the three competencies affect children's learning? Which one would affect more?

  Hypothesis 1: Based on the results of our previous study, we hypothesise that the children would benefit more with the robot where it shows continuous improvement and when it adapts its progress with respect to the child compared to the robot which does not learn.

- **Research Question 2:** Would children respond differently to the robot's different learning capabilities?

  Hypothesis 2: Since, the robot exhibits contrasting capabilities in the continuous- and non-learning conditions, we hypothesise that the children would be able to perceive the changes in the robot's writing by the end of the last interaction. Additionally, in the personalised-learning condition, the children may not perceive it as the robot's progress depends on the child's progress.

- **Research Question 3:** Would the three different competencies of the robot affect children's perceived likeness and friendliness towards it?

  Hypothesis 3: Based on our experience of the Study 4, we believe that the children would like the robot irrespective of its different competencies.

- **Research Question 4:** How would children consider themselves as a teacher in all the three conditions? How would children's self-efficacy towards tutoring the robot differ between the conditions?

  Hypothesis 4: We hypothesise that children in all the conditions would perceive themselves a good teacher irrespective of the robot's competencies.

8.3.2 Participants

We conducted the study in 'Escola 31 de Janeiro' in Parede, Portugal. Thirty-seven Portuguese speaking children participated from the 8- to 9-year-old age group (3^{rd} grade) over a period of 6 to 8 week. Twelve children (M=8.2; SD= 0.43; 6 male and 6 female) participated in the continuous-learning condition (CL), 12 children (M=8.5; SD=.5 years old; 8 male and 4 female) participated in the non-learning condition (NL) and 13 children (M=8.5; SD=.49 years old; 5 male and 8 female) participated in the personalised-learning condition (PL). The children who agreed to participate in the study and whose children signed the consent form took part in the study.

8.3.3 Materials

We used the same experimental tools as in the Study 4 such as a computer with a touchscreen, video camera, Nao robot (only torso part) and English alphabet (uppercase & lowercase) for writing activity. Based on a decade of experiments on children's handwriting, Graham et al. (2008) concluded that all the letters in English alphabet, including uppercase and lowercase are not problematic for children; only a set of letters (lowercase - (b, q, d, k, g, p, z, u, j, n, a), uppercase - (K, Y, Z, W, R, M, F, D)) have shown difficulty in formation. Thus, in the current study, we targeted letters from the above mentioned alphabet set for both the pre-post test and the main activity with the robot (see Appendix E). Additionally, we repeated a few letters in the sessions to explicitly show the robot's writing performance to the children.

8.3.4 Interaction Design

As mentioned before, the experimental setup of the current study is identical to the previous study. Both the tutor-child and the learner-robot perform the collaborative writing activity where the child provides corrective feedback to the robot on its handwritten letters. The turn-taking happens when the robot prompts the child for correction and when the child finishes the correction.

8.3.5 Conditions

To explore the impact of the robot's competencies on the children's learning and perceptions of the robot, our study consists of a between-subjects design with three conditions: continuous-learning & non-learning and personalised-learning. In all the conditions, the scenario involves a one-to-one teaching style based on peer-tutoring approach, where a child acts as a 'teacher' and a robot acts as a 'learner'. In the study design, the interaction between the child and the robot is dyadic where the learner-robot seeks help from the tutor-child to correct the shape of the letters drawn by it. For example, the robot writes a letter on the screen and asks the child to correct it. For correction, the child performs two tasks: first, s/he corrects the shape of the letter through the slider; and second, demonstrate the letter on the touch-screen. The robot's letter and child's corrections correspond to one letter and are performed in the same space on the touch-screen (see details in Chapter 7). Each child interacted with the robot four times with an interaction gap of 4-5 days. The three above-mentioned conditions are describe as follows:

- **Personalised-Learning:** In the personalised-learning, the tutor-robot adapts its writing competecy according to the child's performance throughout the sessions. In the first session, it writes the first letter with a mildly deformed shape; the level of deformation in the consecutive letter will depend directly on the level of legibility of the child's previous letter. For example, for a letter, if the child corrects and writes the robot's letter accurately, the robot would write the next letter accurately. On contrary, if the child does not provide accurate corrections, the robot would write the next letter with a poor shape.

- **Continuous-Learning:** This condition is similar to the 'learning condition' described in the Study 4. As we have two learning conditions in the current study, we changed its name to 'continuous-learning' in order to distinguish it from the 'personalised-learning'. As the name suggests, in the continuous-learning condition, the robot shows progress between and within the sessions. In the first session, it writes poor shapes of letters and by the end of the session, it improves a bit. This progression increases with the sessions; consequently, by the end of the final session, it writes the letters all most with correct shapes. More specifically, it is actually becoming competent in learning how to write and shows advancement in its writing skills independent of the performance of the tutor-child.

- **Non-Learning:** In the non-learning condition, the robot shows the consistent performance throughout the sessions. In the first session, it writes deformed letters and continue to write poor shapes of letters by the end of the final session. To be more specific, it does not learn.

Algorithm for personalised-learning:

For handling the adaptation of the child's performance, we developed an algorithm based on image comparison. This algorithm compares two images on pixel basis and computes a score based on the difference between the two images. The input of the algorithm are two letter trajectories, one is the actual trajectory (correct sample) of a letter and the other trajectory is produced by the child during the activity. For measuring the difference between the two images, we first align the images with respect to the center through scaling and translation methods. Afterwards, for each image, we generate a matrix with 100 x 100 dimension and compare the Euclidean distance between each pair of elements in the two matrix. Then, we compare each pair of elements between the two matrix and finally, generate a confusion matrix of the two images. Figure 8.11 shows an example of the confusion matrix of children's sample letters. The difference of the confusion matrix provides a final score between the two images. This score is further used to determine the robot's writing errors.

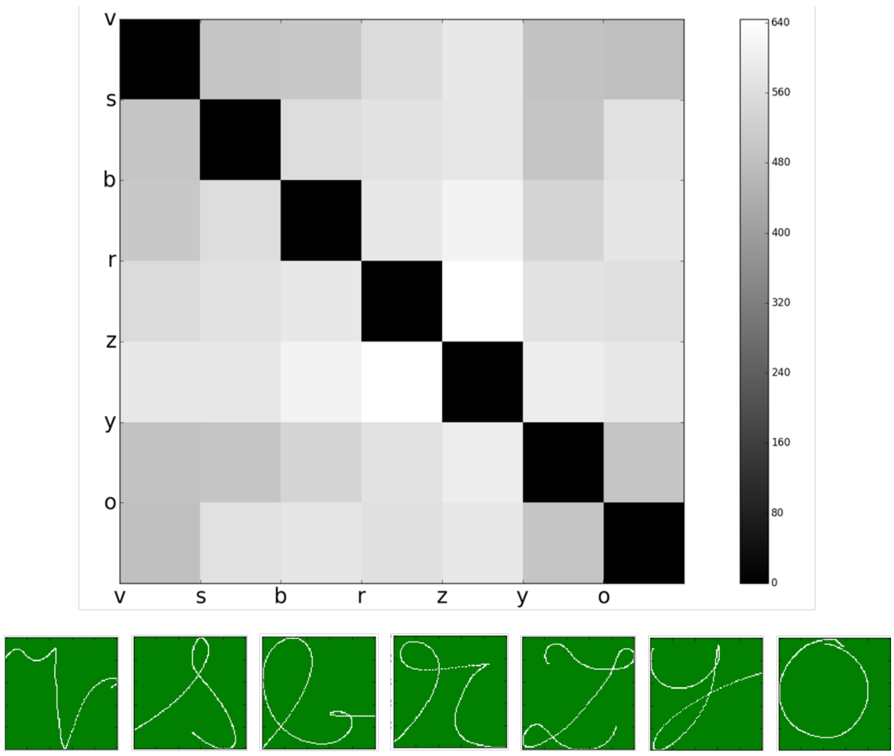


Figure 8.11 – Example of confusion matrix of letters.

As mentioned before, the child corrects each letter through the slider and demonstrate the same letter by writing it. Thus for each written letter by the robot, the child produces two letter trajectories, one through the slider named as *slider letter* and the other in the box named as

Algorithm 2 Score Estimation

Require: L_{actual}, L_{child} ▷ Two letters with different size
Ensure: $Score$
i $Alignment - scaling, translation$ ▷ Two letters with same size
ii $Pair - wise\ comparison$
iii $Calculation of Euclidean distance$ ▷ Get the difference with an Euclidean distance
iv $Confusion matrix$
v $Computing\ final score$

box letter. The generated score for both slider and box letter is averaged and used to determine the robot's performance in the scale of 'good', 'bad' or 'ok'. These variables were determined based on threshold values of the score. After deciding the grading of the robot's letter, the letter is produced with or without errors depending on the grade. For generating the errors in the letter, the first algorithm is further used. Consequently, the robot writes each letter based on the child's performance of the previous letter.

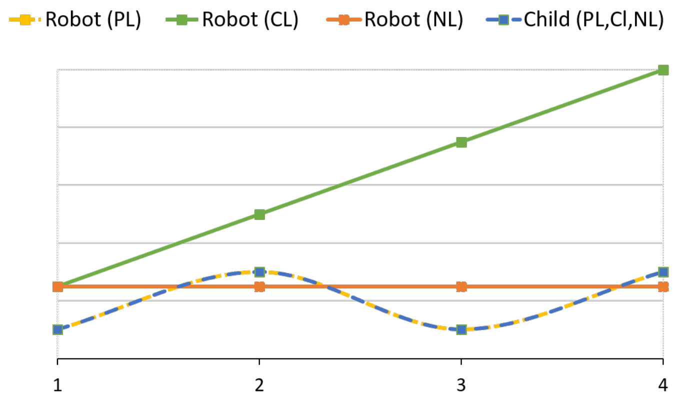


Figure 8.12 – Robot's progression of writing skills is shown in all the three conditions compared to the child's writing skills.

The graph shows the contrasting pattern of robot's performance in terms of its writing skills in each condition, see Figure 8.12. In all the conditions, the robot initiates with the same level of writing skill. However, it further exhibits different writing skills according to the condition, yet still showing the same social behavior throughout the study.

8.3.6 Protocol

The school-teacher randomly assigned the children to one of the three conditions. Each child interacted and performed the collaborative writing activity with the robot for about 14-to-15 minutes per session. We set-up the study in the library room in the school to provide a comfortable and known environment to the children. During the introduction of the study, a researcher informed the participant that s/he was going to interact with the robot 4 times (twice a week) to help it in a handwriting activity. In addition, the researcher explained to the participant his/her role as a ‘teacher’ and that the robot was going to be the ‘learner’. Although, the researcher informed all the participants that they could quit the study anytime if they wished, no participant left the study in between. We named the robot ‘Michael’ to induce friendly interaction with the participants. The study followed a similar protocol as the Study 4, but there exist notable differences between the two studies presented in Section 8.3.7 such as the difference in the pre-post test, interview questions and the additional competency of the robot. The study was organized into following steps:

Tutorial: After introducing the study, the researcher brought the participant to the study room and explained the application features of the tutorial application displayed on a monitor. The features of this application were similar to the *computer application* (the main application) in order to allow the participants to get familiar with the interface in the later interactions.

Pre-test: After the tutorial, the researcher asked the participant to perform the pre-test on the same monitor. The pre-post test app was identical to the main application (explained in 7th Chapter, Section 2.2.5) and was developed to test the participant’s motor and cognition skills related to the legibility of letters. The pre-post app comprised of 9 letters and was divided into 3 groups corresponding the three types of writing errors (3 letters per writing error). For each deformed letter presented on the screen, the participant performed two tasks in a given order: (1) letter correction; and (2) letter writing. For the letter correction task, first the participant corrected the letter by using the slider; then for the letter writing task, s/he demonstrated the letter by writing it on the same screen in a rectangular box. Then, the process was repeated for the rest of the letters.

Teaching activity with the robot: after finishing the pre-test, the researcher left the participant in the study room alone with the robot. In this phase, the participant interacted and performed the collaborative writing activity with the robot. The interaction pattern between them progressed as follows:

- **Welcome greeting:** the interaction between the robot and the participant started when the robot greeted the child, expressed its writing problems and eventually asked for help in correcting the shapes of some letters. This initial introduction created an environment in which the participant found the robot in need of help. Since, the participants consented for the study and were already aware that they were going to help the robot; none of them refused the help.
- **Correction period:** the robot wrote a letter on the screen and prompted the child to correct it by using a slider. Then, the robot asked the child to demonstrate the same letter in the small white box. After finishing the correction and writing, the child moved to the next screen and repeated the process for the remaining letters. In total, the child and the robot worked on 15 letters.
- **Goodbye greeting:** after they both finished the collaborative writing activity, the robot

expressed its gratitude towards the participant. Moreover, the robot informed that it would continue practice these letters until the next interaction.

Post-test: after finishing the interaction with the robot, the researcher asked the participant to perform a post-test, identical to the pre-test.

8.3.6.1 Interview Questions:

following the post-test, the researcher performed an interview with the participant and asked a set of questions for about 10 minutes. Before interviewing the children, the researcher emphasised that honest answers are important for the robot's learning, and the answers will not be disclosed to the robot. The questions presented are specifically designed for the study and based on different aspects such as study research questions, role-theory and Godspeed questionnaire. The researcher presented the questions to the children on a sheet of paper in a child-friendly manner. For example, for some questions, the values of the Likert scale (1,2,3,4,5) were represented with stars (*, **, ***, ****, *****); bars (5 bars with an increment in length in each bar) and so on (see questionnaire in Appendix E). The questions were based on 5-point Likert and categorical scale respectively. For all the questions, the participants could choose one option from the available alternatives. We followed the same protocol in all the three conditions.

Table 8.5 – Table representing the percentage of the deformed letters and writing errors that were included in the sessions.

	S1 (%)	S2 (%)	S3 (%)	S4 (%)
% of deformed letters	60	40	30	20
% of deformation	70	50	30	10

8.3.7 Modifications

As mentioned before, we performed a few modifications in the design of the fifth study after reviewing the design, hypothesis and results of the previous study. We present the list of the modifications as follows:

- **Learning Between and within the sessions:**

  In Study 4, the robot in the learning condition improved its writing skills between the sessions at a constant rate. In the continuous-learning condition of the current study, the robot shows improvement within and between the sessions at a constant rate. For showing the improvement, the % of deformed letters combined with the % of deformation in each letter is used. The collaborative writing activity for the robot and the child included 15 letters in total. These letters were divided into 3 groups representing each writing error (proportion, break or alignment); which means 5 letters per writing error. Since the robot improves within and between the sessions, we employed the deformation rate and number of deformed letters in each session at a constant rate(see Table 8.5). For instance, for the first session, 60% of the letters were highly deformed with 70% of deformation, while the rest of the 40% letters were improved by the robot (with the improvement level of 20%). Moreover, we repeated a few letters (1 or 2) inside a session to explicitly show the robot's improvement on the same letters with the same writing errors. The letters with the same writing errors were presented consecutively to avoid the confusion between the writing errors.

- **Grades:** Unlike the fourth study, we did not show the robot's grades to the children in the current study. The robot exhibits the improvement only in its writing skills.

- **Pre-Post test:** The pre-post test of the current study involves the letter correction and letter writing, which is similar to the tasks the children perform with the robot in the main activity.

- **Addition of personalised-learning condition:** In the fourth study, the robot shows two contrasting competencies: learning vs. non-learning, where these competencies were independent of the participants performance. In the current study, we added one more robot's competency named as personalised-learning where the robot's performance depends on the child's performance.

- **Interview questions:** We performed slight changes in the questionnaire by removing some questions and adding others. For example, the question related to the robot's overall performance was removed and for the question regarding the robot's social role and writing role, we added 'None' option.

8.3.8 Analysis

We collected the data from the questionnaires and logs of the tablets. The results of the Shapiro-Wilk test did not show the normal distribution of the data, so we analysed the data by using the non-parametric tests.

For analysing the questionnaire data, each point in the Likert scale (1-to-5) questions is considered as a score given by the children to the robot; 1 represents the lowest score while the 5 represents the highest score. High score represents the combined score of the 4^{th} and 5^{th} point in the Likert scale. Regarding the non-parametric statistical test, we used Wilcoxon signed-rank test and Friedman test for the Likert based questions and chi-square goodness-of-fit test for the categorical questions. In addition, we also discussed the results in terms of correlations and percentages.

As mentioned before, the pre-post app comprised of 9 letters and was divided into 3 groups corresponding the three types of writing errors (3 letters per writing error). For each deformed letter presented on the screen, a participant performed two tasks in the given order: (1) *letter* *correction*; and (2) *letter writing*. For the letter correction task, first the participant corrected the letter by using the slider and referred as *slider letter*; then for the letter writing task, s/he wrote the letter on the same screen in a rectangular box and referred as *box letter*. Thus, for each deformed letter, we collected two letters from the participant.

Two independent coders analysed each letter (box and slider) by comparing it to the correct model of the letter. The coders analysed the letters based on the legibility factor and rated them in the scale of 1-to-5 points: 1 = unreadable; 2 = difficult to read; 3 = readable with multiple errors such as shakiness, missing stroke; 4 = readable with one error, *and*5 = readable with no error. For each letter, we calculated three types of score: box score corresponding to the letter written inside the box; slider score corresponds to the score of the letter corrected through the slider; and combined average box and slider score. In addition, for the reliability of scores, the Cohen's Kappa showed good agreement, $K = .82$, $p < .05$. For each participant, three separate scores were calculated as box score, slider score and box-slider score. Additionally, for the analysis the children's post-test scores were relatively compared with their pre-test scores and were grouped by conditions. We used two non-parametric tests, the Wilcoxon signed rank test and Kruskal-Wallis test to determine the statistical differences of the children's learning within and between the conditions.

8.3.9 Findings

The findings of the study are related to three aspects: (1) children's demonstrations of letters; (2) children's learning gains; (3) and children's perceptions of the robot. We present the findings in the order of the research questions.

