Modelling communicative behaviours for different roles of pedagogical agents

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Résumé Long

Les agents dans un environnement d'apprentissage peuvent avoir divers rôles et comportements sociaux qui peuvent influencer les objectifs et la motivation des apprenants de différentes manières. L'apprentissage autorégulé (SRL) est un cadre conceptuel complet qui englobe les aspects cognitifs, métacognitifs, comportementaux, motivationnels et affectifs de l'apprentissage et implique les processus de définition d'objectifs, de suivi des progrès, d'analyse des commentaires, d'ajustement des objectifs et des actions de l'apprenant. Dans cette thèse, nous présentons une interaction d'apprentissage multi-agent impliquant divers rôles d'agent pédagogique visant à améliorer l'autorégulation de l'apprenant tout en s'engageant dans une activité socialement partagée. Nous avons utilisé des rôles distincts d'agents, définis par leurs attitudes sociales et leurs compétences, pour proposer des stratégies d'échafaudage de régulation spécifiques à l'apprenant. La méthodologie suivie dans cette thèse a commencé par la définition de rôles d'agent pédagogique dans un contexte de régulation socialement partagé et le développement d'une tâche d'apprentissage collaboratif pour faciliter l'interaction d'apprentissage en se concentrant sur l'autorégulation.

Sur la base du cadre des tâches d'apprentissage, nous avons proposé une interaction d'apprentissage partagé composée d'un agent tuteur fournissant un support de régulation externe axé sur les performances de l'apprenant et d'un agent pair démontrant des stratégies de corégulation pour promouvoir l'autorégulation chez l'apprenant. Une série d'études d'utilisateurs a été menée pour comprendre les perceptions des apprenants sur les rôles des agents, les comportements associés et la tâche d'apprentissage. Les résultats des études initiales suggèrent l'efficacité de la configuration d'interaction nouvellement proposée dans la promotion de la régulation ainsi qu'une perception positive des comportements des agents et des stratégies de régulation associées. Pour améliorer les perceptions du rôle des apprenants, en particulier en ce qui concerne la compétence d'agent, nous avons introduit des comportements d'erreur chez l'agent pair dans nos études ultérieures. Dans les études d'utilisateurs ultérieures, nous avons examiné des modes de régulation distincts en se concentrant respectivement sur la performance et la régulation de l'apprenant et avons trouvé des différences dans la façon dont chaque agent influence les objectifs de performance et d'autorégulation de l'apprenant. Dans l'ensemble, les travaux présentés dans cette thèse explorent comment divers rôles d'agents peuvent être utilisés pour fournir un échafaudage de régulation aux apprenants dans un contexte d'apprentissage socialement partagé.

Introduction

L'apprentissage autorégulé (SRL) a été identifié comme un cadre conceptuel complet qui englobe les aspects cognitifs, métacognitifs, comportementaux, motivationnels et affectifs de l'apprentissage Panadero (2017). La régulation de l'apprentissage Allal (2020) implique les processus d'établissement d'objectifs, de suivi des progrès, d'analyse des commentaires, d'ajustement des actions dirigées vers un objectif et/ou de la définition de l'objectif. L'apprentissage régulé peut être de quatre types, décrits comme suit :

- Apprentissage auto-régulé (SRL), où un étudiant utilise l'auto-évaluation, l'établissement d'objectifs et la sélection et le déploiement de stratégies d'apprentissage pour atteindre l'objectif d'apprentissage.
- Apprentissage régulé de manière externe (ERL), qui implique une entité externe incitant un apprenant individuel à déployer des processus SRL clés au cours de son apprentissage, ce qui peut, à son tour, améliorer son SRL.
- L'apprentissage co-régulé (CoRL), implique un apprenant pair qui se soutient et s'influence mutuellement sur la régulation de l'apprentissage, généralement de manière interdépendante et réciproque.
- Apprentissage régulé socialement partagé (SSRL), qui implique que plusieurs apprenants se régulent en tant qu'unité collective, en utilisant la recherche de consensus et la négociation pour co-construire et prendre des décisions concernant les objectifs, les définitions, les croyances, les stratégies et les connaissances des tâches du groupe.

Dans le contexte de l'apprentissage collaboratif, la régulation socialement partagée est devenue pertinente car elle considère les processus de régulation impliqués dans plusieurs partenaires d'apprentissage dans le même environnement d'apprentissage. Le modèle de régulation socialement partagé de la régulation de l'apprentissage Hadwin et al. (2011), combine les théories fondamentales de l'autorégulation, qui étaient principalement centrées sur les processus individuels, avec les aspects sociaux et interactifs de l'apprentissage collaboratif.

Agents conversationnels incarnés

Les agents conversationnels incarnés (ECA) sont des personnages animés générés par ordinateur avec une apparence anthropomorphe capables de communiquer naturellement avec les utilisateurs Pelachaud (2005). Selon le paradigme Computers as Social Actors (CASA), les humains considèrent les ordinateurs comme des entités sociales et traitent les médias et les ordinateurs comme de vraies personnes appliquant des scripts pour interagir avec les humains tout en s'engageant avec les technologies sociales (Nass and Moon (2000); Reeves and Nass (1996)). L'accent mis sur les relations socio-émotionnelles dans le domaine de l'interaction homme-machine découle des travaux sur les interfaces multimodales naturelles telles que les agents conversationnels incarnés et les robots sociaux (Cassell (2001); Breazeal (2002)). Les agents pédagogiques peuvent être définis comme des partenaires d'apprentissage artificiels intelligents (simples ou multiples) qui peuvent soutenir l'apprentissage de l'élève et utiliser diverses stratégies dans un environnement d'apprentissage interactif Martha and Santoso (2019). Les agents pédagogiques sous la forme de personnages virtuels ou d'incarnations robotiques ont montré un potentiel d'impact sur la motivation, l'engagement et les performances des apprenants à travers diverses études et interactions. Lusk and Atkinson (2007) déclare que « les agents peuvent enrichir et élargir la relation de communication entre les apprenants et les ordinateurs ainsi que fournir des fonctionnalités pédagogiques motivantes et affectives qui engagent activement les élèves ». On observe souvent que les apprenants développent des associations sociales et émotionnelles avec les agents qui influencent leur sens des responsabilités, leur motivation et leurs perceptions de l'activité (Liew et al. (2017) ; Gulz and Haake (2005) ; Krämer and Bente (2010)). Des études ont montré que le fait d'avoir plusieurs agents (virtuels/physiques) jouant des rôles différents (par exemple, tuteur, mentor, camarade de classe, assistant) améliore l'apprentissage et la motivation des étudiants (Baylor (2003b) ; Kim and Wei (2011)). Chaque type d'agent apporte une expertise, crée une relation sociale unique avec les apprenants. Selon leur rôle, les agents ont des objectifs et des croyances spécifiques ainsi que des attitudes envers les apprenants. L'autorégulation d'un apprenant peut être soutenue par des rôles pédagogiques et des types distincts de comportements de régulation présentés par les agents. Pour résumer, dans cette thèse de recherche, nous visons à développer une interaction d'apprentissage multi-agents impliquant différents rôles pédagogiques dans un contexte d'apprentissage socialement partagé, en mettant l'accent sur l'aspect de la promotion de l'autorégulation chez l'apprenant.

ANIMATAS-ITN : Le travail présenté dans cette thèse fait partie d'ANIMATAS, qui est un réseau de formation innovante Marie Skłodowska-Curie Actions (MSCA ITN) financé par le programme de recherche et d'innovation Horizon 2020 de l'Union européenne. Le projet vise à explorer la perception des robots et des agents virtuels dans le contexte de l'apprentissage, à développer de nouveaux mécanismes d'apprentissage et à promouvoir l'adaptation personnalisée à l'apprenant humain dans des interactions d'apprentissage social en évolution dynamique. Nos contributions au projet dans ce contexte de recherche concernaient les aspects de l'incarnation de l'agent et de l'adaptation de l'apprentissage social en développant une interaction d'apprentissage partagé avec plusieurs agents pédagogiques et en menant des études d'utilisateurs pour comprendre l'influence sur les perceptions des agents, les compétences d'apprentissage et d'autorégulation du apprenant.

Questions de recherche

La littérature existante sur les agents pédagogiques s'est principalement concentrée sur les aspects cognitifs, motivationnels et affectifs de l'apprentissage et impliquait généralement des apprenants interagissant avec un seul agent pédagogique assistant l'apprenant (Panadero (2017); Baylor and Kim (2005)). La régulation socialement partagée dans l'apprentissage (SSRL) Järvelä and Järvenoja (2011) présente un scénario dans lequel plusieurs agents peuvent être introduits dans divers rôles d'agent pédagogique pour s'engager avec l'apprenant et lui proposer des stratégies de régulation distinctes. La motivation du travail présenté dans cette thèse était d'explorer l'aspect de l'apprentissage autorégulé dans un contexte d'interaction d'apprentissage partagé en utilisant des agents conversationnels incarnés dans différents rôles pédagogiques pour fournir un soutien de régulation et de corégulation externe à l'apprenant. Dans notre recherche, nous avons exploité la plateforme Greta/VIB Pecune et al. (2014) pour la génération et l'animation en temps réel des comportements verbaux et non verbaux de l'ECA. La plate-forme GRETA est basée sur le cadre SAIBA, qui est un cadre commun pour la création de comportements de communication multimodaux et d'états émotionnels dans les ECA. En particulier, nous nous sommes concentrés sur l'aspect de l'échafaudage de l'autorégulation chez les apprenants et abordons les questions de recherche suivantes :

- **RQ1** : l'engagement dans une interaction d'apprentissage partagé avec plusieurs agents pédagogiques fournissant des stratégies de régulation distinctes améliore-t-il les compétences d'autorégulation de l'apprenant ?
- **RQ2** : les différents rôles des agents influencent-ils différemment l'autorégulation et l'apprentissage de l'apprenant ?

Pour aborder **RQ1** et **RQ2**, nous avons commencé par concevoir une interaction d'apprentissage partagé basée sur une tâche d'apprentissage collaboratif impliquant des agents pédagogiques dans les rôles de tuteur et de pair et en menant des études perceptives pour comprendre les perceptions des apprenants sur les rôles d'agent, les comportements de régulation associés et l'activité d'apprentissage. Nous avons défini les rôles et comportements multimodaux du pédagogue.