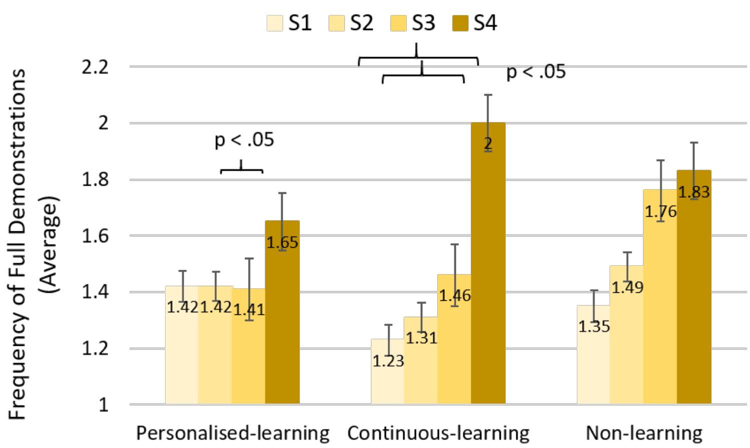


Figure 8.13 – Results of the children's demonstrations of full letters in the four sessions in the three conditions.

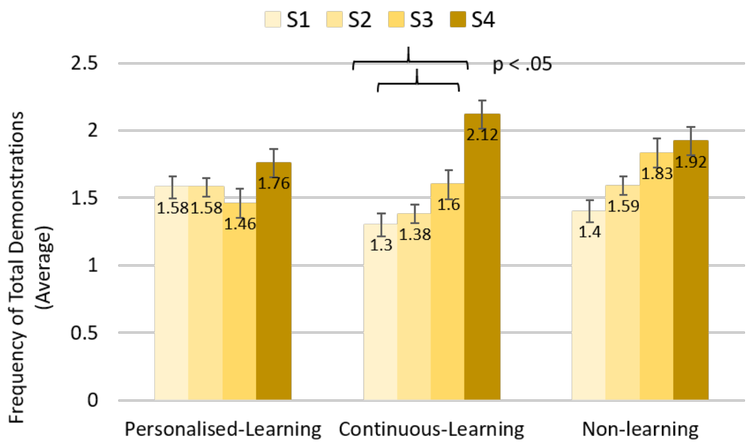


Figure 8.14 – Results of the children's demonstrations including the full and half letters in the four sessions in the three conditions.

8.3.9.1 Children's Demonstrations of Letters

Practice or repeated exercise of writing letters in the process of learning handwriting can improve children's handwriting skills. Thus, we analysed children's demonstrations of letters during the four sessions in the three conditions. We believe that children's demonstrations to the robot may also provide link to their learning gains. In each interaction with the robot, the children taught 15 letters in total. The process of teaching included two tasks: correction and demonstration of letters. We observed that some children frequently provided more than one demonstration for a letter. These demonstrations included full letters and half letters and vary according to each child. We present the results of demonstrations in the following order: (1) within conditions- comparing the sessions in each condition; and (2) between conditions-comparing the conditions for each session.

Within conditions: for the analysis, we applied the Friedman test to determine if there were differences in the number of children's demonstrations between the four sessions in each condition. We found significant differences in the demonstrations between a few sessions in the personalised-learning and continuous-learning conditions and did not find any significant differences in the non-learning condition. Further, pairwise comparisons were performed with a Bonferroni correction for multiple comparisons.

The results of the personalised-learning condition showed a significant difference, X2(3) = 12.32, p = 0.006. Post hoc analysis showed significant differences between Session 3 (Mean = 1.42, Mdn = 1.40) and Session 4 (Mean = 1.65, Mdn = 1.67) (p = .037)(see Figure 8.13). In addition, we found significant differences in the continuous-learning condition in full letter demonstrations of letters between the sessions, X2(3) = 21.88, p = 0.00. Post hoc analysis further revealed statistically significant differences between Session 1 (Mean = 1.23, Mdn = 1.2) and Session 4 (Mean = 2.0, Mdn = 1.73) (p= .000); and between Session 2 (Mean = 1.31, Mdn = 1.23) and Session 4 (p = .004) (see Figure 8.13), but not between the remaining combinations of the sessions.

Likewise, the results of total demonstrations containing the full and half demonstrations of letters also showed similar results in the continuous-learning condition, X2(3) = 19.05, p = 0.00. There were significant differences between Session 1 (Mean = 1.30, Mdn = 1.23) and Session 4 (Mean = 2.12, Mdn = 1.96) (p = .002); and between Session 2 (Mean = 1.38, Mdn = 1.30) and Session 4 (p = .004). Further, the personalised-learning condition also showed significant difference, X2(3) = 8.15, p = 0.043. But, post hoc analysis revealed the difference only between Session 3 (Mean = 1.46, Mdn = 1.40) and Session 4 (Mean = 1.76, Mdn = 1.80) with p = .059 (which is close to the significant value).

There exists an interesting variation in number of demonstrations from Session 1 to Session 4 in all the three conditions (Figure 8.13). For example, in the personalised condition, the numbers of full demonstrations are almost constant during the first three interactions; however, there is a sudden increase in the fourth interaction (Figure 8.13). In both continuous- and non-learning conditions there is a consistent increment in the number of demonstrations from Session 1 to Session 4. Comparing these two conditions, there seem to be at least two differences: (1) the number of demonstrations in the non-learning conditions are relatively higher in the first three sessions than the continuous-learning condition; (2) a sudden increment in the numbers in the last session in the continuous-learning condition compared to the non-learning condition (Figure 8.13). If we look at the total number of demonstrations in the continuous- and non-learning condition, similar pattern can be seen. The reasons for overall results of demonstrations are not clear but it can be believed that the continuous- and non-learning condition impacted the children differently compared to the personalised-learning condition. The children in the former two conditions provided demonstrations in an incremental fashion while the personalised-learning condition does not follow this pattern.

Between Conditions: we used Kruskal-Wallis Test to determine if there are differences in the number of full and total demonstrations in each session between the conditions. The results did not show any significant differences in any of the sessions between the conditions for both types of demonstrations (full and total).

8.3.9.2 Children's Learning Gains

The results of the children's learning are discussed in terms of their box, slider and combined box-slider scores. First, we detail the results within each condition, then we discuss them between the conditions.

In the *personalised-learning* condition, the results of the Wilcoxon signed-rank test show a significant increase in box post-test scores (Mean = 2.71, Mdn = 2.78) compared to the pre-test scores (Mean = 2.40, Mdn = 2.44), z = 2.56, p = .01, see Figure 8.15. Out of thirteen participants, eleven elicited an improvement and two did not show increment in post-test scores. Regarding slider scores, the results showed improvement (Pre Mean = 4.63, Post Mean = 4.70; Pre Mdn = 4.67, Post Mdn = 4.78;) but no statistically significant improvement was observed between the pre- and post-test scores, p > .05, z = 1.48. Nevertheless, there was a statistically significant

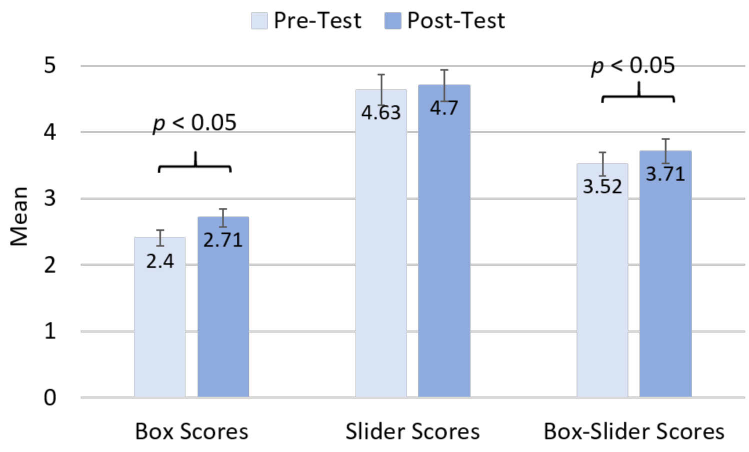


Figure 8.15 – Pre- and Post-test scores in personalised-learning condition.

increase in the combined box-slider post-test scores (Mean = 3.71, Mdn = 3.72) compared to the pre-test scores (Mean = 3.52, Mdn = 3.55), z = 2.71, p = .007. Out of 13 participants, eleven improved, one did not improve (equal pre-and post test scores) and one showed decrement in post-test scores.

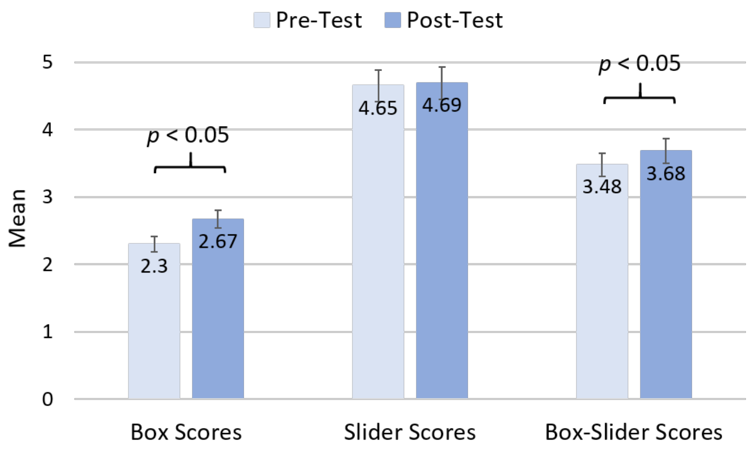


Figure 8.16 – Pre- and Post-test scores in the continuous-learning condition.

As shown in Figure 8.16, the results of the test indicate that the children in the *continuous learning condition* showed increment in the box post-test scores (Mean = 2.67, Mdn = 2.78) compared to the box pre-test scores (Mean = 2.30, Mdn = 2.33), z = 2.27, p = .023. Out of 12 participants, nine elicited an improvement, one did not show improvement (equal pre- and post-test scores) and 2 showed decrement in post-test scores. On contrary, the children did not show improvement regarding the slider pre- and post-test scores (Pre mean = 4.65, Post mean = 4.69; Pre Mdn = 4.67, Post Mdn = 4.67), z = .57, p > .05. However, after combining the box and slider scores, there was a statistically significant increase in post-test scores (Mean = 3.68, Mdn = 3.69) compared to the pre-test scores (Mean = 3.48, Mdn = 3.47), z = 2.18, p = .029. Out of 12 participants, eight elicited an improvement, one did not show improvement (equal pre-and post test scores) and 3 showed decrement in the post-test scores.

Finally, in the *non-learning condition*, the results of the test regarding box scores showed improvement (Pre mean = 2.46, Post mean = 2.63; Pre Mdn = 2.50, Post Mdn = 2.61) but no significant improvements between the pre- and post-test scores were observed, $p > .05$, $z = 1.6$. Additionally, we found the similar non-significant results concerning the slider scores (Pre mean = 4.61, Post mean = 4.65; Pre Mdn = 4.72, Post Mdn = 4.78; $p > .05$, $z = .822$) and the combined box-slider scores (Pre mean = 3.53, Post mean = 3.64; Pre Mdn = 3.55, Post Mdn = 3.61; $p > .05$, $z = 1.41$).

Overall, out of the three conditions, only the children in the personalised- and continuous-learning conditions improved significantly in terms of their writing skills.

As shown in the Figure 8.16 and Figure 8.15, the children got higher pre slider-scores compared to the pre box-scores in both conditions, the results of the pre-test scores suggests that the initial corrective skills (slider-score) of children were better than their motor skills (box-score). It means that the children perceived the error present in the letter and consequently, corrected the shape by moving the slider. But, when they had to demonstrate the same letter on the screen, they could not achieve the same result as in the slider task. We believe this is due to the fact that writing by hand requires coordination between the motor, perceptual and cognitive abilities. The slider allowed children to provide feedback without involving motor skills. A better performance in this type of feedback suggests that the children may be able to recognise the correct shape but not able to write it due to the motor complexity.

On comparing the pre-test and post-test scores, the findings revealed that the children improved significantly (in the personalised- and continuous-learning) in the box post-test when they actually wrote the letters. On contrary, they did not show any improvement in the slider post-test (equal pre-post slider scores). There might be a few reasons for these findings: First, as shown in the Figure 8.16 and 8.15, the children's slider-scores were almost reaching to the highest average score (five) which they could get in the test; therefore, there might not be enough space to improve their corrective skills; and second, the children might need more than four sessions in order to see these improvements.

Further, we run two-way repeated measures ANOVA to determine the effect of the three conditions over time (pre and post) on children's box scores and box-slider scores. The analysis of the studentised residuals revealed normalised data through the Shapiro-Wilk test and no outliers were found in the data. The results suggest that there was no statistically significant two-way interaction between conditions and time points (pre and post) in box ($F(2, 34) = .765$, $p = .47$) and in box-slider scores ($F(2, 34) = .476$, $p = .62$). The main effect of time showed that there was a statistically significant difference between the two time points in box scores ($F(1, 34) = 19.44$, $p < .00$) and box-slider scores ($F(1, 34) = 16.36$, $p < .00$). And in both scores the main effect of conditions did not show significant difference. Overall, these results indicate that the effect of time points on children's learning was significantly more than the conditions. We further discuss the results of interaction effects in Section 8.4.4.1.

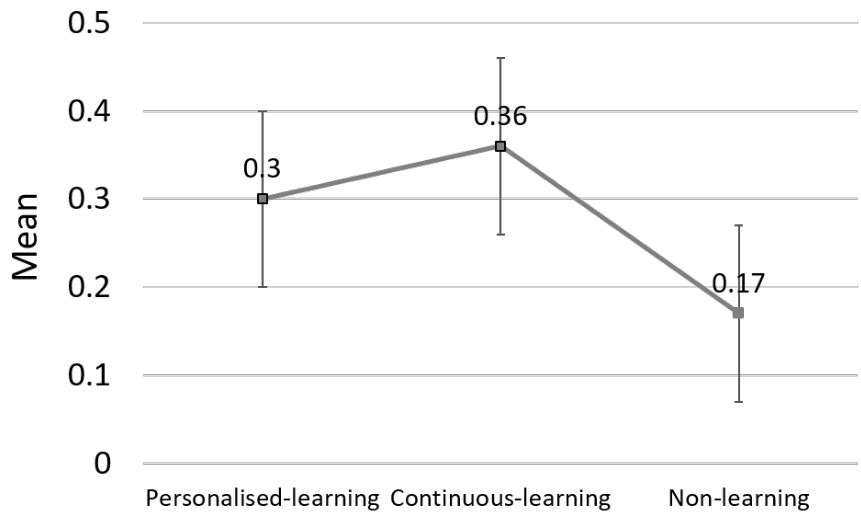
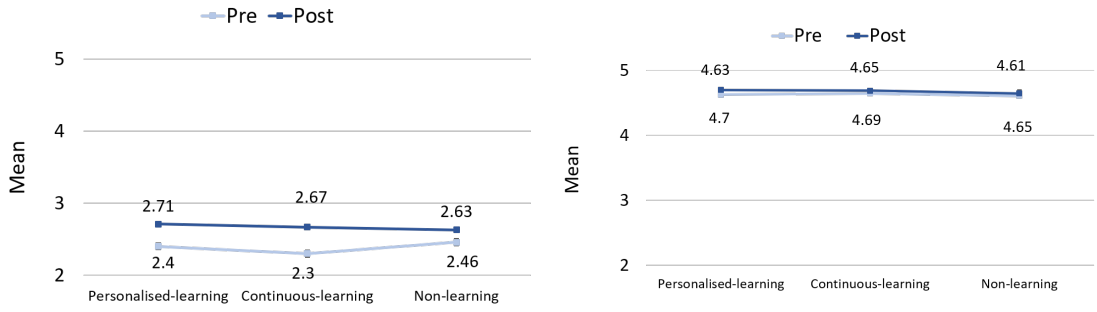


Figure 8.17 – Results of the learning gains in all the three conditions.

Moreover, a Kruskal-Wallis test was conducted to determine if there were differences in the learning-gain scores between the three conditions: the personalised learning (n = 13), continuous learning (n = 12) and non-learning (n = 12). The learning gain scores were obtained by subtracting the pre-test scores from the post-test scores. As the children in the personalised- and continuous-learning conditions showed increment in the post-test scores but not in the non-learning condition, we expected to find differences in the children's learning gains between the non-learning and the other two conditions. Despite the increment in children's learning gain score in both the continuous and personalised-learning condition compared to the non-learning condition (see Figure 8.17), we did not find any significant difference between the conditions across the box, slider and combined box-slider scores, $p > .05$.

The reason for this result is not clear but it might be due to the small sample size and unequal initial skills of the children in all the conditions. As shown in the Figure 8.18a, the box pre-test scores of the children in the non-learning condition were higher compared to the other two conditions; which suggests that prior to study, the children had better writing skills in the non-learning condition compared to the children in other conditions. Therefore, we might not get significant difference in the learning gains. The overall results do not validate our first hypothesis that the children would improve more in the continuous- and personalised-learning condition compared to the non-learning condition.

Our first hypothesis that the robot with the continuous- and personalised learning would affect children's learning is partially proved because even when the children showed significant improvement in their writing skills within the conditions, they did not show significant improvement between the conditions.



(a)

(b)

Figure 8.18 – Results of the children's pre-post test scores in all the conditions related to: (b) box scores; (a) slider scores.

Table 8.6 – Percentage of children who gave high scores to the questions concerning the robot's writing capability after the last interaction (1st category).