Rôles des agents

Les relations sociales émergentes entre les partenaires d'apprentissage à travers l'échange d'informations, la construction conjointe d'objectifs d'apprentissage et les interactions verbales et non verbales jouent un rôle décisif dans un environnement d'apprentissage Alonso et al. (2015). Selon Haythornthwaite (2001), l'apprentissage peut être décrit comme une relation sociale à travers laquelle les apprenants échangent, partagent, fournissent et reçoivent différentes expériences de construction de connaissances individuelles et collectives. Dans une interaction d'apprentissage impliquant des agents pédagogiques, les croyances et les attitudes liées aux relations sociales peuvent différer en fonction des rôles joués ou assumés par l'agent. Par exemple, Baylor and Kim (2005) a présenté trois agents pédagogiques jouant différents rôles de motivateur, d'expert et de mentor caractérisés par une apparence, une animation, une voix et des caractéristiques affectives distinctes. Une étude sur la perception des rôles et l'impact de ces rôles a révélé que les agents de motivation (Motivator et Mentor) favorisaient plus d'auto-efficacité et d'engagement chez les apprenants tandis que les agents d'information (Expert et Mentor) ont amélioré les performances de transfert que l'agent de motivation. Dans l'ensemble, l'agent mentor qui combinait à la fois l'information et le soutien motivationnel s'est avéré bénéfique pour la motivation et la performance dans les groupes d'apprentissage. Dans d'autres études basées sur l'effet de personnalité divisé, Baylor and Ebbers (2003) a comparé un seul agent mentor (motivation + information) à deux agents distincts (expert et motivateur) en fonction de la fonctionnalité, observant un meilleur apprentissage dans la condition à deux agents. Ce résultat a été attribué à la théorie de la charge cognitive, qui suggère que la présence de deux agents avec des caractéristiques distinctes pourrait permettre à l'apprenant d'attribuer plus facilement les réponses et les comportements associés à un agent, réduisant ainsi la charge cognitive impliquée dans le processus. En outre, l'interactivité collaborative accrue aurait pu entraîner l'activation d'une meilleure agence chez l'apprenant. Ces observations suggèrent l'avantage de rôles distincts et de comportements associés dans l'orchestration des interactions d'apprentissage dans divers contextes.

Les théories de l'apprentissage basées sur des environnements d'apprentissage ouverts basés sur la découverte et le tutorat assisté par les pairs Topping and Ehly (1998) et l'enseignement réciproque Rosenshine and Meister (1994) ont conduit au développement de représentations d'agents semblables aux pairs tels que les agents enseignables et les agents co-apprenants citepareto2012teachable. En tant que partenaires d'apprentissage actifs ou passifs, les rôles de pairs des agents peuvent réduire l'anxiété de l'apprenant et accompagner l'apprenant dans l'apprentissage grâce à des comportements plus amicaux et moins intrusifs par rapport aux rôles manifestes d'instructeur Chase et al. (2009). La mise en œuvre d'agents pédagogiques en tant que compagnons d'apprentissage (PAL) Kim et al. (2006) a exploré l'aspect de l'agence dans l'apprentissage à travers divers niveaux de comportements des pairs. Les agents en tant que pairs passifs dans un environnement peuvent améliorer l'agence personnelle qui implique le contrôle et la régulation de la tâche d'apprentissage. L'agence par procuration est une forme d'agence à médiation sociale, qui permet aux gens d'obtenir des ressources des autres pour atteindre leurs objectifs. Des agents pairs actifs qui transmettent des connaissances et des compétences pourraient augmenter les effets de modélisation en partageant des attributs similaires avec l'apprenant Kim et al. (2007). Les pairs agents en tant que partenaires d'apprentissage collaboratif peuvent promouvoir l'agence collective qui est un prédicat de l'action de groupe. Kim (2013) a mis en œuvre un agent de pair virtuel dans une leçon de lecture en ligne pour promouvoir la compréhension et les perceptions du texte et a observé que les apprenants qui ont interagi avec le pair virtuel ont obtenu de meilleurs résultats que ceux qui n'ont reçu qu'un support de contenu. Le projet Co-Writer Chandra et al. (2018) a utilisé l'idée d'"apprendre en enseignant" pour enseigner l'écriture manuscrite à un robot Nao où le robot assumait le rôle d'un novice. Les résultats de l'étude ont indiqué que les apprenants étaient indulgents avec les erreurs du robot et prenaient souvent l'initiative de fournir des commentaires au pair Johal et al. (2016). En comparant les effets des agents de type expert et de type pair sur les perceptions des apprenants, les attitudes et les performances liées aux tâches, Liew et al. (2013) a observé que les apprenants accordent une plus grande confiance aux informations fournies par l'agent de type expert alors qu'ils associent une plus grande intérêt pour l'activité avec un agent de type pair.

La conception et la définition des rôles des agents sont cruciales, en particulier dans les environnements d'apprentissage multi-agents, car les attentes de l'apprenant doivent correspondre aux fonctionnalités de l'agent Sunal et al. (2003). Par exemple, Yadollahi et al. (2018) a observé que les gestes déictiques d'un agent pair robot dans une tâche de lecture distrayaient les enfants ayant un faible niveau de lecture, les empêchant de comprendre le texte et les erreurs pendant l'activité. Chen et al. (2020) a expérimenté la commutation adaptative des rôles de tuteur et de tuteur dans une activité collaborative d'apprentissage des mots et a trouvé une amélioration de l'acquisition du vocabulaire lors de la session d'instruction du tuteur et un engagement affectif plus élevé lié aux sessions de tuteur (figure **??**). L'appropriation des rôles d'agent dépend donc fortement du contexte d'apprentissage et des objectifs de l'apprenant. Un agent expert conviendrait pour introduire un nouveau sujet d'apprentissage ou démontrer une nouvelle procédure dans un domaine d'apprentissage bien défini. L'agent de motivation peut être plus efficace dans les environnements d'apprentissage constructivistes où la motivation et l'intérêt de l'apprenant sont importants. Un agent de mentorat pourrait être idéal lorsqu'un soutien de motivation et d'information est requis pour l'apprenant. Les agents semblables peuvent être efficaces pour activer les processus de suivi et de planification chez l'apprenant, ce qui peut améliorer l'agence et la régulation de l'apprentissage. Cela souligne la nécessité d'une définition et d'une distinction claires entre les rôles des agents et leurs comportements associés dans le contexte de la régulation pour une orchestration efficace des systèmes d'apprentissage multi-agents.

Travail connexe

Par rapport au nombre d'études et de systèmes basés sur des interventions d'apprentissage basées sur des agents pédagogiques, les explorations axées sur l'aspect d'apprentissage métacognitif de l'apprentissage autorégulé sont considérablement moins nombreuses. Les travaux existants qui ont utilisé des agents pédagogiques pour promouvoir l'autorégulation chez les apprenants diffèrent grandement dans la caractérisation et la mise en œuvre des agents ainsi que dans le cadre théorique de l'autorégulation sur lequel ils sont fondés. Les systèmes basés sur SRL tels que Metatutor Azevedo et al. (2009) et Betty's Brain (Leelawong and Biswas (2008); Biswas et al. (2010)) avaient des agents animés 2D intégrés dans l'environnement d'apprentissage tandis que certaines études utilisaient des robots sociaux comme partenaires d'apprentissage favorisant l'autorégulation citejones2018know ; Vrochidou et al. (2018). De nombreuses études de ce type ont également limité les agents pédagogiques à leur présence dans l'environnement Mudrick et al. (2014) et à un engagement non réciproque dans les processus réglementaires qui reposaient principalement sur la fourniture d'incitations et de commentaires pendant l'apprentissage. Cela a souvent abouti à une réglementation inégalement répartie qui est loin des interactions d'apprentissage qui se produisent dans des scénarios du monde réel tels que les groupes d'apprentissage et les salles de classe Bransen et al. (2021). De plus, les modèles de SRL qui soutiennent ces systèmes varient dans leurs hypothèses sur l'apprenant ainsi que dans les approches de la progression de l'apprentissage Boekaerts and Niemivirta (2000). Les systèmes SRL basés sur une approche descendante ou un parcours de croissance considèrent les objectifs d'apprentissage comme plus pertinents pour les étudiants et mettent davantage l'accent sur les croyances personnelles et les processus mentaux de l'apprenant. L'approche ascendante ou les systèmes basés sur le cheminement du bien-être ont été comportementaux et se sont davantage appuyés sur les actions et l'environnement pour promouvoir la régulation dans laquelle les élèves activent leurs objectifs pour protéger leur concept de soi et leurs croyances motivationnelles.

Une autre distinction entre les systèmes existants de SRL concerne la manière dont ils conçoivent les actions et les réponses de l'apprenant en fonction de ses connaissances et compétences antérieures. Selon Zimmerman and Kitsantas (2005), il est nécessaire d'avoir des processus cognitifs, motivationnels et émotionnels qui sont devenus un modèle de réponse automatique afin que les apprenants puissent activement employer des stratégies de régulation avec moins de charge cognitive. Cela inclut des processus tels que l'accès aux connaissances antérieures, l'activation des objectifs, la réflexion, la régulation émotionnelle, etc. Les systèmes SRL tels que Betty's Brain ont utilisé le tutorat assisté par les pairs Topping and Ehly (1998) et l'enseignement réciproque Rosenshine and Meister (1994) en supposant que l'apprenant s'autorégulant ainsi que les partenaires d'apprentissage pendant l'interaction, tandis que les systèmes d'invite et de rétroaction SRL comme Bouchet et al. (2013) et Harley et al. (2017) reposaient sur des agents déclenchant et médiateurs des processus de régulation.

Les principaux défis de la recherche concernant l'utilisation d'agents pédagogiques dans la promotion de l'autorégulation sont liés au rôle de l'environnement d'apprentissage, aux caractéristiques des agents, à la mesure et à l'interprétation des résultats métacognitifs des interactions. En ce qui concerne l'environnement d'apprentissage, la portée des processus réglementaires peut aller d'une focalisation individuelle à des groupes socialement influencés tels que des équipes collaboratives et des salles de classe. Boekaerts and Niemivirta (2000) indique que l'interprétation du contexte par l'apprenant active différentes voies d'objectifs qui peuvent influencer les rôles qu'ils adoptent au cours du processus d'apprentissage. Par exemple, l'apprentissage autorégulé se concentre sur le moi et les processus individuels impliqués dans la régulation de l'apprentissage et de la performance. L'apprentissage co-régulé met l'accent sur l'interaction entre l'apprenant et le contexte qui implique une médiation émotionnelle, motivationnelle, cognitive et métacognitive à travers des interactions sociales avec les autres dans l'environnement. Selon les rôles assignés à ces partenaires d'apprentissage et ses conceptions par l'apprenant, un spectre de relations hiérarchiques est possible dans une interaction d'apprentissage à travers divers rôles tels que pair, mentor, tuteur, etc. Une régulation socialement partagée de l'apprentissage émerge lorsque des groupes d'apprenants régulent leur apprentissage collaboratif, orienté vers des objectifs construits conjointement pour l'équipe dans le contexte. Par conséquent, parallèlement à l'étude de l'impact des caractéristiques pédagogiques des agents sur les résultats d'apprentissage, il devient important d'examiner les interactions agent-apprenant dans divers contextes d'environnements et leurs influences sociales potentielles sur le comportement d'autorégulation.

Les caractéristiques de l'agent pédagogique telles que l'incarnation, le réalisme, les rôles et comportements pédagogiques peuvent avoir un impact significatif sur les résultats d'apprentissage et de motivation Baylor and Kim (2004). Une revue Heidig and Clarebout (2011) sur l'impact de la conception d'agents pédagogiques et des fonctions associées sur les résultats d'apprentissage et la motivation a présenté des résultats mitigés mentionnant des cas avec des avantages ainsi que des obstacles à l'apprentissage. Les différences dans la conception, ainsi que les fonctions des agents allant de la tête parlante animée Moundridou and Virvou (2002) aux robots humanoïdes Mubin et al. (2013b) et relativement moins d'études axées sur les aspects métacognitifs de l'apprentissage et la motivation dans l'apprentissage le rendent difficile de tirer une conclusion sur les caractéristiques effectives requises pour un agent pédagogique. Par conséquent, il reste difficile de concevoir les fonctionnalités de l'agent et d'étendre leurs représentations à des formes telles que des personnages 3D animés, des robots sociaux, etc. Compte tenu des représentations d'agent 2D minimales utilisées dans les systèmes SRL existants, il existe une grande possibilité d'expérimentation avec des animations virtuelles. personnages et robots dans divers rôles de partenaires d'apprentissage.

Un autre défi clé dans le domaine de l'apprentissage autorégulé est la difficulté de quantifier les résultats de l'apprentissage et de la régulation grâce à des outils de mesure fiables Panadero et al. (2018). Un certain nombre de méthodes d'évaluation telles que les protocoles de réflexion à haute voix Greene et al. (2011), les questionnaires d'auto-évaluation, les entretiens structurés Andrade and Dugan (2011) qui reposent fortement sur le point de vue de l'apprenant ont dominé la recherche et l'analyse concernant l'apprentissage autorégulé jusqu'à ce que les mesures en ligne basées sur l'activité et la performance de l'apprenant ont émergé. Cela a également déplacé la conceptualisation de la SRL d'une perspective basée sur les traits à une perspective basée sur les processus permettant une analyse séquentielle et temporelle des modèles d'apprentissage et de régulation pour l'évaluation Panadero et al. (2016). La mesure en ligne permet également de réduire l'impact de l'évaluation sur le SRL de l'apprenant et de définir plus concrètement les traces d'activité favorisant l'apprentissage et les observations comportementales de l'apprenant. La réactivité de l'apprenant, qui se définit comme les changements qui surviennent dans le comportement d'un individu du fait d'un suivi métacognitif, rend compte de l'impact de la mesure du SRL sur la régulation elle-même. Ainsi, les instruments de mesure du SRL se traduisent souvent par des interventions provoquant un effet de réactivité à partir d'auto-observations. Cela peut être considéré comme un défi ainsi qu'une opportunité de chevauchement des phases d'intervention et de mesure au cours de l'apprentissage. L'émergence du tutorat et de l'échafaudage informatisés a élargi le champ de la conception d'outils qui sont des méthodes hybrides mesure-intervention capables de promouvoir la SRL. Les outils SRL tels que Radar, OurPlanner et OurEvaluator Panadero et al. (2013) ont tiré parti de cet aspect pour permettre à un groupe d'apprenants de refléter l'état cognitif, métacognitif et émotionnel de leurs collègues apprenants et de construire conjointement des objectifs liés aux tâches dans le contexte d'une régulation socialement partagée de l'apprentissage. La présence d'agents pédagogiques peut aider à atteindre un meilleur rassemblement informel des conceptions de soi de l'apprenant grâce à des interactions basées sur le dialogue et des signaux non verbaux permettant une interaction d'apprentissage naturelle qui minimise l'effet de réactivité.

GRETA VIB

GRETA-VIB est une plate-forme permettant de visualiser les agents conversationnels incarnés (ECA) et leur génération et animation en temps réel de comportements verbaux et non verbaux Pecune et al. (2014). La plate-forme GRETA est basée sur le cadre SAIBA, qui est un cadre commun pour la création de comportements de communication multimodaux et d'états émotionnels dans les ECA. L'architecture GRETA permet de spécifier la fonction communicative et le comportement communicatif associé à deux niveaux d'abstraction. Le niveau fonctionnel dénote l'intention de l'agent et le niveau comportemental détermine comment l'agent communiquera en instanciant l'intention à travers la réalisation multimodale de gestes, de paroles, d'expressions faciales, etc.

L'architecture GRETA implique différents niveaux de génération de comportements, mis en œuvre à travers trois modules principaux qui sont :

- Intent Planner : il s'agit d'un module de haut niveau qui gère les intentions de communication de l'agent telles que les objectifs, les croyances, les états émotionnels, etc. Les intentions de l'agent sont codées dans des fichiers Functional Markup Language (FML) et peuvent contenir une séquence des actes de dialogue tels que poser une question, donner son avis, etc. Par exemple, un fichier FML contenant le dialogue : "Bonjour, je m'appelle Camille. Comment t'appelles-tu ?" associe les intentions communicatives d'emphase (*accent de hauteur*), de marqueur de question (ton limite), de salutation et de questionnement (performatif), pour générer le comportement de l'agent.

- Behavior Planner : ce module traduit les intentions de communication reçues du module de planification d'intentions en fonctionnalités multimodales telles que les expressions faciales, les gestes, les poses, etc. et sont encodées dans des fichiers Behavior Markup Language (BML). Par exemple, l'intention communicative de '*greet*' peut être exprimée à travers une expression faciale de sourire avec des sourcils levés, un regard direct, un geste de salutation défini dans un ensemble de comportements non verbaux appelés '*behaviour set* '. Le module de planification du comportement sélectionne les signaux multimodaux pertinents pour chaque balise BML en fonction des intentions de l'agent.

- Behavior Realizer : ce module produit les animations pour le visage, les lèvres et le corps de l'agent qui sont alignés avec l'audio de la parole généré à partir des descriptions BML données par le module de planification du comportement. Les gestes impliquent une combinaison de diverses trajectoires de mouvement de la main avec des paramètres expressifs variables tels que la spatialité, la temporalité, l'ouverture, etc. Les expressions faciales sont réalisées grâce à des animations de traits du visage tels que les mouvements des yeux et de la bouche, sur la base des paramètres d'animation faciale (FAP) Pandzic and Forchheimer (2003) qui décrivent les unités d'action faciale liées à divers états émotionnels de l'agent.

Interaction d'apprentissage triadique pour SSRL

La régulation socialement partagée de l'apprentissage se produit lorsqu'un groupe d'apprenants régule ensemble en tant que collectif en construisant des perceptions de tâches et des objectifs partagés et en prenant des décisions par le biais d'interactions collaboratives. Cette régulation partagée de l'apprentissage peut impliquer divers types distincts d'échafaudages de régulation tels que : (i) Régulation externe : facilitée par des partenaires d'apprentissage plus capables ou mieux informés tels qu'un expert ou un tuteur fournissant des instructions, des retours ou des stratégies d'incitation qui peuvent améliorer la régulation de l'apprenant ou (ii) Co-régulation : lorsqu'un pair apprenant influence les comportements de régulation de l'apprenant par le biais d'objectifs et de décisions construits conjointement. Les agents pédagogiques artificiels ont un grand potentiel pour être utilisés pour des interactions d'apprentissage avec des objectifs et des comportements de régulation spécifiques. Selon le cadre dimensionnel proposé pour les rôles d'agent pédagogique au chapitre 3, les agents dans un contexte d'apprentissage partagé peuvent avoir divers rôles et attitudes sociaux distincts qui influencent l'autorégulation d'un apprenant de différentes manières. À ce jour, les interactions d'apprentissage multi-agents impliquant différents rôles d'agents pédagogiques dans un contexte SSRL restent largement inexplorées Panadero (2017), et dans cette recherche, nous visons à saisir cette opportunité pour orchestrer des interactions de régulation partagées avec des agents de divers rôles et la régulation associée stratégies d'échafaudage.

En général, une interaction d'apprentissage avec un ou plusieurs agents pédagogiques dans un contexte de régulation socialement partagée peut être décomposée en trois éléments qui sont (i) un apprenant humain, (ii) un ou des partenaires d'apprentissage d'agents pédagogiques et (iii) un apprentissage collaboratif. activité. Pour notre recherche, nous concevons l'interaction d'apprentissage partagé avec deux agents pédagogiques, où un agent assume le rôle d'un autre mieux informé (MKO) fournissant un soutien de régulation externe et l'autre est présenté dans le rôle d'un pair apprenant facilitant les fonctions de corégulation. . Sur la base du cadre dimensionnel des rôles pédagogiques dans le contexte de la SSRL, nous avons opérationnalisé les rôles de tuteur et de pair collaborateur pour représenter respectivement des sources de régulation externe et de corégulation. Par conséquent, l'interaction d'apprentissage proposée impliquerait un apprenant humain et deux agents ayant des comportements de régulation distincts s'engageant dans une tâche d'apprentissage collaboratif.

Agent tuteur : le rôle du tuteur est opérationnalisé à travers des comportements tels que l'instruction de stratégies de régulation, la livraison explicite de connaissances à travers des astuces, des suggestions, etc. et affiche des niveaux modérés de dominance et de convivialité envers les partenaires d'apprentissage. L'agent tuteur se caractérise également par un discours expressif, informel et informatif, des gestes déictiques et ouverts, des dialogues sociaux ainsi que des dialogues axés sur les tâches visant à améliorer les performances de l'apprenant. Étant plus compétent et mieux informé, l'agent tuteur est ainsi considéré comme une source d'échafaudage de régulation externe et prendra le contrôle de l'activité d'apprentissage en termes d'orientation directe, de rétroaction proactive et d'évaluation des performances.

Peer agent : l'agent pair est présenté comme un partenaire d'apprentissage collaboratif amical et curieux qui affiche des comportements d'autorégulation tels que penser à haute voix, demander de l'aide et des suggestions, etc. L'agent pair s'engagera activement dans la démonstration de stratégies de régulation qui l'apprenant peut adopter ou apprendre de. En termes de comportements multimodaux, l'agent pair présente un discours enthousiaste et engageant à travers des actes de reconnaissance et d'encouragement, des dialogues informels et amicaux ainsi que des comportements de prise en charge ou de suivi de l'apprenant pendant l'activité en fonction des états de la tâche.

Tâche d'apprentissage : Les caractéristiques d'une tâche d'apprentissage collaboratif impliquent un sujet d'apprentissage pertinent sur lequel l'activité est structurée. Il est important que l'apprenant développe un intérêt pour l'activité et identifie une valeur à la tâche, afin que l'interaction reste engageante. La tâche d'apprentissage doit également fournir un scénario pour les conceptions partagées des objectifs, des croyances et des actions entre les apprenants. Un autre aspect important d'une bonne tâche d'apprentissage collaboratif en termes de SSRL est la possibilité d'activer des processus de régulation de manière récursive.

Résumé des contributions

Les objectifs de ce travail de recherche étaient de comprendre comment les comportements des agents pédagogiques peuvent potentiellement être utilisés pour favoriser l'autorégulation de l'apprenant. Les questions de recherche qui ont motivé notre travail étaient les suivantes :

- **RQ1** : l'engagement dans une interaction d'apprentissage partagé avec plusieurs agents pédagogiques fournissant des stratégies de régulation distinctes améliore-t-il les compétences d'autorégulation de l'apprenant ?
- **RQ2** : les différents rôles des agents influencent-ils différemment l'autorégulation et l'apprentissage de l'apprenant ?

Pour répondre à ces questions, nous avons commencé par examiner divers modèles d'autorégulation qui peuvent être adoptés pour notre recherche. Au cours de la recherche, nous nous sommes particulièrement intéressés à la conception et à la compréhension d'interactions d'apprentissage multi-agents qui semblaient efficaces pour persuader les utilisateurs et les maintenir engagés dans une tâche Kantharaju et al. (2018). Parmi les différents modèles de SRL, le modèle de régulation socialement partagé de l'apprentissage (SSRL) semblait être le bon ajustement pour notre travail étant le seul modèle théorique qui considère plusieurs partenaires d'apprentissage interagissant ensemble, se régulant et se régulant en même temps.