Questions related to the robot's writing capabilities (1st category)†	PL(%)	CL(%)	NL(%)
Q1. How many stars would you like to give for Michael's writing capabilities?	100	91.6	91.6
Q2. Do you think Michael's handwriting is improving? If yes, how much it is improving?	91.6	91.6	92.3

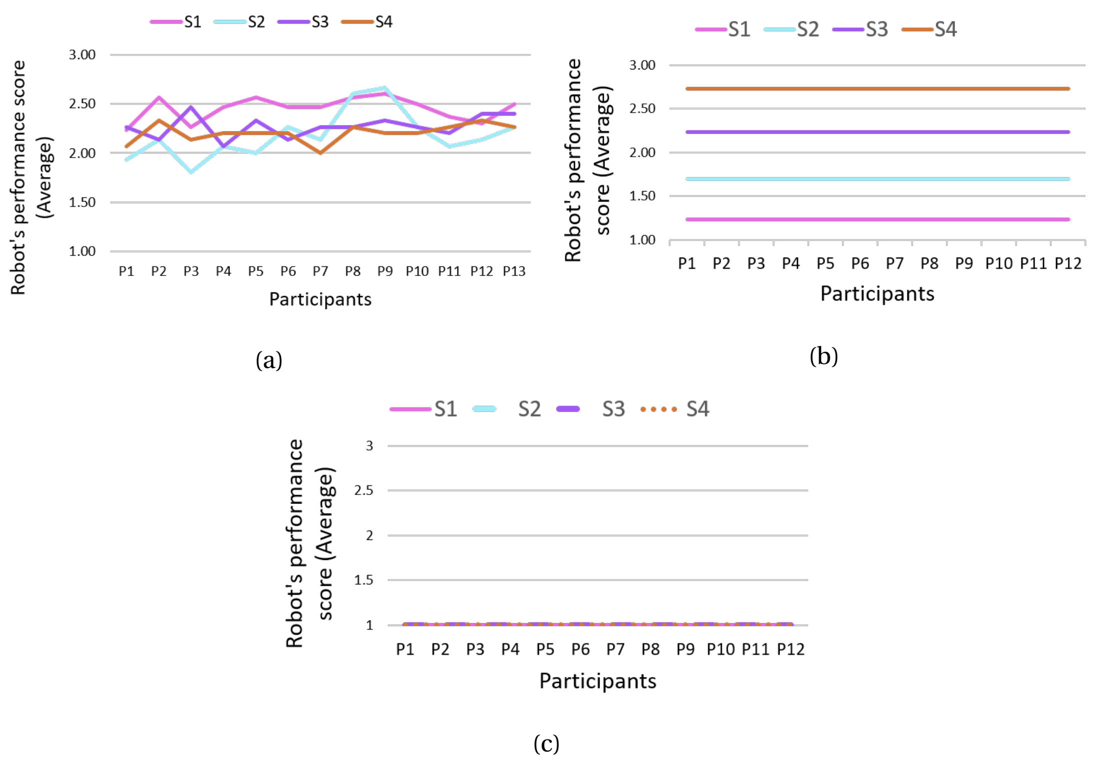
*Personalised-Learning(PL);Continuous-Learning(CL); Non-Learning(NL), †Based on study's research questions.

8.3.9.3 Children's Perceptions of the Writing Capabilities of the Robot

The questions presented in the 1st category such as Q1 (grades to the robot's writing ability) and Q2 (improvement) correspond directly to the robot's learning capabilities (see Table8.6). In this section , we first show the robot's actual performance scores including its writing ability and improvement during the sessions in the three conditions. Then we look at the findings of children's perceptions regarding the two questions.

Figure 8.19 shows the robot's actual writing scores (average) with respect to each child. We present the robot's scores to show its writing performance in each condition. It should be noted that each session included a different set of letters and we used the same set of letters in all the three conditions in the respective sessions. The depicted scores lie between the interval of 1 to 3 where 1 represents its lowest; 2 as its medium; and 3 as its highest performance scores.

It is shown that the robot's actual performance in the personalised-learning condition was based on the child's performance. The scores presented in the graph are the combined scores of the children's box and slider scores (demonstration and correction). The results of the



(a) (b) (c)

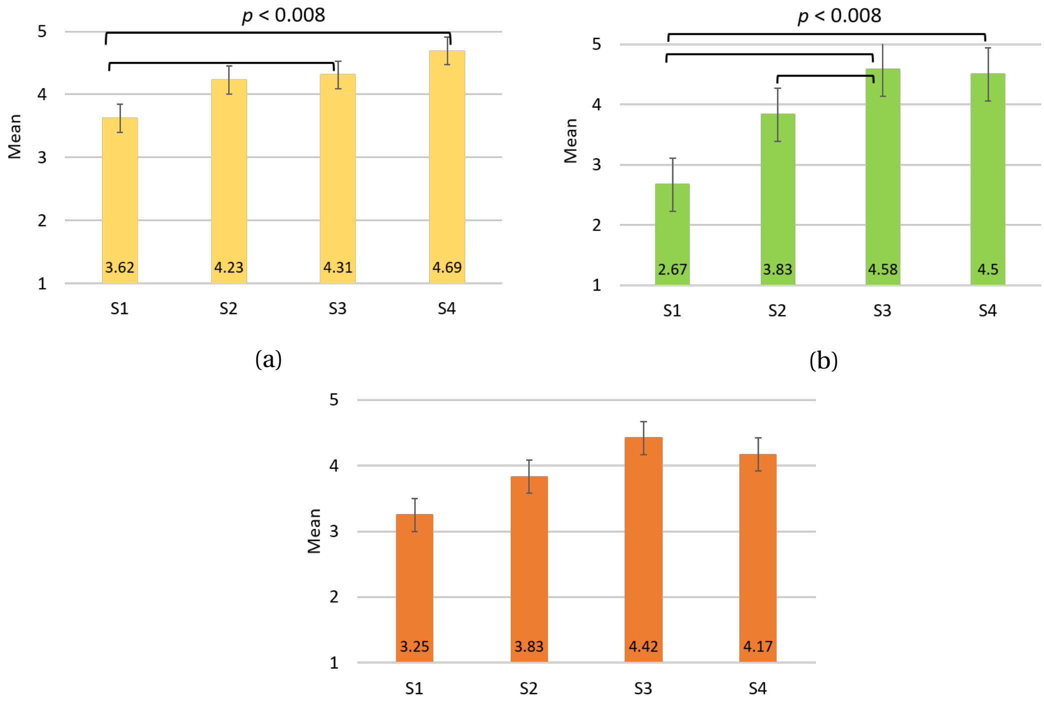
Figure 8.19 – Robot's actual writing performance scores presented in the: (a) personalised-learning; (b) continuous-learning and; (c) non-learning condition.

personalised-learning condition suggests that the robot's performance do not follow any specific pattern and the scores lie in the range of 1.75 and 2.75 scores (see Figure 8.19a). In the continuous-learning, the robot's performance was predefined that improved with each session(see Figure 8.19b). Unlike the robot's performance in the former two conditions, the robot's performance in the non-learning condition was also predefined and remained constant with the score of one throughout the sessions(see Figure 8.19c).

For investigating the children's perceptions related to the questions Q1 and Q2 (see Table8.6, we first look at the results of their perceptions within each condition and then we show the results by comparing the conditions.

Within conditions: For this, we applied the Friedman test to determine if there were differences between the four sessions in each condition. There was a significant difference across the sessions in the grades they provided for the robot's writing ability in the *personalised-learning* condition, $X^2(3) = 18.27$, $p = 0.00$ and *continuous-learning* $X^2(3) = 26.41$, $p = 0.00$. Post hoc analysis with the Wilcoxon signed-rank tests was conducted with the application of the Bonferroni correction in each condition, resulting in a significance level set at $p < 0.008$.

In the personalised-learning condition, we found significant differences between two pairs of sessions: Session 1 and Session 3 ($Z = -2.71$, $p = 0.007$); and Session 1 and Session 4 ($Z = -2.73$, $p = 0.006$)(mean: S1 = 3.62; S2 = 4.23; S3 = 4.31 and S4 = 4.69) (see Figure 8.20a). In addition, in



(c)

Figure 8.20 – Results of the children's perceived writing ability in the: (a) personalised-learning condition; (b) continuous-learning condition; (c) and non-learning condition.

the continuous-learning condition, we found a significant difference between different pairs of sessions: Session 1 (mean = 2.67) and Session 3 (mean = 4.58) (Z = -2.98, p = 0.003); Session 2 (mean = 3.83) and Session 3 (Z = -3.00, p = 0.003); and Session 1 and Session 4 (mean = 4.50) (Z = -2.96, p = 0.003), see Figure 8.20b.

Moreover, we did not find the differences in children's perceptions between any of the sessions in the non-learning condition by taking into account the p value = .008; (mean: S1= 3.25; S2 = 3.83; S3 = 4.42 and S4 = 4.17) (z=-2.64, p = .008 between S1/S2 and S1/S3).

These results suggest that the children in the continuous-learning condition did not perceive the differences in robot's writing abilities in the first two sessions which is a noticeable observation, given that the robot was continuously improving within as well as between the sessions. However, they perceived the advancements in the robot's writing only after the third and fourth sessions. The children's perceptions across the sessions are consistent with the actual writing skills of the robot which suggests that the children took some time but eventually were able to perceive the robot's actual writing performance. A similar trend appeared in the personalised-learning condition where the children perceived the differences only after the third and the fourth sessions. But, we did not expect the association between the children's given grades and the robot's actual writing capability because it does not follow any particular learning trend and its performance is child dependent(see Figure 8.20a). Finally, in the non-learning condition, there were no significant differences in their provided grades across the sessions and therefore we could not establish the link between the robot's actual writing capability and the children's perceptions.

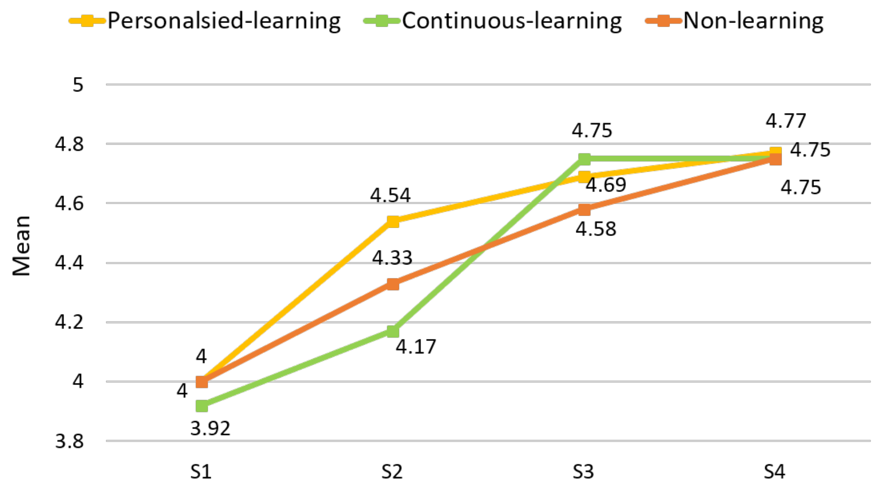


Figure 8.21 – Results of the children's perception of the robot's writing improvement in the personalised-, continuous-, non-learning condition.

As shown in Figure 8.21, regarding the question about the improvement in the robot's handwriting (Q2), the children in all the conditions perceive the increment in the handwriting, but no significant difference was observed between the conditions and across the sessions. Another interesting trend in the personalised- and non-learning condition can be seen in the Figure 8.21; overall the children believed that the robot was improving, but in reality the robot was either performing according to their own performance (which does not follow incremental pattern, see Figure 8.20a) or did not improve at all. This result indicates that the children might not be good in perceiving the robot's improvement. And indeed, after the last interaction, most of the children in all the three conditions (personalised-learning - 91.6%, continuous-learning - 91.6% and non-learning - 92.3%,) provided high scores to the robot's handwriting improvement (see Table 8.6).

Between the conditions: Regarding the children's perceptions between the conditions, the results related to Q1 and Q2 did not show differences between any of the conditions. These findings suggests that although the children were able to perceive the difference in robot's writing abilities across the sessions (at least in the continuous-learning condition), but they could not differentiate the difference in robot's writing abilities and improvement between the conditions. Thus, the results partially validate our second hypothesis.

We further discuss these results in Section 8.3.10.

8.3.9.4 Children's Perceptions of the Robot

The questions in this category are based on the Godspeed questionnaire (Bartneck et al., 2009) and correspond to the children's perceptions of the robot's intelligence (Q1), friendliness (Q2)

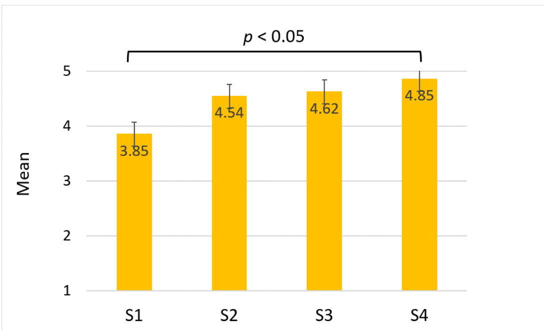
Table 8.7 – Percentage of children who gave high scores to the robot for the questions related to the robot's impression after the last interaction (2nd category).

Questions related to the robot's impression (2nd category) (Bartneck et al., 2009)	PL(%)	CL(%)	NL(%)
Q1. How many stars would you like to give for Michael's intelligence?	92.3	100	91.6
Q2. Do you find Michael friendly? How much?	100	100	100
Q3. Do you like Michael? How much?	100	100	100

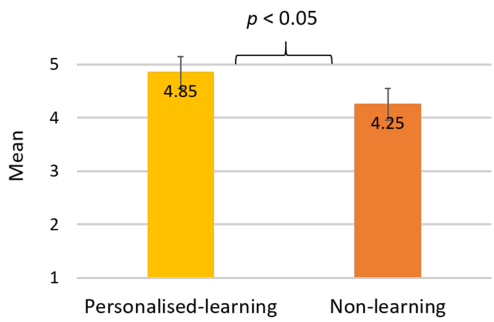
*Personalised-learning(PL), Continuous-learning(CL) and Non-learning(NL).

and likability (Q3) towards the robot, see Table 8.7. We discuss the results in the order of the presented questions. First we discuss the findings in each condition across the sessions and then, we describe the results of the perceptions between the conditions after the last interaction.

Within conditions: A Friedman test was run to determine if there were differences in the children's perception of robot's intelligence (Q1) between the four sessions within each condition. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. The results of the personalised-learning condition showed a significant difference in perceived robot's intelligence between the sessions, $X^2(3) = 15.15$, $p = 0.002$. Post hoc analysis further revealed statistically significant differences between Session 1 (Mean = 3.85; Mdn = 4) and Session 4 (Mean = 4.85; Mdn = 5) ($p = .04$)(see Figure 8.22a), but not between the remaining combinations of the sessions. In addition, we did not observed any significant differences in the continuous-learning and non-learning conditions across the sessions.



(a)



(b)

Figure 8.22 – Results of children's perceived robot's intelligence: (a) in the personalised-learning condition; (b) between the personalised-learning and non-learning condition after the fourth session.

Between Conditions: Additionally, a Kruskal-Wallis test was conducted to determine the differences between the conditions. No significant difference was found in the first three sessions. Only after the fourth session, there was a statistically significantly difference between the mean ranks of at least one pair of conditions. There was a strong evidence of a difference between the personalised learning and non-learning condition, $X^2(3) = 9.09$, $p=.01$.

Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. Adjusted p-values are presented as p = .01. This post hoc analysis revealed statistically significant differences in intelligent scores between the personalised (Mean = 4.85, Mean Rank = 16.27) and non-learning condition (Mean = 4.25, Mean Rank = 9.46), see Figure 8.22b.

Regarding the Q2 (Friendliness) and Q3 (Likeness), significant differences were neither found between nor within the conditions (across the sessions). We observed after the last interaction, all the children (100%) in each condition gave high scores for the fondness and friendliness scale (see Table 8.7, Q2-Q3)). The overall results suggests that the continuous-learning and non-learning competencies of the robot did not affect children's perception of robot's intelligence. But, when the robot adapts its writing skills according to the pace of the children in the personalised-learning condition, they perceived it more intelligent compared to the children in the non-learning condition. These results partially validate our third hypothesis that the children would like the robot and find it friendly and intelligent irrespective of the three different competencies.

Table 8.8 – Percentage of children who gave high scores to the robot for the questions related to the children's self-evaluation of tutoring the robot after the last interaction(3^{rd} category).

Children's self-evaluation towards tutoring (3^{rd} category))†	CL(%)	NL(%)	PL(%)
Q1. Do you like teaching Miguel? How much?	100	100	100
Q2. Would you like to teach Miguel in future?	100	100	100
Q3. How good were you as Miguel's teacher?	100	100	100

*Personalised-learning(PL), Continuous-learning(CL) and Non-learning(NL);, †Based on study's research questions

Table 8.9 – Correlations between perceived self-efficacy towards tutoring and the other capabilities in the personalised-learning & continuous-learning condition.

	Self-efficacy towards tutoring	
	Personalised-learning	Continuous-learning
Intelligence	rs(13) = 1.00, p = .000	rs(12) = .77, p = .003
Improvement	rs(13) = 0.73, p = .004	rs(12) = .67, p = .016
Writing ability	–	rs(12) = .62, p = .029

8.3.9.5 Children's Self-efficacy Towards Tutoring

In order to examine the children's experience of teaching the robot, the researcher asked three questions related to their experience about tutoring (see Table 8.8; (Q1, Q2, Q3)). Out of the three questions, the first two questions correspond to children's current and future likeness of teaching the robot. The third question is specifically designed to assess their perception

Table 8.10 – Questions related to the children's perception of the robot as a writer and social partner.

Children's perceived role of the robot (Kennedy et al., 2015b)	Options
Q1. How do you consider Miguel as a?	Classmate Friend Brother Relative Stranger Parent Neighbor Teacher None
Q2. What do you think Miguel writes like a?	A child younger than you Like you Like your friend Like your teacher Like your parents Like your brother or a sister None

of self-efficacy towards tutoring the robot. In our study, self-efficacy is defined as how the children evaluated themselves as tutors.

The results of the Q3 indicate no significant difference between the conditions at any point. In fact, after the last interaction, all the children in each condition, gave high scores to themselves as a teacher (see Table 8.8). Additionally, all of them gave high scores in the Q2 and Q3; their likeness towards teaching the robot in the study and about future tutoring.

Furthermore, after the last interaction, we found a few strong correlations only in two conditions (continuous- and personalised-learning) related to perceived self-efficacy towards tutoring the robot (see Table 8.9). In the continuous-learning condition, we found three strong correlations between the children's self-efficay towards tutoring the robot and their perception of robot's intelligence, improvement and writing ability. On contrary, in the personalised-learning condition, their self-efficacy towards tutoring was related to only robot's intelligence and the improvement in it's handwriting.

Overall, these results validate our fourth hypothesis that the robot's competencies would not affect perceptions of children about grading themselves as teachers.

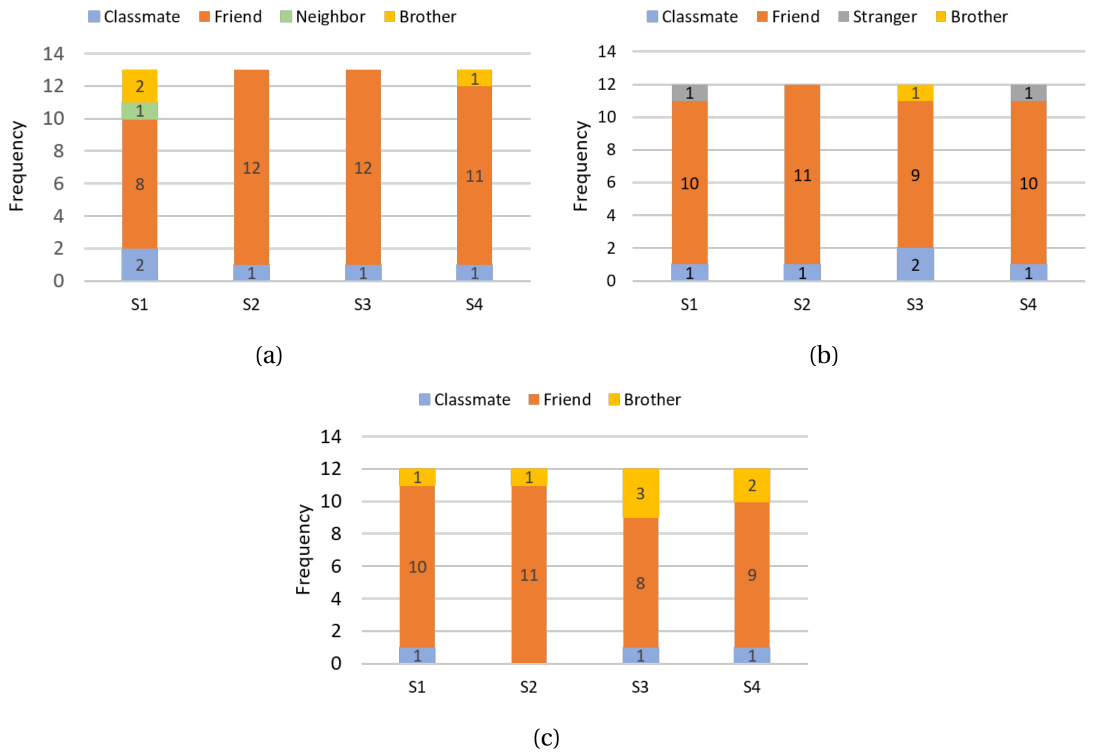


Figure 8.23 – Results of the children's perceived writing role in all the sessions (S1, S2, S3, and S4) for the: (a) personalised-learning; (b) continuous-learning; (c) non-learning; condition.

8.3.9.6 Children's Perceptions of the Robot's Role

Table 8.11 – Chi-square values are presented for each condition in the four sessions.

	S1		S2		S3		S4	
	$X^2(3)$	p	$X^2(3)$	p	$X^2(3)$	p	$X^2(3)$	p
Personlaised-learning	9.46	0.024	9.30	0.002	9.30	0.002	15.38	0.000
Continuous-learning	13.50	0.001	8.33	0.004	9.50	0.009	13.50	0.001
Non-learning	13.50	0.001	8.33	0.004	6.50	0.039	9.50	0.009

(S1 - Session 1, S2 - Session 2, S3 - Session 3, S4 - Session 4).

In a peer-tutoring scenario, it becomes meaningful to explore the roles that a tutor gives to a tutee in terms of a social partner and performer. Would these roles differ according to the tutees performance? and, would these roles change over time? To evaluate these question in our study, we explore children's perception of the robot in a role of a social partner and writer. During the questionnaire round, the researcher asked two categorical based questions, Q1 and Q2, see Table 8.10, in both questions the children had to choose one option. For the analysis, we used a chi-square goodness-of-fit test to determine the differences in the roles within and between the conditions. As such, we present our findings as follows:

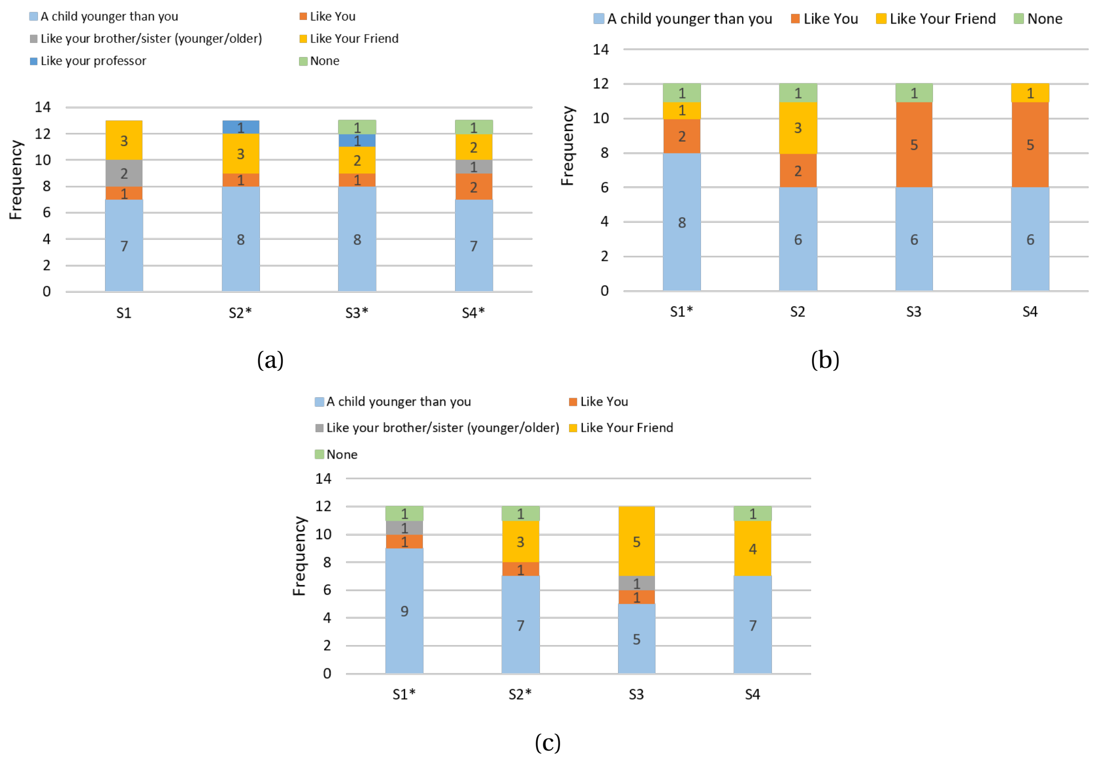


Figure 8.24 – Results of the children's perceived writing role in all sessions for the three conditions: (a) personalised-learning; (b) continuous-learning; (c) and non-learning. [* = significant; S1 - Session1, S2 - Session2, S3 - Session3, S4 - Session4)].

Social Role: As shown in Table 8.11, the results suggest that within each condition and for each session, the children perceived significantly different roles of the robot. And the preferred role as a social partner is a 'friend'. This indicates that the children considered the robot as a friend irrespective of the conditions and sessions. Despite being told by the experimenter multiple times about their role and the robot's role, they perceived the robot as a 'friend' compared to other available options.

Writing Role: The results indicate that the children perceived the robot in a writing role significantly different; but only in a few sessions. Mostly, they considered the robot as being a younger writer than themselves in all the conditions, but over time, the other roles emerged differently in each condition. For example, *in the personalised-learning* condition, the last three consecutive sessions showed significant differences, Session 2 ($X^2(3) = 10.07$, $p = 0.01$), Session 3 ($X^2(3) = 14.3$, $p = 0.006$) and Session 4 ($X^2(3) = 9.69$, $p = 0.04$); where they consistently preferred the robot in a role of a younger child, see Figure 8.24b. We believe that since the robot's performance was dependent on each child's performance, by the end of the last interaction, no major role emerged.

In the *continuous-learning condition*, the children perceived the robot significantly different only in the Session 1 ($X^2(3) = 11.33$, $p = 0.01$), see Figure 8.24b. This result indicates that in the first session, since the robot was a beginner, most of the children perceived it as a

Table 8.12 – Questions asked to the children's parents regarding the study.

Questions asked to parents related with the study	
Q1. Did your son/daughter talk to you about the robot called Michael?	Yes/No
Q2. Did your son/daughter talk to you about the writing activity with the robot?	Yes/No
Q3. Can you explain what s/he talked about the writing activity with the robot?	Descriptive
Q4. What is your opinion on including a robot as a tool in children's educational system?	Descriptive

'younger child'. As the robot improved its writing skills over the sessions, the children did not see it only as a younger child but also like themselves (see Figure 8.24). Thus, due to the continuous-learning competency of the robot, the children considered that the robot writes either like a younger child or like themselves.

Finally, in the non-learning condition, the first two sessions showed significant difference in perceived roles, Session 1 ($X^2(3) = 16.00$, $p = 0.001$) and Session 2 ($X^2(3) = 8.00$, $p = 0.04$). In the first two interactions, they primarily considered the robot as a 'younger child'. As the children did not perceive the changes in the robot's writing ability, over the sessions, they might started considering the robot like their friend (see Figure 8.24c). Hence, as the robot was not doing well, they perceived the robot which writes either like a younger child or like their friend, but of course 'not like them'.

In all the three conditions, we observed a peculiar pattern about the emerged role by the end of the last interaction. In the personalised-learning conditions, when the robot's writing was dependent on the child's performance, no major role emerged. While in the continuous-learning condition, where the robot's writing was improving the emerged role for the robot as a writer was 'like you'; lastly in the non-learning condition, when the robot's writing was not improving, the emerged role was 'like your friend'.

Furthermore, a chi-square test of independence was conducted between the conditions in each session to find the difference in perceived role as a social partner and writer. We did not find any significant difference for both types of roles.

Table 8.13 – Questions asked to the class-teacher regarding the study.

Questions asked to parents related with the study
Q1. What is your opinion about the writing activity?
Q2. Do you think that this activity with the robot can help children to improve their handwriting skills? How much?
Q3. Did the children talked to you about the robot "Michael"? If yes, can you explain what?
Q4. How did children react after finishing the activity?

8.3.9.7 Feedback from the Class-teacher

For conducting the study, we contacted the principal and teachers of the school in advance. In the preparation of the study, a school-teacher was involved who helped us in different aspects, for instance, she showed us different handwriting errors in note-books of the children and informed us that approximately 22-25% of the children in her classroom do not have legible handwriting. It should be noted that none of these children suffer from medical problems and indeed have different levels of handwriting skills resulting different levels of legibility. Although, there is no additional handwriting instruction class for the participants (third graders) but she informed us that she often provide help to individual children who suffer from handwriting problems. Additionally, for the preparation of the study, she passed us the book containing Alphabet from which the children actually practice handwriting in the school. Besides, in our study, she randomly assigned children in the three conditions.

In order to get the opinion of the school-teacher regarding the study, we asked her to perform the writing activity with the robot (same activity which the children performed). After that, we gave her a feedback form containing four questions related to the study and its impact on the children(see Table 8.13).

For the Q1 related to her opinion on the writing activity, she showed positive views. In addition, she mentioned that '*the writing activity was very funny and had a good acceptance among the students*'. For the Q2, she said the activity can definitely help children to improve their handwriting skills and provided 4 out of 5 grades. For the Q3, she explained that the children talked to her about the robot. They mentioned that '*they helped the robot and the robot was friendly and funny*'.

Overall, the teachers opinion about the writing activity, the interaction with the robot and the impact of the activity on children's learning gave us insight that the study was well received by the users. The activity did not only provide the enjoyment to them but also enhanced their learning.

For the Q4 related to children's reaction about the 4-session study, her answer was surprising as she mentioned '*the children were sad because the activity ended*'. This statement provides evidence that the study was well accepted by the children and even after the four interactions with the robot, the children still wanted to teach the robot. While doing the study, we sensed children's excitement and joy to teach the robot. But children's answers for the questions related to their fondness towards the robot, likeness about the current and future tutoring the robot gave us further reliability about the acceptance of the system. However, the statement of the school-teacher regarding the Q4, finally assured us that the activity can be extended for more than four sessions.

8.3.9.8 Feedback from Children's parents

After the last interaction with the robot, we sent feedback forms comprised of four questions to children's parents. After two weeks, we collected the forms from the parents. The questions are presented in Table 8.12 and are related about the study and their opinions regarding inclusion of robots as a tool in their children's education. As the form submission was not mandatory, we received only 21 forms (56.7%) out of 37 forms. As shown in the table, the first two questions are polar (Yes/No) and the other two are descriptive questions.

For all the questions, we received feedback from most of the parents. For instance, for the first question (Q1) which is related to whether their children mentioned about the robot, 100% of the parents answered that their child have spoken to them about the robot. For the second question (Q2), 90.4% of the parents replied that their child talked to them about the writing activity. Similarly, 90.4% of the parents were able to explain about the writing activity and their child's interaction with the robot (Q3). For the last question (Q4), 90.5% of the parents provided feedback about their opinion on including the robots in education.

For the third question, regarding the description of the interaction between the children and the robot, all of the feed-backs explained the prominent aspect of the interaction: the robot; and the handwriting. However, some of them did not have full explanation. One of the example for the Q3 is given below:

> *"The robot called Michael wrote correct or incorrect letters. And my son had to improve them through a horizontal slider. Afterwards, my son had to reproduce the letter by hand. Finally, he had to compare the letter his letter with the robot's letter."*

Besides the information about the interaction, some of the feed-backs included how their children experience the study. In general, the experience of the children through their parents point of view seems to be positive. We present two examples of their feedback including their child's experience:

> *"She was very satisfied with the experiment. She loved the sympathy of the robot."*

> *"She found the activity interesting and she was anxious before starting the activity. During the participation, she loved interacting with the robot. She wanted to keep the robot. "*

These feed-backs reflect that the children liked interacting with the robot. And therefore, were capable of passing their experience to their parents. In addition, some of them expressed their liking towards teaching the robot,

> *"He helped the robot drawing the letters through the touch-screen. He liked teaching the robot named Michael and corrected the letters of the robot. "*

Regarding the feedback of Q4, we wanted to explore the parent's general opinions on including a robot as a tool in children's educational system. As shown in the Table 8.14, we classified the answers in three categories: 1) in-favor; 2) oppose; and 3) rational. As the name suggests the *in-favor* and oppose categories correspond to the fully positive and negative opinions. While, the *rational* category reflects their opinions based on their explicit arguments. We present some examples of the feed-backs based on each category, see Table 8.14.

In total, 66.6% of the parents provided positive answers for the in-favor category, which indicates that the parents are capable of seeing the robots as a new medium in education, they do not only perceive it as a different learning approach but believes that it may add fun and enthusiasm to the learning experience. Approximately, 9.5% of the parents were being rational about the usage of robots in educational system. They believe that the usage of the robots in education can be beneficial as a tool but can not be used as a replacement for human-teachers. Additionally, 9.5% of the feedback belong to the 'oppose' category, the parents in this category are totally against of using the robots in education, they prefer to have human touch with their children rather than the machine. Lastly, 14.2% parents did not provide any answer as they did not have any opinion on this.

8.3.10 Discussions and Conclusions

The results provided partial support to our first hypothesis; the personalised- and continuous-learning competency affected the children's learning but none of them affected more than the other. Similarly, we find partial support to our second and third hypothesis; the children were able to perceive the changes in the the robot's learning capabilities in the personalised-

Table 8.14 – Examples of parent's feedback based on the three categories: in favor; oppose; and rational.

Categories	Frequency (%)	Examples
In favor	14 (66.66%)	Ex.1. My daughter loved this experience and showed enthusiasm. Considering this, I believe that including a robot as a tool may build a positive stimulus for the students. Especially, those that need less traditional approaches. Ex. 2. I think it can be valuable for better catching the students' attention since nowadays they are more focussed towards the new technologies. For what I perceived from my son, he liked the experience and thought it was interesting and funny. It joints learning with fun.
Oppose	2 (14.2%)	Ex.1. Personally, I do not have a favorable opinion because I am against machines. But I know how much children like them including my own son. Ex. 2. I prefer the contact with humans.
Rational	2 (9.5%)	Ex.1. Unfortunately, we are arriving to the age of robotics, but I think if it is for improving child education and teaching to have higher quality, I believe it is beneficial to the younger ones. Ex.2. It depends on the usability. It will never serve as a replacement of a human being.
No answer	3 (9.5%)	Ex.1. We do not have enough information to offer a valid and founded opinion.

and continuous- learning condition and did not perceive the changes in the non-learnning condition. And, they could not distinguish the difference between the three competencies. In addition, the robot's competencies did not affect children's friendliness and likeability towards the robot but affected their perception of the robot's intelligence. Lastly, how good children consider themselves as a teacher did not seem to affected by the robot's poor writing abilities; hence providing support to our fourth hypothesis.

Perception of robot's writing ability and improvement:

We expected that the children would be able to distinguish the robot's writing ability and improvement between the continuous- and non-learning condition. Since the robot in the personalised-learning condition does not follow a specific learning behavior and its performance is dependent on the children's performance; thus, we did not expect that the children would be able to differentiate the robot's personalised-learning behavior from the other two behaviors. For example, with each child if the robot improves in 9 letters out of the 15 letters then it might be difficult for a child to keep track of the robot's performance.

Concerning the scores for the robot's writing capability (Q1, Table 8.6), the findings suggest that the children in the continuous-learning condition incrementally gave high scores (significant differences) between the first and the later sessions(see Figure 8.20b). The result of the continuous-learning condition is consistent with the robot's actual writing performance. However, the results of the non-learning condition shows an increment in the scores given by the children from session 1 to session 3. Nevertheless, these differences are not statistically significant (see Figure 8.20c). And thus we could not establish the link between the children's perceptions and the robot's actual writing performance.

Concerning the robot's improvement (Q2, Table 8.6), the children in the continuous- and non-learning conditions believed that the robot was improving, given that in the non-learning condition, the robot was not improving at all. Even though we grouped the writing errors and repeated a few letters with the same writing error in each session to facilitate the children for noticing the robot's actual performance. They could not distinguish the robot's improvement between the two conditions. In addition, unlike the results of the Q1, the results of Q2 did not show significant differences between the sessions in the continuous-learning condition. It may be because the robot was improving within and between the sessions, the children did not perceive the sudden improvement in the robot's writing between the sessions.