Cadre dimensionnel des rôles d'agent pédagogique en contexte SSRL : La phase initiale de la recherche impliquait la définition des rôles pédagogiques dans le contexte de la SSRL et leur réalisation multimodale associée. Le modèle dimensionnel proposé pour les rôles d'agent pédagogique a défini les rôles de régulation externe et de corégulation basés sur l'attitude sociale et les modes de régulation associés aux agents. L'attitude sociale des agents a été définie selon les dimensions de dominance et de convivialité tandis que le comportement de régulation des agents a été défini par leurs caractéristiques de compétence et de rétroaction. Les rôles d'expert, de tuteur et de motivateur ont été considérés comme des sources de régulation externe et présentés comme des partenaires d'apprentissage plus avertis caractérisés par des compétences plus élevées et des comportements de rétroaction explicites, tandis que les rôles d'agents pairs tels que les pairs collaborateurs, les pairs leaders, les pairs suiveurs, les pairs concurrents et Les co-apprenants étaient caractérisés par des niveaux de compétence inférieurs ou comparables avec l'apprenant et des modes implicites de transmission des connaissances et des comportements de corégulation tels que la réflexion à haute voix et la recherche d'aide.

Développement de la tâche d'apprentissage FRACTOS : La deuxième phase de la recherche impliquait la conception d'une interaction multi-agents basée sur un apprentissage partagé qui exigeait une tâche d'apprentissage facilitant les processus d'autorégulation et engageant l'apprenant. Ainsi, nous avons conçu et mis en œuvre une nouvelle tâche d'apprentissage appelée FRACTOS, basée sur le concept mathématique des fractions, qui impliquait les tâches de construction, de comparaison et d'identification des fractions représentées à l'aide de blocs LEGO virtuels. La tâche FRACTOS comprenait trois phases dédiées à la planification, à la performance et à la réflexion pour chaque exercice effectué par l'apprenant et a permis aux agents de s'engager avec l'apprenant et de fournir un soutien de régulation distinct à l'apprenant à chaque phase d'autorégulation. D'autres études et implémentations réalisées dans ce travail de recherche étaient basées sur la tâche d'apprentissage FRACTOS, qui s'est avérée efficace pour orchestrer l'interaction d'apprentissage.

CardBot : concevoir une nouvelle plate-forme de robot humanoïde abordable pour les études HRI : Au cours de nos recherches, nous avons proposé la conception d'une nouvelle plate-forme de robot humanoïde appelée CardBot, visant à utiliser des robots dans des interactions d'apprentissage. La conception et la mise en œuvre du robot ont assuré un minimum d'efforts et d'expertise dans la construction et la configuration d'un robot humanoïde qui est équipé de la parole, des gestes de base et des actes expressifs pour s'engager socialement avec les utilisateurs. CardBot utilise du carton comme matériau de squelette pour rendre la fabrication abordable, évolutive et accessible. Les comportements verbaux et non verbaux du robot pouvaient être contrôlés à partir d'une interface de contrôle basée sur Unity3D, ce qui le rendait approprié pour une utilisation dans les études d'interaction du Magicien d'Oz en HRI. Le robot CardBot a été utilisé dans les phases initiales de nos recherches et études pilotes menées lors du développement de la tâche d'apprentissage FRACTOS, mais les contraintes et les changements apportés par la situation pandémique ont limité l'utilisation de CardBot dans les phases finales de notre travail, car nous déplacé vers des personnages virtuels et des études en ligne.

Une interaction d'apprentissage multi-agents pour l'échafaudage de régulation dans un contexte SSRL : L'interaction d'apprentissage multi-agents proposée vise à promouvoir les comportements d'autorégulation chez l'apprenant à travers les rôles de tuteur et de pair dans un contexte SSRL. À travers cette configuration d'environnement d'apprentissage avec de multiples partenaires d'apprentissage de différents niveaux de compétences et stratégies de régulation, nous avons voulu explorer comment s'engager dans une tâche d'apprentissage avec divers rôles d'agents peut influencer l'autorégulation et les performances de l'apprenant. L'interaction d'apprentissage impliquait donc un apprenant humain s'engageant dans la tâche d'apprentissage FRACTOS sur la construction et la comparaison de fractions, avec un agent tuteur virtuel et un agent pair robot virtuel. L'agent tuteur, présenté comme une entité mieux informée, se caractérisait par des niveaux modérés de dominance et de convivialité et fournissait un soutien externe à la régulation par le biais d'indices directs, d'une transmission explicite des connaissances et d'un retour d'information, etc. aider, poser des doutes, faire des erreurs, etc. et se caractérise par une compétence moindre et une rétroaction implicite. Le cadre d'apprentissage partagé proposé devient pertinent car il émule les interactions d'apprentissage qui se produisent dans un scénario du monde réel tel que les salles de classe où l'apprentissage implique de s'engager avec plusieurs personnes telles que les enseignants et les co-apprenants.

Études d'utilisateurs pour comprendre l'apprentissage autorégulé et les perceptions des agents des apprenants dans un contexte SSRL

Pour notre recherche sur l'autorégulation à l'aide de rôles multiples d'agents pédagogiques s'engageant ensemble dans une activité d'apprentissage partagé, nous avons abordé les questions de recherche **RQ1** et **RQ2** à travers une série d'études d'utilisateurs portant sur les perceptions des apprenants , les compétences d'autorégulation et les performances pendant l'activité.

1. Perception des apprenants des agents et de l'activité

La première étude utilisateur visant à comprendre la perception des rôles des agents, les qualités associées et l'activité d'apprentissage FRACTOS par les apprenants et à observer l'interaction proposée est efficace pour promouvoir l'autorégulation et engager les apprenants. En abordant **RQ1**, pour comprendre comment les agents qui se concentrent sur la régulation peuvent influencer l'apprenant, nous avons émis l'hypothèse que :

- **H1** : S'engager dans l'interaction d'apprentissage avec le tuteur et l'agent pair améliorerait la perception par l'apprenant des qualités de l'agent.

- **H2** : des perceptions positives des qualités des agents et de l'activité d'apprentissage encourageraient une meilleure autorégulation chez les apprenants.

Les résultats de l'étude ont indiqué une amélioration de l'intelligence perçue du tuteur et des agents pairs après l'activité, tandis que la sympathie restait toujours bonne. En général, nous avons observé un bon intérêt pour l'activité d'apprentissage et la plupart des apprenants ont montré de bonnes compétences de régulation dans l'activité. Il a été observé que les apprenants ayant des compétences d'autorégulation plus élevées associaient une intelligence perçue plus élevée et une plus grande sympathie à l'agent tuteur avant l'activité et présentaient une motivation intrinsèque plus élevée. Concernant la perception des rôles pédagogiques attribués aux agents, la majorité des participants ont pu associer correctement les rôles tuteur et pair aux agents, tandis que peu de participants étaient confus quant au rôle attribué au robot virtuel agent pair. Cela a suggéré une meilleure conception des comportements des agents pairs pour transmettre clairement le rôle pédagogique prévu.

2. Impact des comportements erronés des pairs

Selon la conception de l'interaction d'apprentissage, il est nécessaire que l'apprenant associe les rôles de tuteur et de pair aux agents visés afin d'éviter une mauvaise interprétation des stratégies et des comportements de régulation. Pour améliorer la perception des rôles d'agent par l'apprenant et transmettre clairement les niveaux de compétence des deux agents, nous avons introduit des comportements d'erreur dans l'agent pair pour notre deuxième étude d'utilisateur. Dans ce contexte, nous avons émis l'hypothèse que :

- **H1** : le comportement d'erreur de l'agent pair favoriserait une perception correcte des rôles de l'agent et des qualités associées.
- **H1a** : L'agent pair sera perçu comme moins intelligent que l'agent tuteur après l'activité.
- **H1b** : La perception du rôle d'agent pair de l'apprenant s'améliorera après l'activité.
- **H2** : Les comportements erronés de l'agent pair favoriseraient une meilleure régulation chez les apprenants.

En analysant les données de l'étude, nous avons observé que le comportement d'erreur de l'agent pair avait des effets significatifs sur la perception des qualités de l'agent ainsi que sur les rôles pédagogiques associés. L'intelligence perçue du seul agent tuteur s'est améliorée après l'activité tandis que celle du pair est restée presque la même, établissant ainsi le niveau de compétence prévu pour le pair. En outre, presque tous les participants qui confondaient l'agent pair avec un tuteur avant l'activité ont acquis une perception correcte des rôles de l'agent en s'engageant dans l'activité. En comparant les résultats de l'étude avec les données de l'étude précédente, nous avons observé que l'intelligence perçue du pair diminuait lors de l'introduction de comportements erronés, ce qui résultait également en un facteur d'intérêt pour l'activité plus faible. Ainsi, il apparaît que les épisodes d'erreurs au cours de la tâche peuvent non seulement aider à améliorer la perception du rôle, mais également affecter négativement l'engagement de l'apprenant si des erreurs apparaissent souvent.

3. Comprendre les effets de la régulation externe et de la corégulation
La troisième étude visait à comprendre comment les modes distincts de régulation externe et de corégulation influencent différemment l'apprenant tout en s'engageant dans l'interaction d'apprentissage multi-agents proposée. Pour explorer **RQ2**, pour comprendre comment différents rôles et stratégies de régulation associées influencent l'apprenant, nous avons émis l'hypothèse que :

- **H1** : Le discours pédagogique des stratégies de régulation externe par l'agent tuteur motiverait un comportement d'apprentissage orienté performance chez l'apprenant
- **H2** : La démonstration de stratégies de co-régulation par l'agent pair motiverait un meilleur comportement d'apprentissage orienté régulation chez l'apprenant

Les résultats de l'étude ont indiqué des différences significatives dans l'autorégulation et les performances d'activité entre les groupes qui ont reçu chacun des modes de régulation. Il a été observé que le score d'activité qui indiquait le niveau de performance de l'apprenant était significativement plus élevé pour le groupe dirigé par une régulation externe. L'autre groupe qui a reçu des stratégies de corégulation de la part de l'agent pair à autorégulation active s'est avéré avoir de meilleures compétences d'autorégulation, confirmant ainsi nos hypothèses. Cependant, étant donné qu'une interaction d'apprentissage efficace devrait faciliter à la fois l'autorégulation et la performance de l'apprenant, nous avons ensuite orienté notre recherche vers l'atteinte d'un équilibre entre les deux modes de régulation par le biais du tuteur et des agents pairs.

4. Approche d'échafaudage de régulation dirigée par l'apprenant
L'étude d'utilisateur finale a permis à l'apprenant de demander l'aide de l'agent préféré à divers moments au cours des phases de planification et de réflexion de l'activité d'apprentissage. Nous avons émis l'hypothèse que :

- **H1** : un échafaudage de régulation adaptative piloté par les préférences des apprenants des agents pendant l'activité améliorera à la fois les performances et les scores d'autorégulation des apprenants.
- **H2** : les apprenants préféreraient demander un soutien de régulation externe au tuteur pendant les phases de planification de la tâche.
- **H3** : les apprenants préféreraient rechercher un soutien de corégulation auprès du pair pendant les phases de réflexion de la tâche.

L'approche d'échafaudage axée sur l'apprenant impliquait un bon intérêt pour l'activité et des perceptions positives du rôle et des comportements des agents. Après s'être engagés dans l'activité d'apprentissage, davantage d'apprenants ont montré des compétences d'autorégulation plus élevées, mais il n'en a pas été de même en termes d'exécution des tâches. En ce qui concerne la préférence des apprenants envers les agents, il a été observé que les apprenants préféraient majoritairement avoir l'agent tuteur pour fournir un soutien pour les phases de planification de l'activité tandis que pour la phase de réflexion, il y avait une tendance à rechercher plus d'aide de l'agent pair en tant que l'activité a progressé.

En général, les résultats des études suggèrent la nécessité d'un échafaudage de régulation adaptative basé sur les objectifs de performance et d'autorégulation de l'apprenant pendant l'activité ainsi que de mener des études à plus long terme pour comprendre comment ces objectifs évoluent au fur et à mesure que l'apprentissage progresse.

Limites

Les contributions présentées dans cette thèse ne sont pas exemptes de limitations. Dans Dans les paragraphes suivants, nous discutons de certaines limitations concernant la mise en œuvre des comportements des agents ainsi que les scénarios utilisés dans nos études expérimentales.

Limites de l'agent et de la tâche

Notre approche de l'apprentissage autorégulé dans le contexte d'un apprentissage partagé avec plusieurs agents dans différents rôles et stratégies associées exigeait de l'apprenant qu'il répartisse son attention entre les deux agents et qu'il distingue les agents en fonction de leurs rôles et objectifs connexes au cours de la tâche. L'apprenant a souvent besoin d'un certain temps pour se familiariser avec les agents afin d'acquérir une compréhension claire et des attributions aux agents. Cependant, dans nos études, comme nous devions décomposer l'activité en différentes phases de planification, d'exécution et de réflexion pour chaque exercice effectué, l'introduction aux agents était souvent courte et centrée sur la tâche. En ce qui concerne le sujet d'apprentissage des fractions qui était initialement destiné aux enfants apprenants, certains participants adultes ont trouvé la tâche d'apprentissage moins difficile et donc peu engageante. Nous avons dû augmenter la difficulté des exercices de la tâche pour rendre la tâche d'apprentissage plus intéressante pour les apprenants. De plus, en ce qui concerne les fonctionnalités des agents, les participants ont souvent indiqué que l'animation et la voix des agents n'étaient pas réalistes.

Limites expérimentales

En ce qui concerne les études d'utilisateurs, il a été observé que la réalisation d'études en ligne rendait l'interaction avec les agents moins intuitive car les participants devaient effectuer certaines actions sur l'écran sans rapport avec la tâche (comme passer à la vidéo suivante, activer la vue plein écran, etc.) qui leur a demandé de naviguer dans l'étude. De plus, étant donné que les participants ont été recrutés en ligne, nous ne pouvions pas contrôler l'environnement dans lequel ils menaient l'étude. Ces facteurs pourraient également avoir influencé l'intérêt et les perceptions des apprenants. Dans les premières étapes de notre recherche, nous avions l'intention de mener l'interaction proposée en laboratoire avec des enfants apprenants interagissant avec des agents à l'écran et effectuant la tâche sur une tablette. Nous avons dû adapter notre cadre aux études en ligne en raison des contraintes de la pandémie, ce qui a entraîné des compromis sur les données que nous avons pu collecter à partir des études telles que le regard, les journaux de performances, etc. En ce qui concerne l'aspect de l'autorégulation, puisque la études ont été menées en ligne, nous avons dû recourir à l'utilisation de questionnaires pour mesurer les compétences de régulation de l'apprenant, ce qui ne permettait pas d'avoir une estimation de l'évolution de l'autorégulation de l'apprenant au cours de l'activité. Les études menées étaient également limitées en termes de durée d'interaction réelle avec les agents et la réalisation d'études à plus long terme avec plusieurs sessions d'apprentissage pourrait fournir plus d'informations sur la façon dont les perceptions des agents et la régulation des apprenants changent au fil du temps.

Perspectives futures

Dans cette section, nous envisageons les perspectives futures de la recherche d'agents pédagogiques dans le contexte de la SSRL et les améliorations potentielles de nos implémentations et approches pour assurer un meilleur échafaudage de régulation.

Combinaisons de rôles pédagogiques pour SSRL

L'interaction multi-agents présentée dans cette thèse impliquait le rôle d'un tuteur pour faciliter la régulation externe et le rôle de pair pour assurer la corégulation. Le cadre dimensionnel des rôles pédagogiques dans le contexte SSRL, que nous avons présenté mentionne différents rôles tels que l'expert, le motivateur, etc. entité dans l'interaction d'apprentissage. Ainsi, diverses combinaisons de ces rôles peuvent être expérimentées pour comprendre comment les changements dans les niveaux de dominance et de convivialité peuvent influencer l'apprentissage différemment d'un couple tuteur-pair apprenant.

Mesure en ligne de SRL

Comme mentionné dans les limites de notre travail, la mesure du SRL reste une tâche difficile Panadero et al. (2016). L'une des améliorations futures du travail devrait impliquer une mesure en temps réel des états de régulation de l'apprenant à partir de signaux multimodaux ainsi que de l'engagement de l'apprenant. Par exemple, le comportement du regard de l'apprenant peut être utilisé pour estimer le niveau d'attention sur l'activité ainsi que l'évolution des préférences envers les agents. De même, les mesures de trace de différentes phases de la tâche peuvent également être utilisées pour informer sur les objectifs de performance et de régulation de l'apprenant pendant l'interaction. Il est également possible d'intégrer des outils de mesure « en ligne » tels que des agendas structurés et des protocoles de réflexion à haute voix pendant l'activité qui peuvent servir d'outil d'intervention et de mesure pour SRL en même temps.

Automaticité et échafaudage adaptatif

Les résultats des études menées ont suggéré la nécessité d'un équilibre entre l'accent mis sur la régulation et la performance dans une interaction d'apprentissage partagé. Dans l'une de nos études, l'amélioration de la régulation s'est faite au prix d'une baisse de la performance des tâches, tandis que les préférences des apprenants envers les agents pairs qui se concentraient sur les objectifs de régulation s'amélioraient au fur et à mesure que l'activité progressait. L'automaticité dans l'apprentissage fait référence à l'émergence d'un modèle de réponse automatique dans les processus cognitifs, métacognitifs et motivationnels chez l'apprenantZimmerman and Kitsantas (2005) Boekaerts (2011). Au fur et à mesure que l'apprenant devient plus familier avec l'activité et compétent dans le sujet d'apprentissage, certains objectifs et stratégies peuvent être activés ou déclenchés directement par des signaux environnementaux, sans conscience ni charge cognitive supplémentaire de l'apprenant Pintrich (2000). Dans notre recherche, nous avons utilisé l'agent tuteur en se concentrant sur la régulation externe pour orienter l'apprenant vers l'amélioration de la performance des tâches grâce à des conseils et des instructions directs. L'agent pair démontrant des stratégies de régulation dans l'interaction se concentre plutôt sur la promotion des comportements de régulation chez l'apprenant. Pour trouver un équilibre entre ces deux modes de régulation, il nous faudrait mieux comprendre les comportements de l'apprenant et la performance des tâches pour déduire le mode de régulation approprié et l'agent approprié pour fournir le soutien à tout instant. La mise en œuvre d'un tel système rendrait l'interaction d'apprentissage partagé proposée plus efficace en termes d'amélioration des aspects de régulation ainsi que des comportements des agents à l'avenir.

Abstract

AGENTS in a learning environment can have various roles and social behaviours that can influence the goals and motivation of the learners in distinct ways. Self-regulated learning (SRL) is a comprehensive conceptual framework that encapsulates the cognitive, metacognitive, behavioural, motivational and affective aspects of learning and entails the processes of goal setting, monitoring progress, analyzing feedback, adjustment of goals and actions by the learner. In this Thesis, we present a multi-agent learning interaction involving various pedagogical agent roles aiming to improve the self-regulation of the learner while engaging in a socially shared learning activity. We used distinct roles of agents, defined by their social attitudes and competence characteristics, to deliver specific regulation scaffolding strategies for the learner. The methodology followed in this Thesis started with the definition of pedagogical agent roles in a socially shared regulation context and the development of a collaborative learning task to facilitate the learning interaction focusing on self-regulation. Based on the learning task framework, we proposed a shared learning interaction consisting of a tutor agent providing external regulation support focusing on the performance of the learner and a peer agent demonstrating co-regulation strategies to promote self-regulation in the learner. A series of user studies have been conducted to understand the learner perceptions about the agent roles, related behaviours and the learning task. Results from the initial studies suggested the effectiveness of the newly proposed interaction setup in promoting regulation as well as positive perception of agent behaviours and related regulation strategies. To improve the role perceptions of the learners, especially regarding the agent competency, we introduced error making behaviours in the peer agent in our further studies. In the later user studies, we examined distinct modes of regulation focusing on performance and regulation of the learner respectively and found differences in how each agent influence the performance and self-regulation goals in the learner. Altogether, the work presented in this Thesis explores how various roles of agents can be utilised in providing regulation scaffolding to the learners in a socially shared learning context.

Keywords: <human-agent interaction, self-regulated learning, multi-agent interaction, pedagogical agent roles, regulation scaffolding>.

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Part I

Introduction

Chapter 1

Context of the Thesis

Contents

This chapter introduces the context where this Thesis is placed, in particular, the research questions we addressed and the approach followed to answer these questions. The field of pedagogical agents and self-regulated learning is briefly introduced and the motivation of this work is also presented. The chapter finishes with a list of contributions of this Thesis and the summary of the Thesis structure mentioning the parts and chapters involved.

1.1 Introduction

Learning can be described as an active process of engaging and manipulating objects, experiences, and conversations in order to construct, modify and maintain mental models of the world, to increase the potential of improved performance and future learning (Marhan (2006); Piaget and Inhelder (2014); Vygotsky (1980)). learners build knowledge as they explore the world around them, observe and interact with phenomena, converse and engage with others, and make connections between new ideas and prior understandings. Humans are innate learners and learning is the key for our existence as well. We have passed various ages of evolution that demanded different sets of skills and competencies. As hunter-gatherers, observation and imitation were deciding factors while later on adaptation and improvisation became relevant as communities and civilizations began to prosper. This was followed by a time when refinement and innovation paved the way for cultural and scientific growth which led to an age of scientific discovery and reasoning.

With the replacement of hand tools with power-driven machines, began the industrial age that demanded procedural skills and collaboration with machines. Presently we are taking our steps through the information age where information has become the driving factor of social evolution. Information has become more accessible and abundant and the skills demanded by the present and future has also changed. The new challenge faced by the learners of present times is to effectively use and assess this abundant information and transform it into relevant knowledge and skills. The World Economic Forum summit 2015, Forum (2015) have proposed a framework consisting of 16 most critical "21st-century skills" after conducting a meta-analysis of research about 21st-century skills in education across nearly 100 countries (Figure 1.1). The most relevant part of this framework is the aspect of lifelong learning that demands the learner to be self-directed and constantly motivated in planning, monitoring and reflecting on one's own learning Fischer (2000).