Some possible reasons for the children's inability to distinguish between the two robot's writing performance are: (1) the children in the age group of 7-9 years are not good in perceiving the robot's writing capability because they considered themselves a good teacher and believed that the robot was learning. (2) it may also due to the use of different letters in each session. For instance, if we have used the same set of letters with same type and degree of errors in all the sessions, it might be easier for them to recognise the robot's improvement between and within the sessions in the non-learning condition;(3) the changes in shapes of the letters might be more subtle for them and thus, it was not easy to keep track of the improvements (Q2) in the shapes in consecutive sessions; (4) due to the concealment of grades, they did not have the clarity of the robot's actual performance; and (5) they could perceive the actual writing abilities of the robot, but gave more grades to the robot in the sessions in order to be nice with the robot and to please the interviewer.

Children's role and self-efficacy: As children believed that the robot was learning, all of them (100%) in each condition not only rated themselves as a good teacher but also liked tutoring the robot and wanted to teach it in future (see Table 8.8). These results clearly indicate that the role of a teacher affected children's self-efficacy towards tutoring in a positive way and indeed, was remained unaffected by the robot's varied competencies.

Children's learning: one of the results related to children's learning in all the conditions revealed that the children were exceptionally better in correcting shapes of the letters through the slider compared to producing them through writing. This also suggests that they might be able to perceive the letter errors and consequently, corrected them. The reasons for this result could be the limited number of sessions. Within four sessions of learning interaction with the robot, the children showed significant improvement in their writing skills but this duration may not be enough to show the significant improvements in their correcting skills. The other reason may be that there was no scope of improvement because they were already good in the pre-test scores (approx 4 out of 5) (see Figures 8.16 and 8.15).

Initially, we anticipated that the number of demonstrations provided by the children may be directly linked to their learning because improvement in handwriting skills often need more practice. However, our results suggests that the children's learning may not be only limited to the repeated exercise of writing letters. Although there is no significant difference in the number of demonstrations provided by the children between the conditions, it should be noted that the children provided greater number of demonstrations in the non-learning condition compared to the learning and personalised condition in the first three sessions (see Figures 8.13 and 8.14). They did not improve significantly in the post-test in the non-learning condition rather they showed significant improvements in the other two conditions (see Figures 8.16 and 8.15). This suggests that children's learning is not only related to their practice of writing letters but can be affected with other factors such as motivation, knowledge construction and so on.

Addition of the personalised-learning condition: addition of the personalised-learning condition in this study revealed two relevant outcomes. The first outcome is related with the children's perception: for instance, due to the capability of the robot to personally adapt the performance of each child revealed that the children's perceptions of the robot's intelligence may change over time. In our case, the children perceived the robot significantly more intelligent by the end of the last interaction. Also, the children in the personalised-learning condition considered the robot more intelligent compared to the non-learning condition sfter the last interaction. The second outcome concerns with the children's learning: the children in the personalised learning condition significantly improved in the post-test. We believe that since the robot's performance was dependent on children's performance, the children may have put more attention in the process of teaching, which consequently improved their writing skills in the post-test.

8.3.10.1 Conclusions

In this study, a social robot autonomously interacts with a child in a one-to-one tutoring scenario, where the child acts as a tutor and corrects the handwriting of the learner-robot. The interaction scenario between the child and the robot aims to boost child's writing skills. Besides, children's learning, we explore children's perceptions of the robot's capabilities and behavior. We carried out the study with three versions of the robot as three conditions: first where the robot improves its writing skills; second where the robot does not improve at all and continue to show poor writing skills; and third where the robot adapts its performance according to a child's performance. The children interacted with the robot four times, twice a week with a gap of 3-4 days.

The results showed that the children improved in the post-test within the learning and personalised conditions but did not show significant improvement in the non-learning condition. Regarding the children's perception of the robot's writing capabilities, the results of the continuous-learning condition revealed that in the first two interactions with the robot, their perceptions did not change. And only after the third and fourth interaction, their perceptions changed. In addition, their perceptions are consistent with the robot's actual performance. But in the non-learning condition, we could not establish the link between their perceptions and the robot's actual performance as there were no significant differences between the four interactions. Moreover, the children could not distinguish the robot's writing abilities between the conditions.

Another result indicated that robot's continuous- and non-learning competency did not affect children's perception towards the robot's intelligence. But, the robot's personalised-learning competency affected children's perception. Thus, by the end of the last interaction, the children in the personalised-learning condition found the robot more intelligent. Overall, multi-session interactions are found to be relevant to examine children's learning and their perceptions of certain skills in a robot. Finally, we collected children's parent's feedback regarding their opinions about including the robot as a tool in education. The general results reflect that the robots should be used as a tool in education as they provide a different learning approach and may bring fun, enjoyment during the learning process.

8.4 Insights in the Fourth and Fifth Studies

In this chapter, we presented two studies where we investigated children's learning and their perceptions towards a social robot that exhibited varied learning competencies. Both studies followed a similar protocol based on the peer-tutoring approach, where a child helps a robot by providing corrective feedback on its handwriting. After analysing the results of the fourth study, we conducted our fifth study with some modifications.

The major modifications in the fifth study include: (1) *robot's learning*- in the fourth study, the robot improved its writing skills between the sessions, while in the fifth study, it improved between as well as during the sessions; (2) *robot's grades*- in the fourth study, the robot showed its fictitious grades explicitly, but in the fifth study, it did not show its grades; (3) *pre-test & post test*- the pre- and post-test in the fourth study included two tasks: letter selection and letter writing, while in the fifth study, it included letter correction through the slider and letter writing; (4) *conditions*- in the fifth study, we added one more robot's competency referred as *personalised-learning* (as a third condition). We believe that the modifications performed in the fifth study affected some of the results. Here, we discuss the similarities and differences in the findings of both studies:

8.4.1 Similarities in the Findings

Children's learning: the common conditions between the two studies are the learning-, continuous- and non-learning condition. **In the learning-condition; where the robot is actually being competent to learn handwriting, the children showed significant writing improvement in their post-test scores in both studies.** Similarly, in both conditions, the children with the non-learning robot showed progress but did not improve significantly in the post-test. For achieving significant results, the children may need more than four interactions with the robot. These findings suggest that despite the differences between the studies (modifications in the second study), the learning competency of the robot significantly improved the children's post-test scores in both studies. However, we could not verify whether the children would always improve more with the learning robot compared to the non-learning robot because in the last study the difference in their learning gains between the two conditions was not significant.

Children's demonstrations of letters: initially, we anticipated that the number of demonstrations provided by the children may be the strongest clue that can be linked to their learning because an improvement in handwriting skills is related with practice. However, our results of both studies do not fully comply with it. In the first study, the demonstrations in the learning condition are greater than the non-learning condition throughout the sessions, yet no significant difference was found between the two conditions and within the sessions of each condition. In the second study, we found significant differences between the sessions of each personalised- and continuous-learning condition but not in the non-learning condition. These demonstrations can be linked with children's increased post-test scores in the two conditions. But again, no significant differences were found between the three conditions. Therefore, **the overall results gave the impression that children's learning may not be only linked to their practice of writing letters but might also be linked to other subtle factors such as motivation and knowledge construction.**

Self-efficacy towards tutoring: in both studies, we did not find any differences between the conditions for the question related to how the children considered themselves as a teacher.

In fact, despite perceiving the varied competencies of the robot, after the last interaction, 92% of the children in the first study and all the children in the second study gave themselves high scores as tutors in all the conditions. **These results suggest the robot's competencies did not affect children's self-efficacy towards tutoring the robot. And, the role of a teacher had a positive impact on how the children considered themselves as a teacher.** **Robot's impressions:** regarding the common conditions in both studies (learning and non-learning), we obtained similar results related to the robot's impressions such as friendliness, likeness and intelligence on children. Once again, the robot's contrasting competencies did not affect children's perceptions of how much they like the robot and how much intelligent they consider the robot.

Effect of multi-session studies: extended period of interaction between children and social robots can lead to the gain in children's knowledge acquisition, social support, and positive perceptions of a robot (Leite et al., 2013, 2014; Kanda et al., 2004b). **It became evident that conducting the muti-session studies has more advantages in certain aspects compared to single-session studies.** In both studies, we have seen that the children's perceptions of the robot's writing capabilities not only changed over time, but the children could perceive the robot's actual abilities only after the third and fourth interactions. Which means in the first two interactions, they either could not perceive or were building up their conviction about the writing capabilities of the robot that actually existed. However, the perceptions regarding the improvement in the robot's writing changed over time but not significantly. Similarly, the perceptions regarding the role of a robot in terms of a writer, changed over time and seem to be associated with their perception of the robot's learning capabilities. However, certain perceptions remains unchanged through out the sessions such as likeness and friendliness towards the robot.

8.4.2 Differences in the Findings

Perceptions: the children in the fourth study could distinguish the learning and non-learning capabilities of the robot related to its writing ability and overall performance after the last interaction. On contrary, in the fifth study, the children could not recognise the robot's learning and non-learning capabilities.

Demonstrations: the number of demonstrations provided by the children in the fourth study did not significantly vary between the sessions within each condition; however, in the fifth study, they varied significantly between the sessions of personalised- and continuous-learning condition.

Learning gains: in the fourth study, the children's learning gains were significantly higher in the learning-condition compared to the non-learning condition; however the fifth study did not produce the same result.

Role: in the fourth study, the children's perception regarding the robot as a writer showed significant differences in both conditions after the first two interactions. In the beginning, the children in the learning-condition considered it as a younger child but in the non-learning condition, they considered it equally as a younger child and a friend. Contrary to this, the children in the 5th study did not significantly perceived the robot's role differently between the two conditions.

8.4.3 Effects of the the Modifications

Robot's learning: in the continuous-learning condition, we added the functionality of the robot's writing improvement within a session because we wanted to show the children that their teaching efforts led to the improvements in the robot's writing. To assess the children's perception regarding this robot's learning we asked two questions: related to the robot's writing capabilities (Q1); and improvement in its handwriting (Q2) (see Table 8.6). As discussed before, in both studies regarding Q1, the children were able to perceive significantly the actual writing abilities of the robot in the condition across the sessions. But, regarding the Q2 (improvement) they could not perceive significantly across the sessions in both studies. Irrespective of this modification, in both studies the children's perceptions regarding Q1 is consistent with the robot's actual writing capability.

Grades: although the display of robot's grades (fictitious) to the children in the fourth study was trivial; nevertheless, we believe that the grades provided a strong clue of the robot's performance and might have affected the children's perceptions related to the robot's learning capabilities (writing ability, overall performance and improvement) and role in the fourth study. Thus in the fifth study, the robot did not show grades and only exhibits performance through its writing. One of the results of the fifth study reveals that the children could not distinguish the robot's writing capability between the continuous- and non-learning condition. It may be due to the concealment of grades: the children did not have a strong conviction of the robot's writing capabilities and consequently could not distinguish the robot's learning and non-learning capability in any of the sessions. In addition, due to the lack of this recognition, their perceptions related to the robot's role as a writer might get affected. Furthermore, we do not know if the exhibition and concealment of the grades affected children's learning in both studies.

Pre-post tests: since the pre-post tests in both studies differ at least in one task, we think that it might affect the children's learning in the common conditions. For example, in the fourth study, the children in the learning condition benefited more compared to the children in the non-learning condition. But, we cannot say the same for the fifth study because no differences were found between the continuous- and non-learning conditions.

Conditions: as mentioned before, addition of the personalised-learning condition in the fifth study revealed that the children perceived the robot with personalised-learning competency more intelligent compared to the robot with non-learning competency. In addition, this competency also improved the children's writing skills in the post-test significantly.

8.4.4 General Conclusions

In this chapter, we presented two longitudinal studies with 4 sessions where we investigated children's learning and perceptions of a social robot (Chandra et al., 2018, 2017b). In both studies, we tested the system (described in the Chapter 7) which provided an educational scenario where a social robot autonomously interacts and performs a collaborative handwriting activity with a child in order to foster his/her writing skills. The interaction mode between the child and the robot relied on the *peer-tutoring* approach where the robot acted as a learner and the child acted as a teacher.

The first study compared two contrasting competencies in the robot: *'learning'vs. 'non-learning'* and presented as two conditions in the study. In the *learning* condition, the robot showed consistent progress in its handwriting skills, but in the *non-learning* condition, it did not show any progress. **The results suggest that the children learned more in the learning condition compared with the non-learning condition** and their learning gains seem to be affected by their perception of the robot. The results did not lead to any significant differences in the children's perception of the robot in the first two weeks of interaction. However, by the end of the 4^{th} week, the results changed. The children in the learning condition gave significantly higher *writing ability* and *overall performance* scores to the robot compared with the non-learning condition. In addition, the change in the robot's learning capabilities did not show to affect their perceived intelligence, likability and friendliness towards it.

Although, the results of our first multi-session study showed positive influence, we reviewed the learned lessons and consequently modified and extended its protocol. Based on these modifications, we further conducted a second multi-session study. Although, the research goals for both studies concerns with children's learning and their perceptions towards the robot. In the second study, the robot exhibits varied learning competencies under three conditions: '*continuous-learning*'; '*non-learning*'; and '*personalised-learning*'. The results suggest that the children improved in the post-test within the continuous- and personalised-learning conditions but did not show the similar performance in the non-learning condition. The children were able to perceive the actual robot's learning capabilities in the continuous-learning condition. **In addition, they could not distinguish the robot's learning capabilities between the three conditions.** Other results revealed that the robot's varied competencies did not affect children's self-efficacy towards tutoring the robot and their fondness towards the robot.

In general, we found that the system was well accepted by the children in both studies for a few reasons. First, we were able to conduct two multi-session studies successfully in two different schools and the children really engaged with the robot over a period of 4 weeks; second, we found that most of the children wanted to teach the robot in the future; and third, the feedback of the school-teacher in the fifth study provided positive feedback for the general acceptance of the robot.

8.4.4.1 Limitations

We acknowledge some limitations of the study that restricted our deeper understanding of the interaction and must be improved for future explorations.

Missing predictor of the children's learning: when looking at the performance of children in individual condition in both studies; the learning, continuous-learning and personalised-learning conditions have shown significant increments in the children's post-test scores. On the contrary, the children in the non-learning condition did not show such significant increments.

We believe that the learning, continuous- and personalised-learning competencies of the robot might have impacted positively children's motivation because the robot was either improving independent of the children's performance or improving dependent on the child's performance. Thus, the children might be getting the rewarding feeling as the robot learns which motivated and allowed them to pay more attention in the robot's handwriting; and consequently enhanced their writing performance in the post-test. However, in the non-learning condition, due to consistent poor performance of the robot, the children might not have similar motivation and attention to improve robot's writing and as a result, they improved but not significantly.

In both studies, we did not measure the children's motivation and attention that they put while tutoring the robot; more specifically, we measured only the number of demonstrations that they provided in each session in all conditions. And, the outcomes did not verify if the number of demonstrations can be a good predictor of their learning. Thus, the actual predictors responsible for children's improvements are unknown. The other predictors could also be related to their cognitive and perceptual efforts such as motivation, attention and knowledge construction. Perhaps, adding an analysis of engagement of the children would provide more insight into the reasons for the results we found. **In a nutshell, it is not clear why these competencies affected the children's performance.** Hence, we think that the studies lack evidence and further research is needed to examine the causes of the children's learning.

Best competency of the robot to improve children's learning: In both studies, the results of the interaction effect between the conditions and the time points did not show significant difference. Only the results of the main effect of time have shown significant difference. These findings suggests that the children's learning was time dependent but not condition dependent. We believe that the lack of interaction effect between the conditions and the time points is due to the small sample size of data and unequal initial handwriting skills of children between the conditions. However, in the fourth study, further analysis of children's learning gains have revealed that the children learned more with the learning robot compared to the non-learning robot. Yet, the fifth study did not produce the similar results. It was also not clear whether the personalised-learning behaviour of the robot was better than the other two behaviours (continuous- and non-learning). In other words, we can say that the children in the fifth study learned solely by teaching the robot despite of its three different learning competencies. We speculate at least two reasons behind these results: (1) it might be due to the modifications performed in the fifth study, such as the changes in the pre-and post-test and the concealment of the robot's grades (fictitious) during the interaction; (2) unequal distribution of children according to their initial handwriting skills among the conditions; and (3) the small sample size of the data.

Overall, we believe that the fifth study can be repeated in future to re-verify the results. And more such types of studies need to be done considering the mentioned limitations to further verify the existing results.

Defecits in System: Moreover, we recognise a few defecits in the developed system. First, the system used offline models of the letter trajectories and the Nao robot used an animated handwriting movement while writing. Due to the lack of technicalities in the Nao robot like degrees of freedom in its arm and light plastic body, the robot could not grasp the pen, write smoothly and provide flawless writing demonstration by touching the screen. Nevertheless, the robot wrote on the screen (close to the screen) as it was writing in the air and used an animated handwriting movement while writing. In our knowledge, none of the child showed concerns about the robot's air writing style. In the near future, we plan to address the above-mentioned limitations by testing the system with online model trajectories and using different framework, planner and server connections that would allow us to avoid the use of animations.

Participant's sample size: The sample size used in the studies is relatively small (25 participants in the fourth study and 37 students in the fifth study) and therefore, the results may not apply to broader populations. However, the current results give insight about the relevance of children's critical perceptions of the robot and effects on children's learning. Further, these results may motivate other researchers in the future in the design of educational child-robot studies based on two and three competence models of the robot. We believe that the existing system can be exploited in schools to improve children's handwriting skills.

9 Summary and Conclusions

In this thesis, we have explored the different child-robot interaction scenarios in the context of handwriting to enhance children's handwriting skills. This chapter concludes the findings of our research. First, we summarize the results of our studies and also explain how the results of one study lead to the conduction of next study. Then, we synthesize our findings by reviewing our general research questions. Following this, we summarize contributions of our research and finally, we provide limitations and future work.