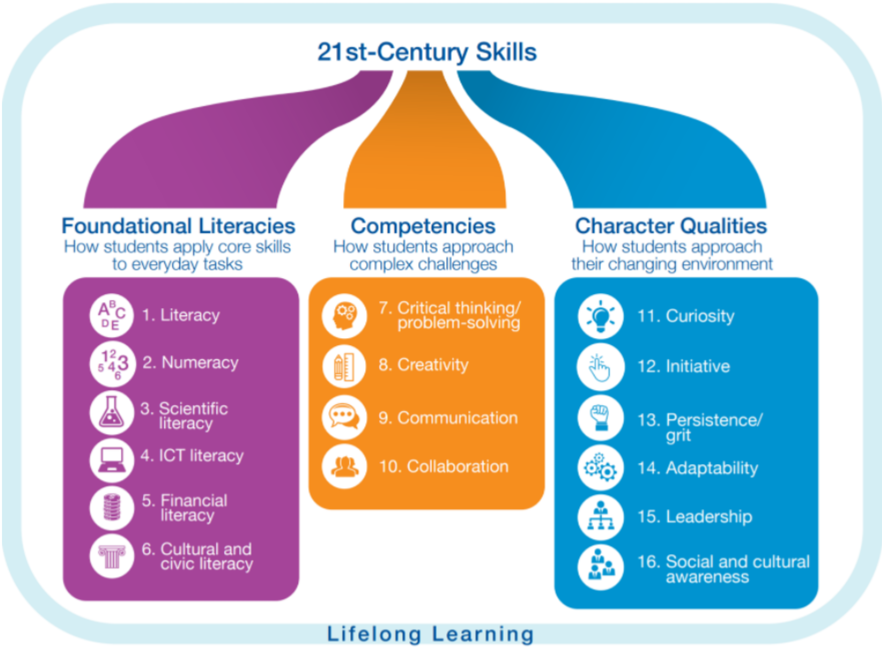

Figure 1.1: Framework of 21st century skills Forum (2015)

Self-regulated learning (SRL) has been identified as a comprehensive conceptual framework that encapsulates the cognitive, metacognitive, behavioural, motivational and affective aspects of learning Panadero (2017). Regulation of learning Allal (2020) entails the processes of goal setting, monitoring progress, analyzing feedback, adjustment of goal-directed actions and/or of the definition of the goal. Regulated learning can be of four kinds, described as follows:

- Self Regulated Learning (SRL), where a student uses self-assessment, goal setting, and the selection and deployment of learning strategies to reach the learning goal.

- Externally Regulated Learning (ERL), which involves an external entity prompting an individual learner to deploy key SRL processes during their learning, which may, in turn, enhance their SRL.

- Co-Regulated Learning (CoRL), involves a peer learner supporting and influencing each others regulation of learning, typically in an interdependent and reciprocal manner.
- Socially-shared regulated learning (SSRL), which involves multiple learners regulating themselves as a collective unit, using consensus building and negotiation to co-construct and make decisions about group task goals, definitions, beliefs, strategies, and knowledge.

In the context of collaborative learning, socially shared regulation has become relevant as it considers regulation processes involved in multiple learning partners in the same learning environment. The socially shared regulation model of learning regulation Hadwin et al. (2011), combines the foundational theories of self-regulation, which were mostly centred on individual processes, with the social and interaction aspects of collaborative learning.

1.1.1 Embodied Conversational Agents

Embodied Conversational Agents (ECAs) are computer-generated animated characters (Figure 1.2) with an anthropomorphic appearance capable of carrying on natural human-like communication with learners Pelachaud (2005). According to the Computers as Social Actors (CASA) paradigm humans considers computers as social entities and treat media and computers like real people applying scripts for interacting with humans while engaging with social technologies (Nass and Moon (2000); Reeves and Nass (1996)). The emphasis of socio-emotional relationships in the field of Human-Computer Interaction derives from the works on natural multimodal interfaces such as embodied conversational agents and social robots (Cassell (2001); Breazeal (2002)).

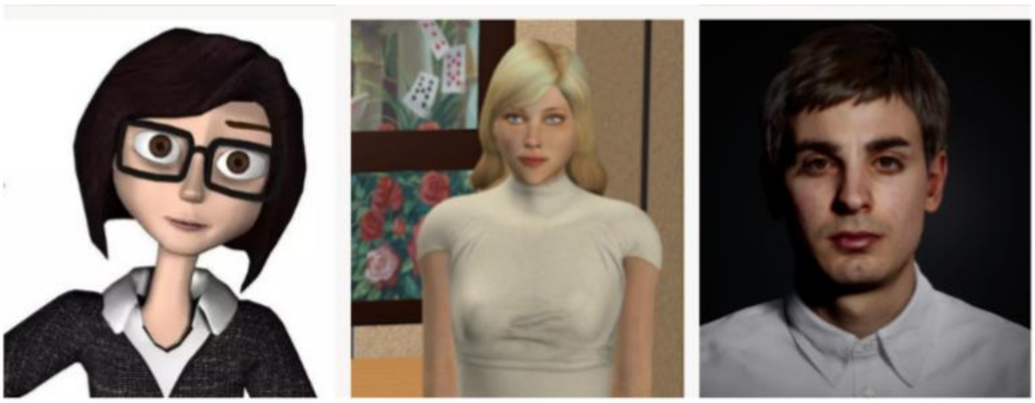

Figure 1.2: Examples of various virtual agents. (From left) SARA, a socially aware personal assistant Matsuyama et al. (2016), Alice, a engagement aware agent Mancini et al. (2019) and finally, Vincent, a realistic virtual human Vincent (2019)

Pedagogical agents can be defined as intelligent artificial learning partners (single or multi) that can support the student's learning and use various strategies in an interactive learning environment Martha and Santoso (2019). Pedagogical agents in the form of virtual characters or robotic embodiment have shown potential for impacting the motivation, engagement and performance of the learners through various studies and interactions. Lusk and Atkinson (2007) states that "the agents can enrich and broaden the communicative relationship between the learners and computers as well as provide motivational and affective instructional features that actively engage students". The learners are often observed to be developing social and emotional associations with the agents that influence their sense of responsibility, motivation and activity perceptions (Liew et al. (2017); Gulz and Haake (2005); Krämer and Bente (2010)). Studies have shown that having several (virtual/physical) agents playing different roles (e.g. tutor, mentor, classmate, helper) enhances learning and motivation of the students (Baylor (2003b); Kim and Wei (2011)). Each agent type brings expertise, creates a unique social relationship with learners. Depending on their role, agents have specific goals and beliefs as well as attitudes toward the learners. Self-regulation of a learner can be supported by pedagogical roles and distinct kinds of regulation behaviours exhibited by the agents. To summarize, in this research thesis, we aim to develop a multi-agent learning interaction involving different pedagogical roles in a socially shared learning context, focusing on the aspect of promoting self-regulation in the learner.

Figure 1.3: Examples of various virtual pedagogical agents. Laura Bickmore (2004) (top left), Cosmo Lester et al. (1997b) (top right), Rea (bottom left) Haake and Gulz (2009) and Steve Johnson and Rickel (1997) (bottom right)

ANIMATAS-ITN: The work presented in this dissertation is part of the ANIMATAS, which is a Marie Skłodowska-Curie Actions Innovative Training Network (MSCA ITN) funded by the European Union's Horizon 2020 research and innovation program. The project aims at exploring the perception of robots and virtual agents in the context of learning, develop new learning mechanisms and promote personalised adaptation to the human learner in dynamically evolving social learning interactions. Our contributions to the project within this research context were in the aspects of agent embodiment and social learning adaptation through developing a shared learning interaction with multiple pedagogical agents and conducting learner studies to understand the influence on agent perceptions, learning and self-regulation skills of the learner.

1.2 Research Questions

Existing literature on pedagogical agents has mostly focused on cognitive, motivational and affective aspects of learning and usually involved learners interacting with a single pedagogical agent assisting the learner (Panadero (2017); Baylor and Kim (2005)). The socially shared regulation in learning (SSRL) Järvelä and Järvenoja (2011) presents a scenario where multiple agents can be introduced in various pedagogical agent roles to engage with the learner and deliver distinct strategies of regulation to the learner. The motivation of the work presented in this thesis was to explore the aspect of self-regulated learning in a shared learning interaction context using embodied conversational agents in different pedagogical roles for providing external regulation and co-regulation support to the learner. In our research, we exploited the Greta/VIB Platform Pecune et al. (2014) for the real-time generation and animation of ECA's verbal and nonverbal behaviours. The GRETA platform is based on SAIBA framework, which is a common framework for the creation of multimodal communicative behaviours and emotional states in ECAs. In particular, we focused on the aspect of scaffolding the self-regulation in learners and addresses the following research questions:

- **RQ1**: Does engaging in a shared learning interaction with multiple pedagogical agents providing distinct regulation strategies enhance the self-regulation skills of the learner?
- **RQ2**: Do various roles of agents influence the learner's self-regulation and learning differently?

To address **RQ1** and **RQ2**, we started by designing a shared learning interaction based on a collaborative learning task involving pedagogical agents in the roles of tutor and peer and conducting perceptive studies to understand learner perceptions of agent roles, related regulation behaviours and the learning activity. We defined the roles and multimodal behaviours of the pedagogical agents based on their social attitude along the dimensions of dominance and friendliness and defined the regulation behaviours of agents based on their competence level and feedback characteristics. The research questions were then investigated based on the proposed learning interaction through learner studies focusing on agents delivering distinct regulation scaffolding and evaluating the impact on self-regulation and performance of the learners.

1.3 Summary of contributions

The scientific contributions of this Thesis can be summarized as follows:

Dimensional framework of pedagogical agent roles in SSRL context
The realisation of pedagogical agents in a multi-agent learning interaction required a clear definition of various pedagogical roles relevant in SSRL context. We defined the roles of pedagogical agents based on their social attitude along the dimensions of dominance and friendliness characteristics and distinguished the roles that provide external regulation and co-regulation scaffolding based on the competence and feedback features. Along with defining the dimensional dynamics of each role, we also associated the relevant multimodal behaviours such as gestures, speech, gaze and facial expressions for operationalising the agent behaviours.

Development of FRACTOS learning task

The shared learning interaction involving multiple pedagogical agents required a collaborative learning task that can facilitate different phases of self-regulation such as planning, performance and reflection. Thus, we developed a new learning task based on the mathematical concept of fractions, called FRACTOS, which involved learning exercises of building fractions, comparing a set of fractions and identifying fractions using virtual LEGO block representations.

CardBot: Designing a new affordable humanoid robot platform for HRI studies In the course of the research work for designing pedagogical agents of various roles, we came up with the design of a new humanoid robot called as CardBot, which is intended as an affordable rapid prototyping platform for orchestrating HRI studies, particularly based on Wizard of Oz methods. The robot character was presented in the role of a peer in the early stages of our research and some of the pilot studies while developing the learning task. However, we later shifted our focus exclusively to virtual characters considering the constraints of the pandemic situation.