9.1 Summary of Results

First, we began our research by conducting an exploratory study (the **child-child study** presented in Chapter 4) with four to five years old children (preschoolers) in a school setting. The goal of the study was to explore the peer-learning and peer-tutoring methods as modes of interaction and to investigate children's common handwriting errors. More specifically, we wanted to understand whether the children would be able to comprehend the employed methods and how would the methods reflect on their interaction behavior and learning. Therefore, we introduced the two methods as conditions in a scenario where a pair of children performed a collaborative writing activity in the presence of a human facilitator. The presence of the human facilitator aided the interaction flow by giving task instructions and needed help. The findings of the study indicated that the children were able to understand the interaction modes. In general, we found the peer-tutoring mode richer than the peer-learning mode in terms of children's provided gestures, verbal responses and excitement. But, **the overall results regarding their non-verbal behaviors, corrective-feedback and learning gains did not show significant differences between the peer-tutoring and peer-learning mode. Consequently, we did not find necessary evidences to show that one learning method was better than the other.** This may be due to their age factor (four to five years) and because of that they could not provide much corrective-feedback on their peers performance. The second reason could be the sample-size of the participants as we had only twenty children (five groups per condition) in the study, which might not be enough to see the differences between the conditions. Additionally, one session study could be the other reason and the children might need multiple-sessions to improve their writing skills. Regarding the children's handwriting errors, we collected a database of their handwritten letters and created a first version of taxonomy of handwriting issues (Chandra et al., 2017a).

As the results of the first study did not show enough evidence to distinguish the interaction modes, we further explored the two learning methods in our second study (**robot vs. human facilitator's study** described in chapter 5). While considering the limitations of the previous study, this time we targeted forty children in the age-group of six to eight years. Since our research aim is to integrate a social robot in an educational setting, we further accommodated a social robot in the second study. The goal was to explore the impact of integrating a robot vs. human facilitator in a collaborative writing activity for children. The two conditions with a human and robot involved the peer-tutoring mode, and followed the similar protocol of the first study. The findings of this study were related to the children's responsibility towards their peers, their interpersonal distance with both facilitators and their learning gains in the presence of the facilitators. We relate the children's responsibility towards their peers with the type of the verbal feedback they provided. We found that **the children who acted as teachers provided more extended corrective-feedback in the presence of the robot facilitator compared to the human facilitator. In the human condition, they provided more minimal corrective-feedback compared to the robot condition. Since the teacher-children gave more of both types of feedback, particularly extended corrections to their peers in the robot condition, they felt more responsible in the presence of the robot.** Additionally, the emergence of interpersonal model was also studied. On one hand, the children followed the reciprocity model with the robot facilitator because the robot gazed them for a long time and in tun, they provided more feedback. On the other hand, they followed the compensation model with the human facilitator. **Regarding the learning gains of children, they improved in the post-test in both conditions, but no learning gains were found between the robot and human condition** (Chandra et al., 2015). Although, we saw that the type of corrective-feedback given by the children is important because it may elevate their responsibility but in our study, we did not measure the effect of children's corrective-feedback on their learning. Thus, the current study lacks this evidence. The overall results of this study have shown feasibility to integrate a robot in our further research.

The results of the second study gave a sign that a social robot as a 'facilitator' can be accommodated in an educational setting that relies on peer-tutoring method. But, we still did not know which of the learning method (peer-learning and peer-tutoring) would be more adequate to enhance children's handwriting skills. Thus, we conducted our third study (**peer-tutoring vs. peer-learning study** reported in Chapter 6) with forty children in the age-group of six to 8 years using the same protocol. The study compared the peer-tutoring and peer-learning method as two study conditions and run only in the presence of a robot facilitator. The two learning methods were explored in terms of children's self-disclosure to the robot facilitator, corrective-feedback towards their peers and children's learning gains. **The findings showed that all the children (teachers and learners) in the peer-tutoring situation provide more extended corrective-feedback and self-disclosure compared to the peer-learning situation** (Chandra et al., 2016). This suggests that the peer-tutoring situation, where the children had different roles (unequal in terms of position) have impacted children's verbal interaction in terms of corrective-feedback and self-disclosure. Concerning the learning gains in the individual condition, **the children showed significant improvements (increased post-test scores) in the peer-tutoring situation, but no improvements were shown in the peer-learning situation.** We believe there could be a few reasons behind it: one is the single session study that might not be enough to see the improvements; the second could be the small sample-size of the children in the peer-learning condition (16 participants); the third reason could be that the children in the peer-learning condition had better pre-test scores than the other condition and they could have reached the maximum score (post-test) beyond which, they could not improve. **As the children's pre- and post-test scores were constant in the peer-learning condition, we could not compare their learning gains between the conditions. Thus, it is not clear which condition enhanced children's learning more.** The other finding in the peer-tutoring condition revealed the possible connection between chidlren's corrective-feedback and significant increment in their post-test scores; more corrective-feedback lead to high post-test scores. Moreover, we collected the children's handwriting data in the second and the third study; and further revised the built taxonomy based on the children of six to eight years. **This study lacks the measurements of how the children's corrective-feedback and social-disclosure affected their learning gains.** It also lacks the exploration of the children's perception about the robot which could have been useful to understand how their experience affected their learning. The global results of this study showed that the peer-tutoring situation lead to more corrective-feedback and self-disclosure compared to the peer-learning situation. In terms of learning gains in the individual condition, the peer-tutoring showed positive effects (increased post-test scores) but peer-learning showed neutral effect.

So far, **the three studies have contributed to three major outcomes: (1) exploration of writing errors and creation of a taxonomy of writing errors in the age-group of 4-8 years; (2) more benefit of using peer-tutoring method compared to the peer-learning method; and (3) positive indication to incorporate a robot as a 'facilitator' in an educational system.** These outcomes encouraged us to explore other modes of child-robot interactions, where instead of attributing a role of a facilitator to the robot, we wanted to examine the impact of a social robot that participates in the direct learning interactions with the child. Consequently, we further explored the impact of the robot as a 'peer'. We pursued the idea of conducting the fourth study where we imagined a social robot that could directly interact and participate in a collaborative learning with a child. To achieve this, we first looked at some of the limitations of our previous studies such as using the WoZ technique, conducting the studies with a single-session and the lack of exploration concerning children's perception; due to these shortcomings we could not explore child-robot learning interaction deeply. Therefore, for our further exploration, we build a system, where we developed an autonomous social robot with different learning competencies that can be used to foster children's handwriting skills. The system relied on the peer-tutoring method where the robot played a role of a 'learner' and a child acted as a 'teacher'. In the interaction scenario, the tutor-child corrected the writing errors of the learner-robot. For generating the child-like writing errors for the robot, we used algorithms capable of synthesizing the shape of a letter with varied scale of deformations. We chose a set of three errors from the built taxonomy and employed in the designed system.

Further, we tested the system to conduct our fourth study (**learning vs. non-learning study** described in Chapter 8) with twenty-five children in the age-group of 7-9 years. The robot showed learning and non-learning competency and asked help from the tutor child to provide corrective feedback on its writing performance. The goal of the study was to investigate the children's learning gains and perceptions of the robot's capabilities over time. **The findings suggest that the children's writing skills improved with the learning robot compared to the non-learning robot.** By seeing the improved writing skills and grades of the robot, the children might have put more efforts and attention in the correction process which in turn improved their handwriting skills. Although, we analysed the number of letter demonstrations provided by children to the robot in all the sessions and considered it as children's learning predictor. But, we did not find any significant difference in the number of demonstrations between the two conditions. **Thus, the study lacks evidence of the learning predictor for the children's improvement with the learning robot.** Regarding the perceptions, the children could perceive the actual writing skills of the robot only after the third and fourth interaction. **One unexpected result indicates that even after acknowledging the poor writing abilities of the robot, they considered themselves as a good teacher.** Additionally, the robot's different learning competencies did not affect children's perceived impressions of the robot such as friendliness, fondness and intelligence (Chandra et al., 2017a, 2018, 2017b).

After performing the fourth study, we have realised a few limitations that might affected the findings of the study. The identified limitations were: (1) the robot was learning only between the sessions and not during the session; and (2) explicit display of the robot's grades which may have affected children's perceptions. In order to take account of the mentioned-limitations, we tested the system again by conducting the fifth study (**multi-learning study** reported in Chapter 8) with thirty-seven children of 8-9 years of age. This study followed same protocol as the above study with further modifications such as consideration of the above-mentioned limitations, changes in the pre- and post-test and additional competency of the robot. In the study, the robot showed three competencies: continuous learning- where it improved between and within the sessions; non-learning- where it did not improve; and the personalised-learning- where it adapted the performance of a child. The results showed the significant increase in the children's post-test scores in the continuous- and personalised-learning conditions. While, in the non-learning condition, their post-test scores improved but not significantly. When we compared their learning gains between the conditions, no significant difference was found. The reason could be that the children in the non-learning condition had better pre-test scores compared to the other conditions. **The overall results of their learning suggests that the children improved solely by teaching the robot irrespective of its different competencies.** In terms of their demonstrations of letters, we did not find any significant difference between the conditions; however, only the continuous- and personalised- learning condition showed significant differences across the sessions. Regarding their perceptions of robot's writing ability, they could perceive the robot's actual capabilities in the continuous-learning condition across the sessions. In the non-learning condition, since there were no significant differences in children's perceptions between the sessions, we could not establish the link between their perceptions and the robot's actual writing performance. Children's perceptions regarding the robot's improvement revealed that all the children believed that the robot was improving. **Unlike the study 4, they could not distinguish the robot's writing capabilities between the continuous-, personalised and non-learning competencies.** The reasons are not clear but we believe this may be due to the fact that the robot did not display any grades to the children and the children did not have the clarity of the robot's actual performance. We observed one interesting result, that the children found the robot with personalised-learning competency more intelligent compared to the non-learning robot.

Both studies lack the predictors responsible for the children's learning. The overall findings of the last two studies revealed that the multi-session studies are relevant in the exploration of children's learning and their perceptions.

9.2 Review of General Research Questions

In the following section, we review our findings in regard to our general research questions that guided our research (See Introduction, Section 1.3).

1. **Exploration of peer-based learning methods**

   We used peer-learning and peer-tutoring methods as means of interaction in order to maximise children's learning gains through a child-child or child-robot interaction. In our scenarios, we have applied these methods in dyadic and triadic settings, where a pair of participants performed a collaborative writing task and provide corrective-feedback on the other's performance (depending on the used method). In the first three studies, we measured the impact of these methods on children's corrective feedback, their self-disclosure to facilitators and their learning gains. We compared the two methods only in the first and third study. Since, the first study with a human facilitator did not show significant results, we first discuss the impact of peer-learning vs. peer-tutoring on the basis of our third study where we used a robotic facilitator. Then, we discuss the influence of the peer-tutoring method based on the findings of our second, fourth and fifth study.

   We define corrective-feedback *as a formal response from one child on the writing performance of another child.* We classified these feedback into two types: extended and minimal. As the name describes, the extended feedback represents their explanatory answers on the peer's task performance while the minimal feedback corresponds to their short response (*e.g.*yes, no). In the second study, the children in the peer-tutoring condition gave more extended corrective feedback to their peers compared to the children in the peer-learning condition. However, for the minimal feedback, there was no difference between the methods. The other result which showed difference between the two methods was children's self-disclosure to the robot facilitator. Self-disclosure of the children to the robot facilitator correspond to their responses to the general social questions (*e.g.*which is your favorite ice-cream flavour?). It was also classified into extended and minimal types. The children in the peer-tutoring situation disclosed more to the robot compared to the children in the peer-learning situation. **Both findings regarding corrective-feedback and self-disclosure ensures the strong impression of the peer-tutoring methods on children's verabal behavior.** Regarding the improvement in children's handwriting skills (legibility) in each condition, they improved in the peer-tutoring condition (increased post-test scores); but not in the peer-learning condition (same pre- and post-test scores). One of the possible reasons could be the difference between the initial knowledge of children between the two conditions. Since the children in the peer-learning conditions showed same pre- and post-test scores, we could not compare the two methods in terms of their learning gains. Nevertheless, the peer-tutoring method seemed to improve children's writing skills only in a single-session study; however, further studies are needed to explore the perr-learning method.

In the second study, we used only the peer-tutoring method to examine the impact of the robot vs. human facilitator on the children. We observed that in the human condition, the children who acted as teachers provided more minimal type of corrective feedback to their peers. But, with the robot facilitator they gave more extended type of corrective feedback. This finding clearly indicates that the impact of the robot on children's feedback is different compared to a human. And, the presence of the robot may enhance children's corrective feedback. **In other words, the presence of the robot can affect the children's verbal interaction in the peer-tutoring based scenarios.**

Similarly in the fourth and fifth study, we used only peer-tutoring method in a one-to-one teaching scenario. In both studies, the children acted as teachers and the robot as a learner. One of the aims was to investigate the impact of different learning competencies of a learner on a teacher. Thus, we designed three types of learning competencies for the learner-robot: personalised-, learning- and non-learning competencies. The results of the fourth study clearly suggested that the teacher-children learned more with the learning-robot compared to the non-learning robot. However, the results of the fifth study did not show the same result.

The peer-tutoring method was better than the peer-learning method in terms of corrective-feedback and self-disclosure when the robot acted as a facilitator. In the peer-tutoring method, the performance of children as teachers may get affected by the learning performance of the robot when it acts as a learner.

2. **Investigation of handwriting errors by children and synthesizing errors:**

   As mentioned in Chapter 1, our first motive to investigate the children's handwriting errors was to find the common writing errors that they produce. Thus, we collected the handwriting samples of children in the age-group of 4-8 years in the first three studies.

Further, we identified the errors in the corpus, classified the errors and built a taxonomy of writing errors based on English alphabet (uppercase and lowercase, cursive and print style). **The most common types of errors found were *proportion, alignment, position, size* and *breaks.*** The goal of investigating the children's handwriting errors was to get deeper understanding of the problems faced by children in forming the shapes of letters.

The second motive was to synthesise the common errors digitally in order to use them in child-robot educational scenarios to further enhance children's handwriting skills. To address this, we build a child-robot interaction scenario based on the peer-tutoring method, where we imagined that if the child could provide the corrective feedback on the writing errors of the robot, it may enhance his/her handwriting skills. Thus, we tested the scenarios in two studies that involved a learner-robot that writes letters with deformations and asks a teacher-child to correct those letters. To generate the errors in the robot's writing, we chose three errors: *proportion*, *alignment* and *breaks* from the most common handwriting errors. And to synthesise these errors digitally, we used algorithms that integrates human movement inspired features and has the capability to generate good and bad letters (Yin et al., 2016). **The use of algorithms provided the digital approach to control a wide range of deformities in the shape of a letter. Hence, allowed the robot to exhibit letters with child like errors.** By correcting the robot's error which resembles like children's own error, the tutor-children in last two studies improved their writing skills through learning by teaching.

3. **Development of a system that incorporates an autonomous social robot with varied learning capabilities**

   The applicability of a social robot in the second and third study encouraged us to build a system where we developed an autonomous behavior of a social robot that could help children to enhance their handwriting skills. The developed system includes three major aspects: (1) autonomous social behavior of the robot; (2) inclusion of a set of errors from the built taxonomy; and (3) serves as a system for further exploration. The system provides an educational scenario based on the peer-tutoring method where a robot learns from the child; more specifically, the child acts as teacher and the robot acts as a learner. The main idea in the given scenario is: the learner-robot writes a letter with an error and asks the teacher-child to correct it. The teacher-child provides the corrective feedback on the robot's writing. Consequently, the child improves his own handwriting legibility by correcting the handwriting errors of the robot. The autonomous social behavior of the robot allowed the interaction without involving a Wizard like in WoZ technique and yet engages a child in the collaborative writing activity. Since the robot is continuously aware of the child's performance, the robot is able to facilitate the interaction. In addition, the synthesis of a set of writing errors allowed the robot to produce child-like errors. Further, we attributed different learning capabilities such as personalised- , learning- and non-learning competencies to the learner-robot and examine the effect of these competencies on children in two longitudinal studies in a school setting environment. The results of the first multi-session study suggests that the learning-competency showed improvement in children's learning compared to the non-learning competency. However, the second study did not reveal the same results. Nevertheless, **the system was well accepted by the children and school-teachers and showed the possibility of using the social robots with children.**

4. **Impact of the roles.**

   Role enactment produces changes in cognition, self-concept, attitude and behaviour (Allen, 1976). Through out our five studies, the roles of the children and robot impacted the interaction dynamics. On one hand, due to the employment of peer-based learning methods, we explored the roles of children either as a teacher or a learner. Although both the roles influenced the interaction, but the role of a teacher seemed to be more effective. For instance, in our third study, the children in the peer-learning condition provided less corrective-feedback to their peers and self-disclosure to the robot compared to the children in the peer-tutoring condition. This result indicates that when children in a dyadic interaction do have equal roles or position they may not produce as much verbal responses as compared to the situation where there have unequal positions.

   On the other hand, we investigated the robot in a role of a facilitator and a learner. In both second and third studies, the robot acted as the facilitator and consequently, provided the task instructions during the interaction. **The findings support that in this role, the robot appeared to be suitable in the given learning scenarios as all the children completed the writing task in the presence of the robot.** In the last two studies, the robot primarily acted as a learner; however it also facilitated during the activity by giving a few task instructions. **Since the robot was a learner and seeking help from the children in correcting its handwriting skills, it created an atmosphere where the children liked teaching the robot and wanted to teach it in future. In addition, the other results hinted that the children's role as a teacher is associated with their self-efficacy towards tutoring the robot.**

5. **Investigation of children's learning and perceptions of the social robot in longitudinal studies.**

   We wanted to explore children's perceptions of the robot to understand how their experience with the robot that exhibits different competencies affect their learning. To achieve this, we conducted two longitudinal studies (Study 4 and 5) with 4-sessions. On one hand, the results of the fourth study suggest that the children showed more improvement with the learning robot compared to the non-learning robot. On the other hand, the children in the fifth study learnt with the robot independent of its three different competencies (continuous- , personalised- and non-learning). The combined results regarding improvement in children's writing skills show that we need further investigation to verify which competencies of the robot can effectively enhance children's learning.

   Regarding the children's perceptions, in the fourth study, the children were able to distinguish some of the robot's learning and non-learning capabilities (such as perceived writing capability and overall performance) by the end of the interaction. But, the children with the non-learning robot still believed that the robot was learning. In the fifth study, the children could not distinguish any of the robot's capabilities (writing capability and improvement) between the conditions. They all believed that the robot was learning. In both studies, the robot's different learning competencies affect children's self-efficacy towards tutoring the robot and fondness towards it. But the children in the fifth study, considered the personalised robot more intelligent, compared to the non-learning robot.