A multi-agent learning interaction for regulation scaffolding in SSRL context
Based on the dimensional framework of pedagogical agent roles for regulation scaffolding and the developed FRACTOS learning activity, a multi-agent learning interaction in SSRL context was implemented. The interaction involved a virtual agent in the role of tutor providing external regulation support through explicit feedback, suggestions and direct hints while the peer agent demonstrated co-regulation strategies of thinking aloud, asking questions, making mistakes etc. The proposed learning interaction enabled the learner to perform the task of learning about fractions by going through regulation processes of planning, performance and reflection being directed and supported by both agents.

User studies towards understanding self-regulated learning and agent perceptions of the learners in SSRL context z We conceived a series of learner studies aimed at understanding the effectiveness of the proposed multi-agent learning interaction as well as the perception of learners about the agent roles of tutor and peer, their related behaviours and their influence on self-regulation and performance of the learners. The combined aspect of multi-agent learning interactions and self-regulated learning, which presents as a unique scenario for understanding regulation scaffolding using agents, is explored in these studies. The results suggested a positive perception of learners about the learning activity and the influence of agent roles and behaviours on the self-regulation of learners. It was also observed that the tutor and peer agents, on delivering distinct regulation strategies have influenced learners differently as the interaction evolved. The studies also looked at the traits of highly self-regulated learners as well as learners who struggled with self-regulation to understand the differences in their perception of agents and strategies.

1.4 Thesis Structure

This thesis is organised into 6 parts, including this Introduction. In Part II we present the theoretical background about self-regulated learning and various models of self-regulation (in Chapter 2).

In Part III, we discuss the related work about theories of pedagogical agents, their evolution, characteristics and impact on various aspects of learning (Chapter 3). This chapter also presents pedagogical agent systems and research focusing on self-regulation and its limitations.

Part IV, describes the design and development of various elements of shared learning interactions used in our research. In Chapter 4, we present a dimensional framework for defining pedagogical agent roles in SSRL context focusing on the social attitude and regulation mode of the agents. The Chapter 5, describes the motivation behind building CardBot, which is an affordable humanoid robot platform for HRI studies, which we designed to be used in the role of a peer learner for our research. In Chapter 6, newly designed collaborative learning task called FRACTOS, which was developed for facilitating self-regulation oriented learning interaction is presented. Finally, Chapter 7 introduces the proposed multi-agent learning interaction in SSRL context that focuses on promoting self-regulation in learners while engaging in the FRACTOS learning task involving the pedagogical agent roles of tutor and peer.

In Part V, we present the four user studies conducted in course of this research work to address the research objectives and understand how various roles and behaviours of the agents influence the self-regulation of the user. The Chapter 8, presented the perceptive study on user perceptions of agent roles, qualities and the learning activity while Chapter 9 looked at the impact of error making behaviours in the peer agent, introduced to improve the user perceptions and self-regulation. The Chapter 10 presents another user study on understanding distinct modes of regulation scaffolding through the roles of tutor and peer user in SSRL context. The Chapter 11 presents the final user study, which involved a user-driven approach for regulation scaffolding that looked at how user preferences for both agents evolved and influenced the self-regulation and performance of the user during the interaction.

Finally, part VI that consists of the Chapter 12, we summarise the research work conducted and our contributions to the domain, present the significance and limitations identified and propose future perspectives on enhancing the proposed shared learning interaction.

1.5 Publications

This Thesis gave rise to several national and international publications, as well as to invited talks and dissemination to non-expert audience. During the course of the research work, we were able to introduce the virtual agents and social robots for learning interactions to the general public and gather feedback from them. Additional discussions about my PhD research has happened in the context of various technical workshops, summer schools related to the ANIMATAS-ITN project and funded by the European Union's Horizon 2020 research and innovation program.

The list of publications and dissemination can be found in Annex A.

The key points of this Chapter:

Research Questions :

- Does engaging in a shared learning interaction with multiple pedagogical agents providing distinct regulation strategies enhance the self-regulation skills of the learner?
- Do various roles of agents influence the learner's self-regulation and learning differently?

Goal of this Thesis

- to design an engaging multi-agent learning interaction in SSRL context and understand how distinct pedagogical roles and related strategies promote self-regulation and performance in the learner.

Part II

Theoretical Background

Chapter 2

Theoretical Background

Contents

In this chapter, we present an overview of main theories of pedagogy and learning and introduce the domain of self-regulated learning. We also discuss various relevant theoretical models of self-regulation and observe how the field evolved during the last few decades in terms of research methods and technological implementation.

2.0.1 Learning and Theories of pedagogy

Learning is defined Marhan (2006) as a process that leads to a change, which occurs as a result of experience and increases the potential of improved performance and future learning. The concept of learning has been looked at from different perspectives based on the factors such as context, cognitive mechanisms, outcome, learner features etc. The learning process involves cognitive, affective and metacognitive activities, employed by the learner, which also gets influenced directly or indirectly by the external agents and the learning environment Vermunt and Vermetten (2004). Cognitive processing activities are those thinking activities that the learner use to process the information provided, to attain a learning goal in terms of knowledge, understanding and skill. Affective activities involve emotions that arise during learning and that lead to emotional states that may positively, neutrally, or negatively influence the progress of a learning process. The metacognitive regulation activities influence both the cognitive and affective activities and thus indirectly impact the learning gain. The interplay of these dimensions of cognition, emotion and metacognition in various stages of learning, such as planning, performance, evaluation and reflection, decides the amplitude and direction of the learning outcome.

Early theories interpreted learning as a product or quantitative increase in knowledge or performance while the later theories approached learning as a process giving more emphasis to affect, experiences and environment than focusing on the outcome. Behaviourist theory of learning Watson (1913) considers the knowledge to be independent and external to the learner and the learning occurs when a provided stimulus brings a behavioural change in the desired direction. This approach often involves repeated action and reinforcement and is ideal for exercises for behaviour management Skinner (2002). In contrast to the behaviourist approach, theories of cognitivism considered learning as an internal processing of information rather than a response to a stimulus. In cognitivist theories, learning is viewed as a process of inputs, managed in short term memory, and coded for long-term recall and involves a change in the knowledge, skills, attitudes, behaviour and world views of the learner. This approach has initiated the interest in various evidence-based educational theories such as schema theory Arbib (1992), cognitive load theory Sweller (2011), information processing theory Simon (1978), dual coding theory Clark and Paivio (1991) etc.

Constructivist theories of learning considered knowledge as constructed by adapting new information based on prior knowledge and experiences of the learner. This makes the learning unique to the individual learner and is interpreted as the process of creating meaning from experiences driven by the learner's choice. The constructivist approach accounts for the complexities and fuzziness of real-life learning environments as it accommodates the complexity and inconsistencies in human learners. This approach later paved the way for the development of constructionist learning theories pioneered by Seymour Papert Papert (2020) which advocated problem-oriented and student-centred, discovery-based learning where the learning involved creating mental models of the world around. The constructionist learning methods claimed Kynigos (2015) that the meanings are naturally generated in the intellectual, social and physical environment and that digital technology can also be leveraged to make the learning environment effective such as creating meaningful play or serious games using digital or tangible artifacts. The evolution of such theories led to the combination of social and physical aspects of learning to be integrated to the processes of learning. Social cognitive theory Sumarni and Kalupae (2020) developed by Albert Bandura addresses the notion of observational and social learning where learning is a process happening in a relationship between people and environment in a social setting that involves various roles and behaviours of participating learners. This theory combines the cognitive, constructivist and behavioural framework and also embraces motivation, self-efficacy and goals etc by presenting the social context of learning Bandura (1988). Elevated interests in behaviours and mental states of the learners led to the development of various theories such as humanist Rogers and Freiberg (1970) and experiential Kolb (2014) theories of learning which interpreted learning as a form of self-actualization fuelled by social, affective and cognitive potential and needs of the learner.

In the late 20th century, various educational and cognitive theories centred on social interactions began evolving and the aspects of collaboration, cooperation and collective engagement in learning started gaining attention. The situated learning theory Lave and Wenger (1991) developed by Jean Lave and Etienne Wenger examines this wider learning spectrum in which the interactions take place in a community of practice involving problem-solving, negotiations, collaboration etc. This approach pays attention to the social engagements and relationships that facilitate learning rather than the cognitive processes. The emergence and evolution of various learning theories have thus produced a comprehensive and coherent understanding of the process of learning and its cognitive, metacognitive, behavioural and social underpinnings over time.

2.0.2 Self-regulated learning

Self-regulated learning(SRL) has been identified as a comprehensive conceptual framework that encapsulates the cognitive, metacognitive, behavioural, motivational and affective aspects of learning Panadero (2017). Regulation of learning Allal (2010) entails the processes of goal setting, monitoring progress, analyzing feedback, adjustment of goal-directed actions and/or of the definition of the goal. Theories on self-regulation in learning started to gain momentum after the introduction of the metacognitive theory of learning and cognitive monitoring by John Flavell, who was greatly influenced by the theories of developmental psychology by Jean Piaget Flavell (1979). Flavell broke down metacognitive monitoring into four components namely, metacognitive knowledge, metacognitive experiences, cognitive goals and cognitive strategies Dinsmore et al. (2008). According to Watkins (2001), metacognition is defined as the awareness of thinking processes, and “executive control” of such processes (Figure 2.1). In general, metacognition has two components Veenman et al. (2006), (i) knowledge about one’s cognitive processes and (ii) regulation of those cognitive processes. The self-regulatory mechanisms Baker (1984) involves planning, monitoring progress, selecting and evaluating strategies, revising etc. Earlier understanding of self regulation as a process was mostly focused on emotions and behaviour being grounded on the theories of social cognition Bandura (1991). The concept of reciprocal determinism introduced by Bandura (1978) described human functioning to be based on interaction with the person and environment, mediated by the emergent regulation of behavioral, emotional and motivational components. The term

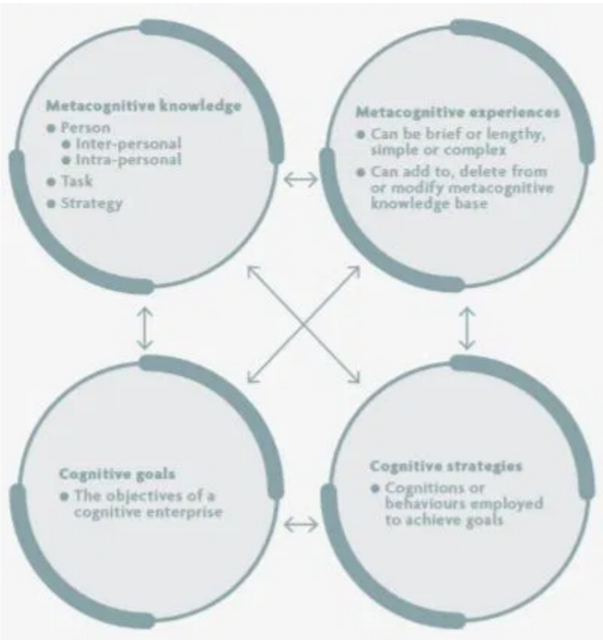

Figure 2.1: Flavell’s model of metacognition and cognitive modelling Flavell (1979)

self-regulated learning began gaining popularity as learning theories such as constructivist and social cognitive that focus on the learner’s choices and actions led to the emergence of self-regulation research in the academic domain. In the initial stages, the SRL research revolved around Zimmerman’s social cognitive model of self-regulation Zimmerman (2000) that was also in line with Vygotskian theories Vygotsky (1980) that social interactions with knowledgeable others would facilitate student’s cognitive and metacognitive development. This enabled considering self-regulated learning as an internal process, assisted and influenced by social interactions such as support provided by peers, teachers, parents etc.