Overall, we can say that the longitudinal studies seem to be relevant in the exploration of children's learning and some of their perceptions in the context of handwriting learning.

9.3 Contributions

This research explored the intersection of the three research domains (see Figure 9.1). Hence, it's scientific contributions are diverse and can be appointed to various research domains such as Pedagogic Sciences, Fundamentals in Education and Human-robot Interaction.

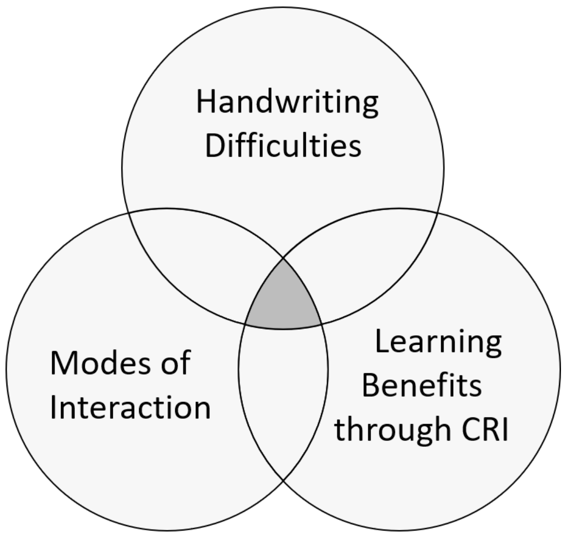


Figure 9.1 – The work lies at the intersection of the three research domains. It targets the issue of children's handwriting difficulties by integrating principles of alternative pedagogic methods as modes of interaction in child-robot interaction scenarios to maximise their learning.

We summarize the contributions within the relevant research domains as follows:

1. **Pedagogic Sciences**

   The three main contributions of the research in the area of pedagogic sciences include: (1) exploration of peer-based learning methods with a social robot; (2) use of contemporary technologies such as social robots, tablets etc.; and (3) investigation of different learning aspects such as learning gains, corrective-feedback and self-disclosure.

We have showed the employment of the 'peer-learning' and 'peer-tutoring' methods as modes of interaction in dyadic and triadic learning scenarios through different studies. Overall, we have explored these methods which have been mostly practiced in the past without the use of social robots and tablets. The first three studies featured a peer-interaction between a pair of children, whereas in the last two studies the peer-interaction happened between a child and a robot in a collaborative writing scenario. Comparing the two methods, the peer-tutoring method was more effective than the peer-learning method in terms of children's corrective feedback towards their peers and self-disclosure to the robotic facilitator. In terms of children's learning gains, the peer-tutoring method improved children's learning in the post-test, but it is not clear which method is more effective to enhance their learning.

2. **Fundamentals in Education**

   Contributions to fundamentals in education include: (1) exploration of children's handwriting errors in the age-group of 4-8 years; (2) creation of taxonomy for the writing errors in English alphabet; and (3) using algorithms to generate and synthesise the errors digitally.

   We have explored the writing errors of children in the age-group of four-eight years old during the first three studies. Then, we classified and presented a taxonomy of writing errors which provides a deeper understanding of common handwriting issues for the letters in the English alphabet (uppercase, lowercase, cursive and print style). The most common errors found were proportion, alignment, position, size and breaks. The taxonomy of writing errors extends the existing literature on handwriting as it contains a few writing issues (e.g.multiple strokes and breaks) that had not been explored previously. Using an algorithm (Yin et al., 2016) we generated and synthesized the errors digitally, allowing the robot to exhibit letters with child-like errors. The implementation of writing errors in the fourth and fifth studies provided a digitalized solution for the children to correct the writing errors of the robot which in turn enhanced their writing skills over four sessions.

3. **Human-robot interaction field**

   In the field of Human-robot interaction field, the prime contributions include: (1) child-robot interaction design in educational robotics; (2) development of a system including an autonomous social robot with varied learning capabilities; and (3) exploration of children's learning gains and perceptions of a social robot in multi-session studies.

   We have experimented different interaction designs such as dyadic and triadic child-robot interaction in the context of education. All the interaction designs included well-defined features such as assignment of roles, turn taking, assignment of tasks etc. For instance, we investigated two different roles of a social robot that could fit in an educational setting and provide a favourable environment for children's learning. The interaction between children and robot resulted in various learning and non-learning aspects.

The development of the system that incorporates an autonomous social behavior of the robot has been successful in the exploration of children's learning and perception. The system provided a scenario where a robot can interact autonomously with a child to foster his handwriting skills. The integration of varied learning competencies of the robot provided some evidence of their effect on children's learning and perceptions. Overall, the testing of the system in the schools indicates the possibility to use social robots with children to enhance their handwriting legibility.

Exploration of children's learning and perceptions over four sessions of interactions revealed certain aspects that could not be possible to explore with single-session studies. The learning competency of the robot improved children's learning gains more compared to the the non-learning competency. Children's perceptions regarding some of the robot's learning capabilities such as the writing capability and overall performance changed over time. Robot's learning and non-learning capabilities did not affect children's perceptions of the robot regarding friendliness, likeness and intelligence. But, robot's personalised-learning competency affected children's perception of the robot's intelligence. Conducting the multi-session study proved to be relevant in the exploration of children's learning and their perceptions.

9.4 Limitations and Future Work

In this section we discuss some of the limitations in our research studies. The sample size of the participants in all studies was small and the results may not apply to a broader populations. However, we covered the participants in the age-group of four to nine years which is relevant for learning handwriting skills.

Another question can be raised 'which peer-based learning method is the best for children's learning ?' Peer-tutoring method proves to be more effective than the peer-learning method in terms of children's corrective-feedback and self-disclosure in a dyadic child-child interaction. But in terms of learning gains, we cannot say the same. Additional similar types of studies are required to prove this. In a dyadic child-robot interaction, the question remains unanswered. It could be a possible extension of this dissertation work.

Similarly, in one-to-one child robot peer-tutoring scenario another point can be argued regarding the best robot's competency among the personalised-, learning- and non-learning competencies in order to enhance children's handwriting skills. The learning-competency of the robot seems to be effective compared to the non-learning competency; however, similar studies comparing the three robot's competencies are needed to verify the existing results.

Obtaining the best predictors of learning is important so that they can be used in different types of scenarios to enhance children's learning. The last two studies lack evidence of the predictor for children's learning. Measuring children's cognitive and perceptual skills such as motivation, attention and knowledge construction may need careful experimentation as they are internal processes and can vary from child to child. Thus, further investigation is required to understand the causes of children's learning which could be other another branch of investigation of this research work.

9.5 Final Words

The focus of this research was on addressing the global research question - *How to create a social robot that can help children to acquire handwriting skills?* This dissertation presented the findings of series of five studies conducted during a few years of research. In the context of the research question, we have (1) explored peer-based learning methods in dyadic and triadic learning scenarios; (2) investigated children's handwriting errors and applied them in the development of a digital platform; (3) built a system that provides an educational scenario where a social robot autonomously interacts with a children to foster their learning of handwriting and finally; (4) examined children's learning and their perceptions of the capabilities of a social robot during two 4-week longitudinal studies. This research could inspire further investigations in various directions. Peer-learning method and learning competency models of a social robot can be further explored in different child-robot interaction scenarios. Investigation of learning predictors for children can also be focused in future research.

***

A Definition of Tests for Detecting Handwriting Problems in Children

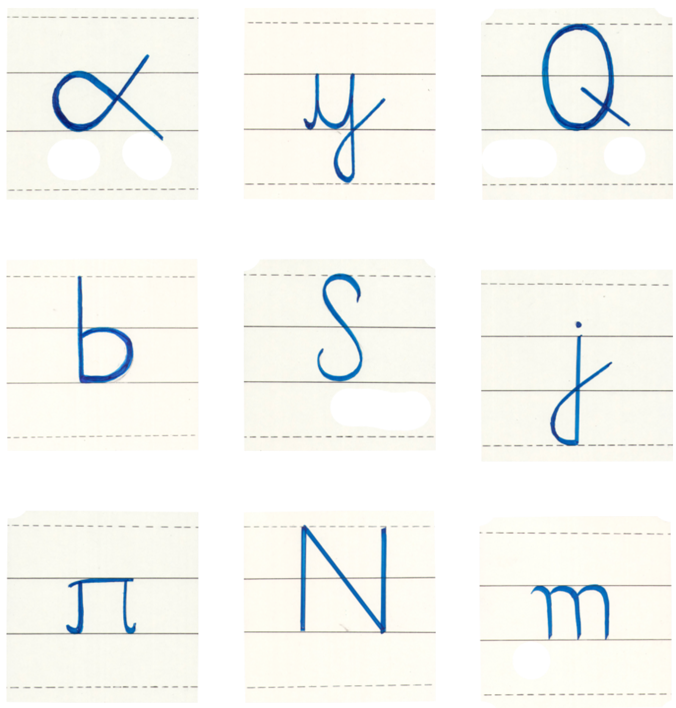
- **Developmental Test of Visual-Motor Integration (Berry's test)**: the berry's test is designed to evaluate the visual-motor skills of children 3-8 years of age. The test relies on copying a set of 15 geometric forms in an increasing difficulty (Berry, 1989).

- **Bruininks-Oseretsky test**: the test was developed to assess the motor development of children in the age group of 4-15 years. The test contains a number of subtests to evaluate response speed, visual-motor control, upper limb coordination, speed and dexterity (Bruininks and Bruininks, 2005).

- **Gardener's visual-perceptual test**: the test evaluates a child's capabilities including visual memory and discrimination, visual-spatial relationships, visual closure and figure-ground. The test relies on matching a correct visual model with the model selected by the child (Gardner, 1982).

B Child-Child Study

Letter cards used during the writing activity and in the pre- and post-test.



C Robot vs. Human Facilitator's Study & Peer-Tutoring vs. Peer-Learning Study

Letters and words used during the main writing activity.

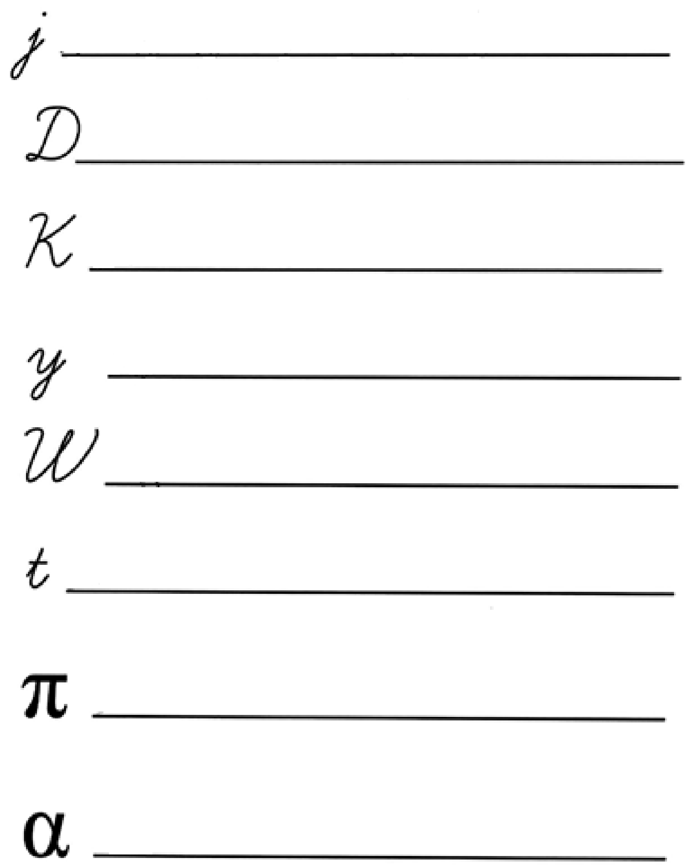
h

Lua

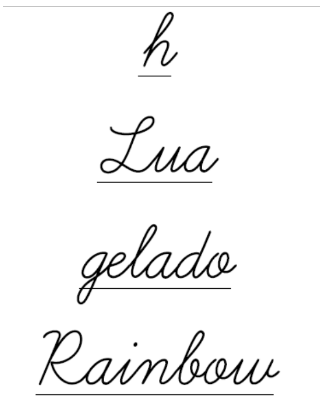
gelado

Rainbow

Letters used in the pre- and post-test.



Self-disclosure questions in Peer-tutoring vs. peer-learning study.



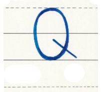
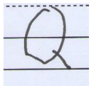
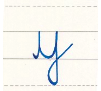
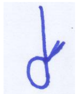
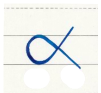
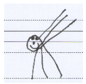
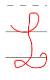
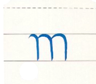
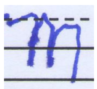
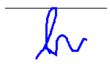
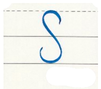
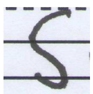
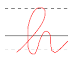
Do you remember a word that starts with this letter (letter 'h')?

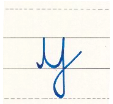
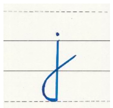
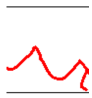
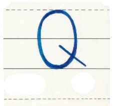
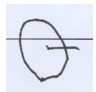
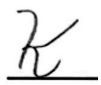
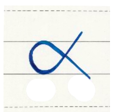
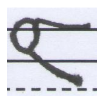
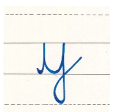
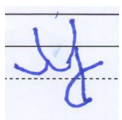
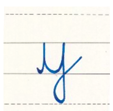
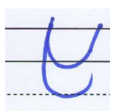
Do you know how many stars are there in the sky? How many moons (Lua) are there?

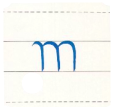
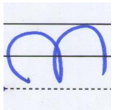
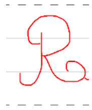
I love strawberry ice-cream (Gelado). How about you? What is your favorite ice-cream flavor?

Do you know at the end of every rainbow there is a treasure? What type of things would you like to find at the end of the rainbow?

D Samples of Children's Handwriting Errors

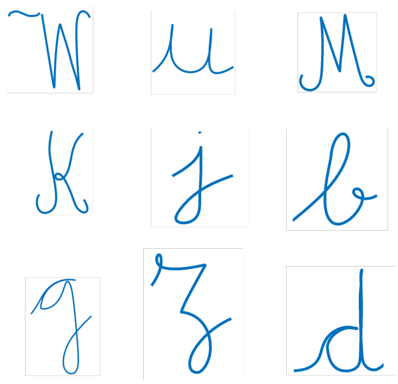
Types of Errors	Models of Letters	Samples in Study 1	Models of Letters	Samples in Study 2&3
Breaks				
Merges				
Missing subparts				
Extra drawing				
Shakiness				
Proportion				

Types of Errors	Models of Letters	Samples in Study 1	Models of Letters	Samples in Study 2&3
Beginning/Endings				
Disfigure				
Alignment				
Primitive Decomposition				
Subpart Decomposition				
Reversals				

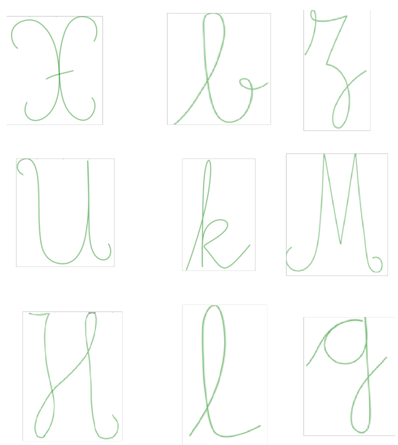
Types of Errors	Models of Letters	Samples in Study 1	Models of Letters	Samples in Study 2&3
Styles				
Different letter	-	-		

E Learning vs. Non-Learning Study and Multi-Learning Study

Letters used in the pre- and post-tests



Learning vs. non-learning study



Multi-learning study

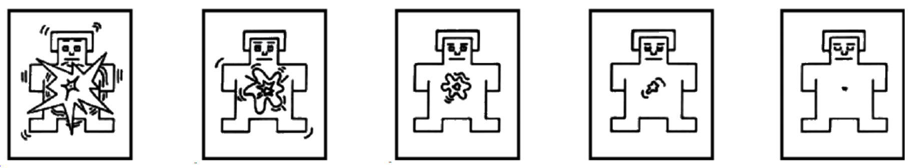
Questionnaire

Godspeed Questionnaire

1. How many stars would you like to give for Miguel's intelligence?

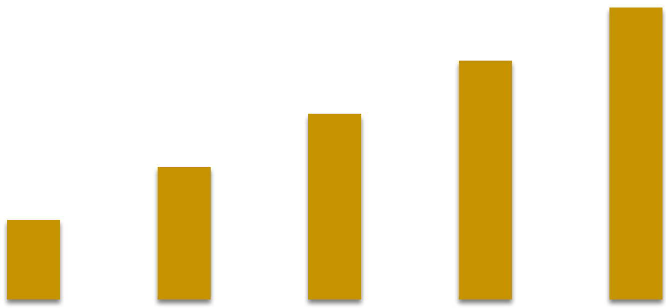
★	☐
★ ★	☐
★ ★ ★	☐
★ ★ ★ ★	☐
★ ★ ★ ★ ★	☐

2. What do you think about Miguel's behavior? How calmly and agitated Miguel behaves?



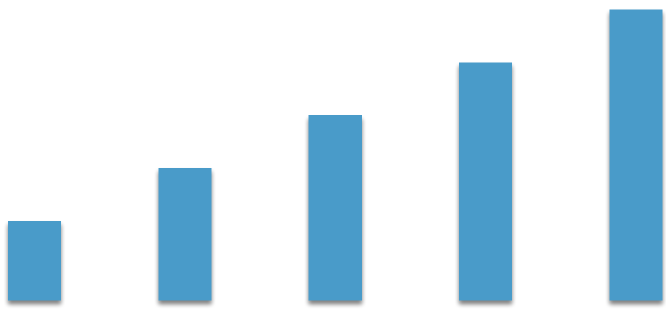
☐ ☐ ☐ ☐ ☐

3. Do you like Miguel? How much?



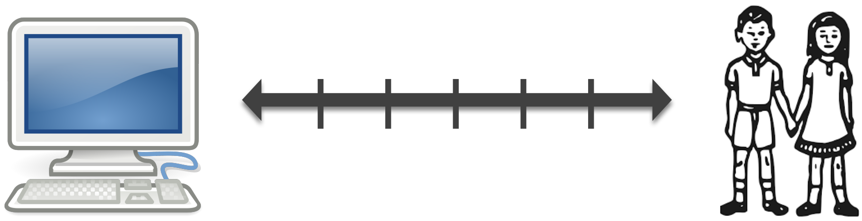
☐ ☐ ☐ ☐ ☐

4. Do you find Miguel friendly? How much?

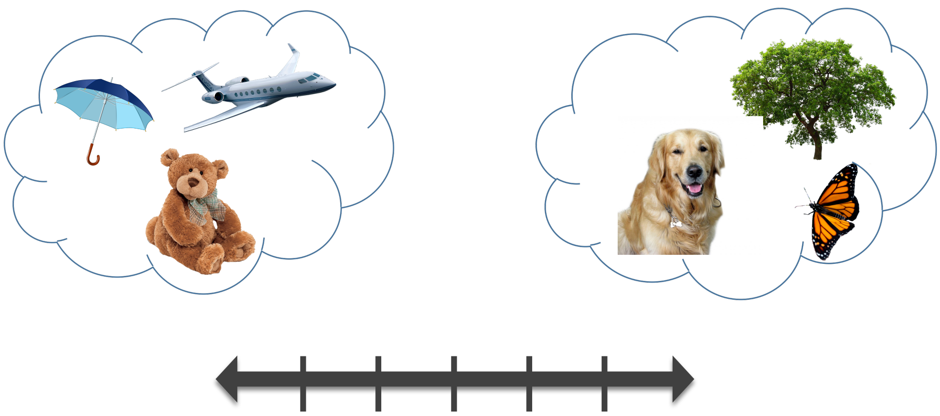


☐ ☐ ☐ ☐ ☐

5. What do you think, Miguel is like a machine or a human being?



6. What do you think Miguel is artificial or lifelike?



Perceived robot's learning abilities

7. How many stars would you like to give for Miguel's writing ability?

★ ☐

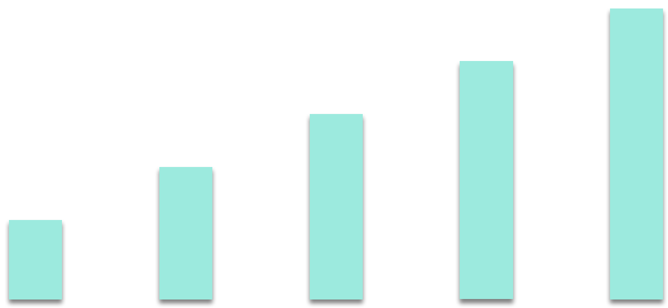
★ ★ ☐

★ ★ ★ ☐

★ ★ ★ ★ ☐

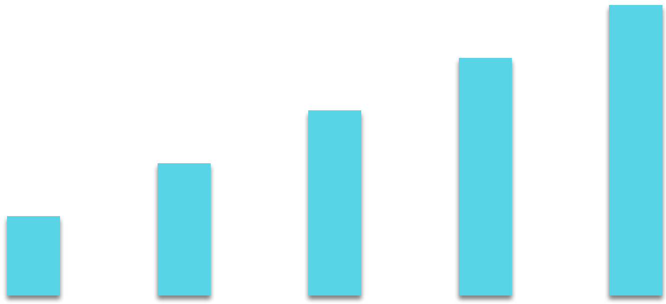
★ ★ ★ ★ ★ ☐

8. Do you think Miguel handwriting is improving or not?



☐ ☐ ☐ ☐ ☐

9. Do you think Miguel knows about its own writing errors? How much?



☐ ☐ ☐ ☐ ☐

10. Can you grade Miguel? How many stars do you think Miguel deserves?

★ ☐

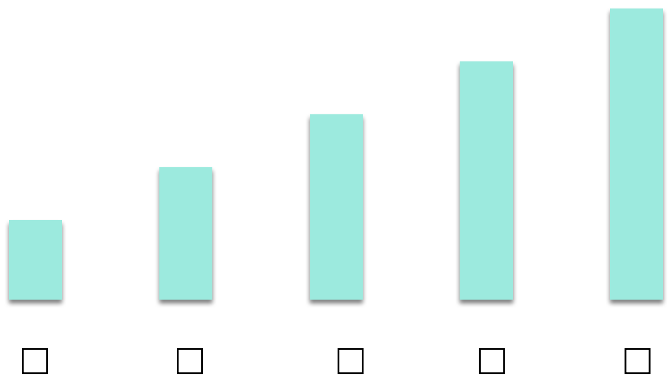
★ ★ ☐

★ ★ ★ ☐

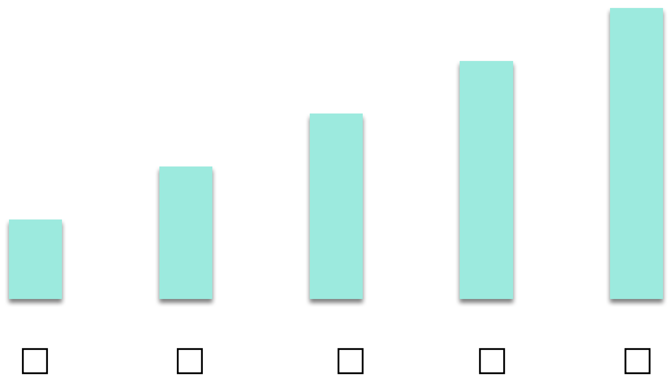
★ ★ ★ ★ ☐

★ ★ ★ ★ ★ ☐

11. Do you think Miguel could help other students in writing?

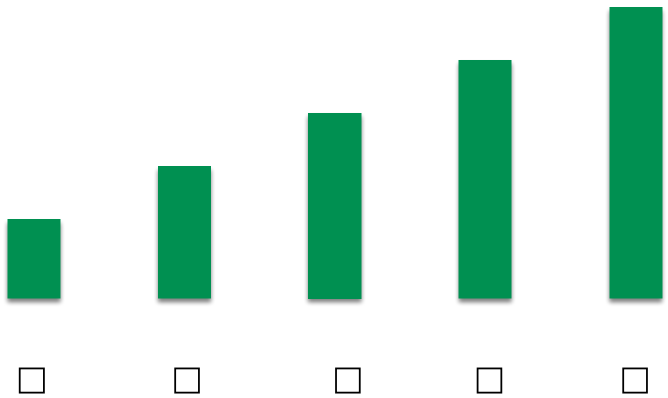


12. Do you think Miguel has learnt from you?

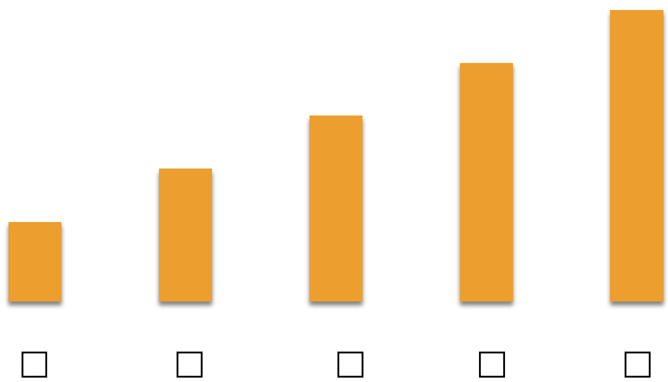


Perceived Teaching abilities

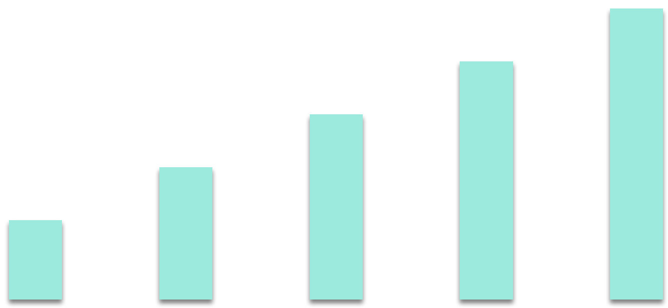
13. Do you like teaching Miguel? How much?



14. Would you like to teach Miguel in future?



15. How good were you as a Miguel's teacher?



☐ ☐ ☐ ☐ ☐

Perceived robot's role

16. What do you think Miguel writes like a?

- A child younger than you
- Like you
- Like your friend
- Like your teacher
- Like your parents
- Like your brother or a sister (younger/older)
- None

17. How do you consider Miguel as a?

- Classmate
- Friend
- Brother
- Relative
- Stranger
- Parent
- Neighbor
- Teacher
- None

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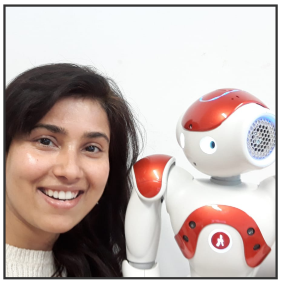

Summary

The goal of my research is to develop social robots for the well-being of people. During my P.hD., I have worked on a Co-writer project which aims to enhance children's handwriting skills with the help of a social robot. This research was conducted at the intersection of research domains such as education and human-robot interaction and added diverse contributions in the field of fundamentals in education, pedagogic sciences, interaction design and social robotics. As a researcher, my vision is to integrate social robots into people's lives that can interact successfully and respond appropriately in real-world settings, and capable of sustaining long-term autonomous interactions.

Education

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- Thesis - Learning How to Write with a Robot (*Passed with Distinction*)

Indian Institute of Information Technology — *Allahabad, U.P., India*

MASTERS OF TECHNOLOGY IN ROBOTICS (INFORMATION TECHNOLOGY) — *2010-2012*

- Thesis - Development of Omni Directional Ankle Strategy for Humanoid Push Recovery based on Interpolation (*Passed with Distinction* | CGPA - 9.3)

K.N.G.D Modi Engineering College — *Modi Nagar, Ghaziabad, India*

BACHELORS OF TECHNOLOGY IN COMPUTER SCIENCE AND ENGINEERING — *2005-2009*

- (*Passed with First Division* | CGPA - 7.8)

Teaching Experience

École Polytechnique Fédérale de Lausanne (School of Computer and Communication Sciences,). — *Lausanne, Switzerland*

TEACHING ASSISTANT — *2013-2015*

- B-tech Course- Programming I for C++ (Fall 2013)
- B-tech Course- Programming II for C++ (Fall 2014)

Publications

Journals

- **Chandra, S.**, Dillenbourg, P., & Paiva, A. "Children Teach Handwriting to a Social Robot with Different Learning Competencies" Behavior Adaptation, Interaction and Artificial Perception for Assistive Robotics" on The International Journal of Social Robotics. (*2018, under submission*))

Conference Proceedings

- **Chandra, S.**, Paradeda, R., Yin, H., Dillenbourg, P., Prada, R., & Paiva, A. "Do Children Perceive Whether a Robotic Peer is Learning or Not?" In Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction (pp. 41-49). ACM. (*2018, Chicago, USA.*)

- **Chandra, S.**, Dillenbourg, P., & Paiva, A. "Classification of Children's Handwriting errors for the Design of an Educational Co-writer Robotic Peer" in the proceedings of Interaction Design and children. (*2017, Callifornia, USA.*)

- **Chandra, S.**, Paradeda, R., Yin, H., Dillenbourg, P., Prada, R., & Paiva, A. "Affect of Robot's Competencies on Children's Perception" in the proceedings of International Conference on Autonomous Agents and Multiagent Systems. (*2017, California, USA.*)

- **Chandra, S.**, Dillenbourg, P., & Paiva, A. "Developing Learning Scenarios to Foster Children's Handwriting Skills with the Help of Social Robots." Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction. ACM, 2017. (*2017, Callifornia, USA.*)

- **Chandra, S.**, Alves-Oliveira, P., Lemaignan, S., Sequeira, P., Paiva, A., & Dillenbourg, P. "Children's peer assessment and self-disclosure in the presence of an educational robot." Robot and Human Interactive Communication (RO-MAN), 2016 25th IEEE International Symposium on. IEEE, 2016. (*2016, Kobe, japan.*)

- **Chandra, S.**, Alves-Oliveira, P., Lemaignan, S., Sequeira, P., Paiva, A., & Dillenbourg, P. "Can a child feel responsible for another in the presence of a robot in a collaborative learning activity?." Robot and Human Interactive Communication (RO-MAN), 2015 24th IEEE International Symposium on. IEEE, 2015. (*2016, Kobe, japan.*)

- Akash, A., **Chandra, S.**, Abha, A., & Nandi, G. C "Modeling a bipedal humanoid robot using inverted pendulum towards push recovery." Communication, Information & Computing Technology (ICCICT), 2012 International Conference on. IEEE, 2012. (*2016, Kobe, japan.*)

Workshop Papers

- **Chandra, S.**, Paradeda, R., Yin, H., Dillenbourg, P., Prada, R., & Paiva, A. "Children's Perceptions of a Learner-Robot"Workshop on Robots for Learning-R4L: Inclusive Learning in the conference of Human-Robot Interaction (HRI).(*2016, Kobe, japan.*)

- **Chandra, S.**, Dillenbourg, P., & Paiva, A. "Approaches and Challenges in Designing Educational Activities for Children with a Human/Robot Facilitator", Workshop on analysing children's contributions and experiences in co-design activities in the conference of Interaction Design and children (IDC). (*2016, Kobe, japan.*)

Posters

- **Chandra, S.**, Dillenbourg, P., & Lemaignan, S. "CoWriter: When Children Teach Robots How to Write", NCCR Robotics Site Visit 2013, 20-22nd November 2013, Lausanne, Switzerland.(*2013, Lausanne, Switzerland.*)

- **Chandra, S.**, Chandra, S., Dillenbourg, P., & Paiva, A. "Co-Writer: Learn to write with a Robot", PhD Open Days, 2nd edition 16-17th May 2016, Lisbon, Portugal. (*2016, Lisbon, Portugal.*)

- **Chandra, S.**, Dillenbourg, P., & Paiva, A. "Developing Learning Scenarios to Foster Children's Handwriting Skills with the Help of Social Robots.", HRI Pioneer Workshop, 6-9th March 2017, Lisbon,Portugal(*2017, Lisbon, Portugal.*)

Volunteer experience & Appreciations

2018	**Volunteer**, In the HRI conference	*Chicago, U.S.A*
2017	**Appreciation as a Pioneer**, in the HRI conference.	*Austria, Vienna*
2017	**Volunteer**, In the HRI conference.	*Viennna, Austria*
2017	**Volunteer**, In the IDC conference.	*California, USA*
2013, 2014	**Volunteer**, In the NCCR.	*Lausanne, Switzerland*
2011	**Volunteer**, In the IITM.	*Allahabad, India*
2011, 2012	**Volunteer**, in 3rd and 4th Science Conclave held at IIIT.	*Allahabad, India*
2011, 2012	**Appreciated as an Active Volunteer**, in 3rd and 4th Science Conclave held at IIIT.	*Allahabad, India*

Other Academic Activities

- Member of NCCR robotics, Swiss research network *(since 2013)*.
- Reviewer in International Journal of Child-Computer Interaction *(since 2016)*
- Student member IEEE *(2013-2015)*.

Fundings

- Funding from Instituto Superior Tecnico (INESC-ID, GAIPS) for the PhD program *(2017-2018)*.
- HRI Pioneer funding *(2017)*.
- Funding from 'Human-robot Interaction' conference to present research work. *(2017, 2018)*.
- Funding from 'Interaction Design for Children' conference to present research work. *(2017)*.
- FCT (Fundação para a Ciência e a Tecnologia, Portugal) provided fully-funded scholarship to develop the PhD research in École Polytechnique Fédérale De Lausanne and Instituto Superior Tecnico. *(2013-2017)*.
- EPFL (École polytechnique fédérale de Lausanne, Switzerland) provided fully-funded scholarship to develop the P.hD. research in EPFL, Lausanne, Switzerland. *(2013-2015)*.
- MHRD (Ministry of Human Resources Development) provided fully-funded scholarship for the Masters program which is given to only high-achiever students who pass a national exam called GATE. *(2010-2012)*.

Other Trainings

Summer School — *Olten, Switzerland*

LEARNING TECHNOLOGIES AND COMPUTER SUPPORTED COLLABORATIVE LEARNING. — *22-25 June 2014*

- Topics- Social robotics, Human-robot interaction, Interaction design, Co-creation.

Alentejo, Portugal

3RD SUMMER SCHOOL ON SOCIAL HUMAN-ROBOT INTERACTION. — *4-8 September 2017*

- Topics - Learning technologies, Collaborative Learning, Media Psychology.

Skills

Languages

- Native Proficiency in Hindi and Urdu.
- Full Professional Proficiency in English.
- Elementary Proficiency in French and Portuguese.

Operating System

- Linux (Ubuntu), Windows, Mac OS.

Software

- Matlab, LaTeX, ELAN, Webots, SPSS.
- Moderate in ROS and R
- Proficient in Python, C, C#.
- Skilled in Python application development.
- Moderate in Android application development.

Interests

Professional

- Social robotics, Long-term human-robot interaction, Autonomus robots, Psychology, Interaction Design, Pedagogy, Education, Artificial Intelligence, Machine Learning.

Hobbies

- Sports - Badminton, Table Tennis, Skiing, Chess.
- Dances - Stage performances: Indian folk and classical dances, hip-hop, contemporary.
- Arts & Design - Sketching, painting, writing poetries, handicrafts, photography, interior decoration.
- Inner Wellbeing - Yoga, meditation, Ayurveda.

Referees

- **Prof. Pierre Dillenbourg**: Head of 'Computer Human Interaction in Learning and Instruction' lab, École Polytechnique Fédérale de Lausanne, email: pierre.dillenbourg@epfl.ch., phone: (+41) 21 69 32071.
- **Prof. Ana Paiva**: Head of 'GAIPS - Intelligent Agents and Synthetic Characters' lab, Instituto Superior Técnico, INESC-ID, email:Ana.Paiva@inesc-id.pt, phone: (+351) 214 233 223.
- **Prof. G.C. Nandi**: Head of 'Robotics' Lab, Indian Institute of Information Technology, Allahabad, India. email:gcnandi@iiita.ac.in, phone: (+91) 0532 292 2058.

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