2.0.3 Models of SRL

The first comprehensive model of self-regulated learning was proposed by Zimmerman, known as **Triadic Analysis of SRL** Zimmerman (1989) that followed the framework of social cognition theory of learning which involves the covert, behavioural and environmental self-regulation of the learner. The model attempted to understand the self-efficacy perceptions and strategy use and explain their relation to student motivation and academic performance. This later evolved into a more concrete model called **Cyclical phases model** Zimmerman (2000) which defined various phases of the self-regulation process as forethought, performance and self-reflection (Figure 2.2). The forethought phase is characterized by processes of goal setting, planning and strategy selection by the learner and involves various self motivation beliefs related to self-efficacy, interest, goal orientation and expectations. During the performance or volitional control phase, the learner engages in acts of self-observation and self-experimentation through self-instruction, attention and task monitoring while engaging in the task or learning. Finally, in the self-reflection phase, the learner makes self-evaluation of actions, strategies and outcomes to generate attributions about their own learning.

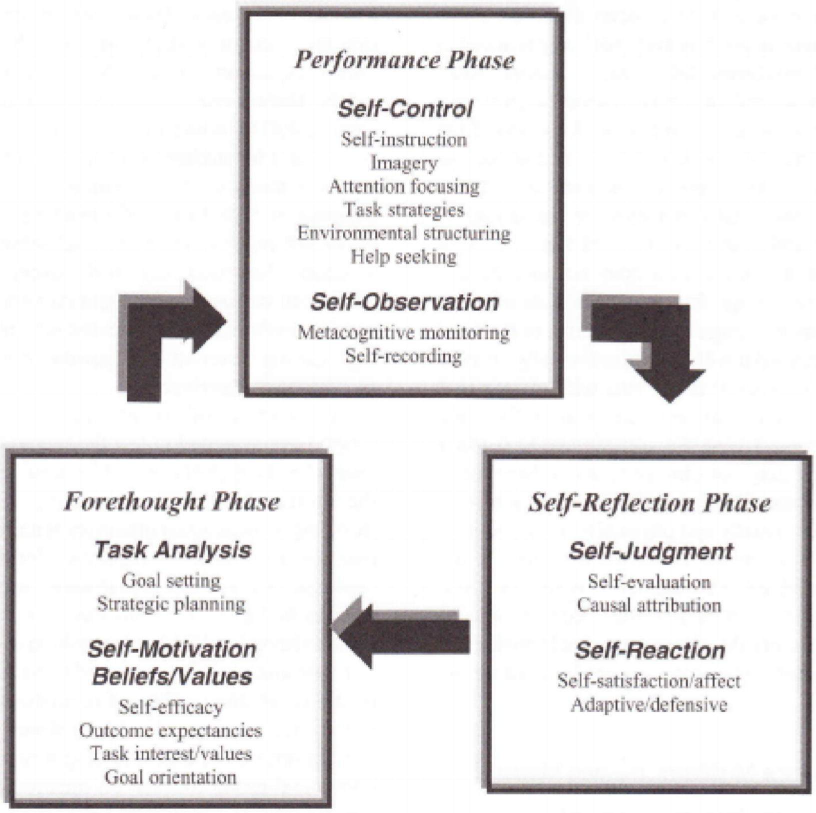

Figure 2.2: Cyclical phases model of SRL. *Adapted from Zimmerman and Moylan (2009)*

The model also tries to predict the qualitative aspect of the learning by distinguishing between proactive and reactive learners Zimmerman (2013) by examining the regulatory phases. The proactive learners are characterized by high-quality forethought and performance phases while the reactive learners focus more on the reflective phase after evaluating the outcomes. Zimmermann also associates higher self-efficacy beliefs, goal and outcome expectations as well as task interest/value traits with proactive learners. According to the model, reactive learner's self-judgement are greatly dependent on the performance of their peers as they insist more on the social comparisons rather than mastery or goal evaluations after the performance. Similarly, attribution of error by reactive learners would invoke negative affect through defensive inferences while proactive learners interpret it as indicators for goal correction and hence sustain positive affect through adaptive inferences.

Various studies conducted based on the Cyclical phases model spread across academic and athletic skills. Woodman and Hardy (2001) evaluated the self-regulation behaviours of adolescent boys in a basketball game task comparing expert, non-expert and novice groups. The study reported evidence for the cyclical phases model as experts displayed higher forethought, self-efficacy and intrinsic interest as well as better self-monitoring and strategy use while non experts and novice groups tended to engage in monitoring only after receiving outcomes. In a subsequent study of instruction with novice students Brown et al. (2006), organized into five groups: one-phase SRL, two phases SRL, three-phases SRL, control group with practice-only and control group without practice. The results found a positive linear trend in performance with respect to the SRL training delivered. A microanalytic study DiBenedetto and Zimmerman (2010) conducted on high school students in a science task concluded that higher achievers tend to use more of the sub-processes in Zimmerman's cyclical phase model than those who are average and low achievers, regardless of gender. Zimmerman's model paved the way for the development of various theories of SRL as well as instruments such as learning diaries Schmitz and Perels (2011).

Another significant model in the earlier stages of the SRL domain was Boekaert's **Dual Processing Self-regulation model** Boekaerts and Cascallar (2006) which offered a framework for including affect and goal orientation to the regulation process (Figure 2.3). This mode of SRL describes two pathways of learning goal orientation, namely (i) mastery and (ii) well-being pathways. According to Boekaerts (2011), there are three different purposes for self-regulation: (a) expanding knowledge and skills, (b) preventing threat to the self and loss of resources so that one's well-being is kept within reasonable bounds and (c) protecting one's commitments by using activities that re-route attention from the well-being pathway to the mastery pathway. The mastery pathway is described as "top-down" where the learners are motivated by the task and personal goals which trigger positive affect while the wellbeing pathway is characterized by risk avoidance and mismatch between task and personal goals that result in negative affect. The redirection of learning directions happens when the affective states of the learner get influenced internally or externally through peer learners or the environment. This allowed Boekart's model to be adapted for various learning interventions and experiments involving the regulation of emotions as a means for influencing the learner goal orientation.

A study on mathematics learning Seegers and Boekaerts (1993) by students of primary education was conducted to understand the interaction between affective and cognitive variables mentioned in Boekaert's model. The results reported that perceived personal relevance and task attraction supported learning. Another study by Boekaerts (2001) which

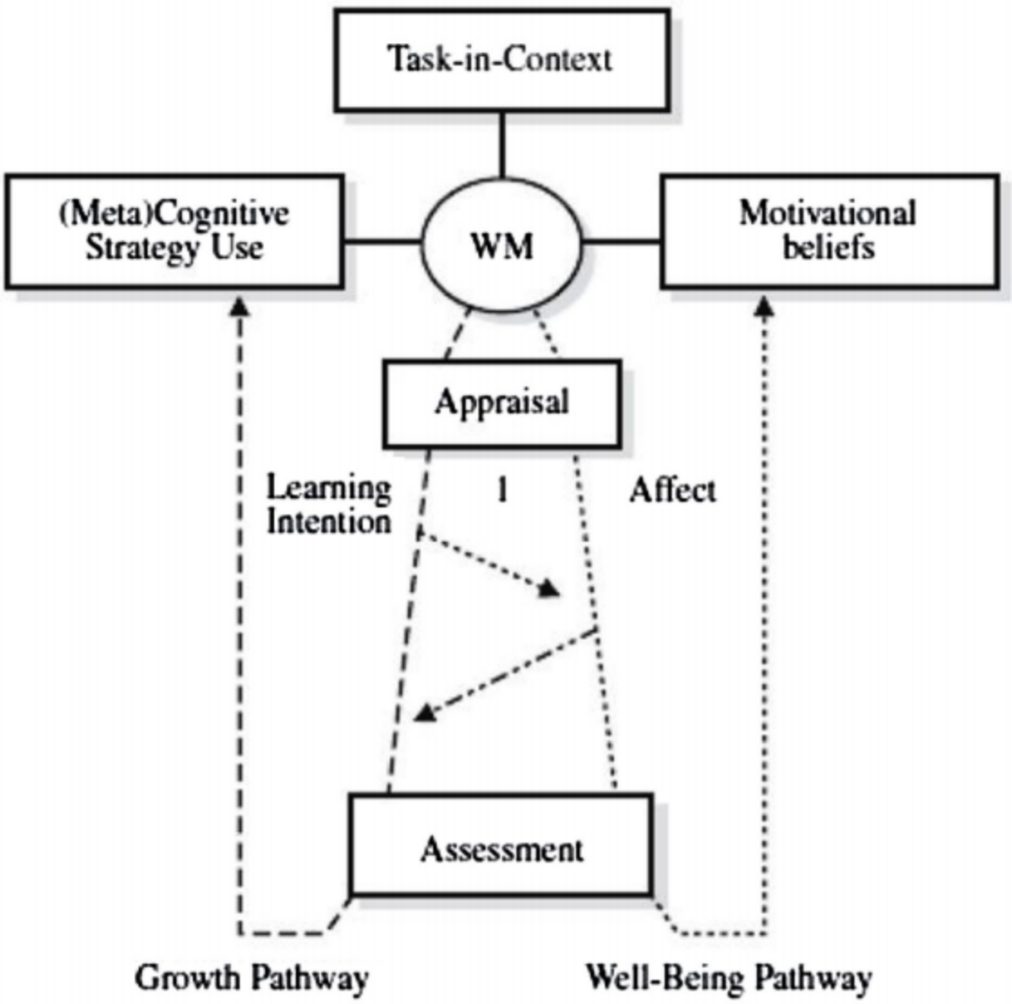

Figure 2.3: Dual processing self-regulation model. *Adapted from Boekaerts (2011)*

looked for the evidence of activation of motivational pathways identified value-directed and outcome-directed learning behaviours that had distinct impacts on the self-concept of ability and affect of the learners. In studies that examined the impact of affective and cognitive variables such as competence and value on outcome attributions Boekaerts (2007), it was found that the learners who reported higher value of the task prior to the performance, expressed increased reported effort as well. Also, the empirical evidence for the dual processing model suggests that invoking positive affect could benefit the learning by improving self-concept of ability, interest and value of the task and activating performance and mastery goals effectively.

Metacognitive aspects of SRL were deeply explored by **Winne's model** Winne (1996) of SRL which followed the framework of information processing theory (Figure 2.4). This model identifies feedback loops of cognitive and metacognitive processes involved in self-regulation as the distinct episodes in the learning interaction. According to this model, the self-regulatory process during the learning involves four phases of (i) Task definition: when the learners formulate the understanding of the task, (ii) goal setting and planning: as they identify goals and strategies to be exercised, (iii) enacting study tactics and strategies: as they apply the selected strategies for achieving personal or cognitive goals and (iv) metacognitive adoption: which occurs when the learners evaluate the outcomes and adapt themselves for changing goals, beliefs or strategies for further learning. These phases are defined as open and recursive and are bound to a feedback loop and draw relevant metacognitive monitoring and control Nodoushan (2012).

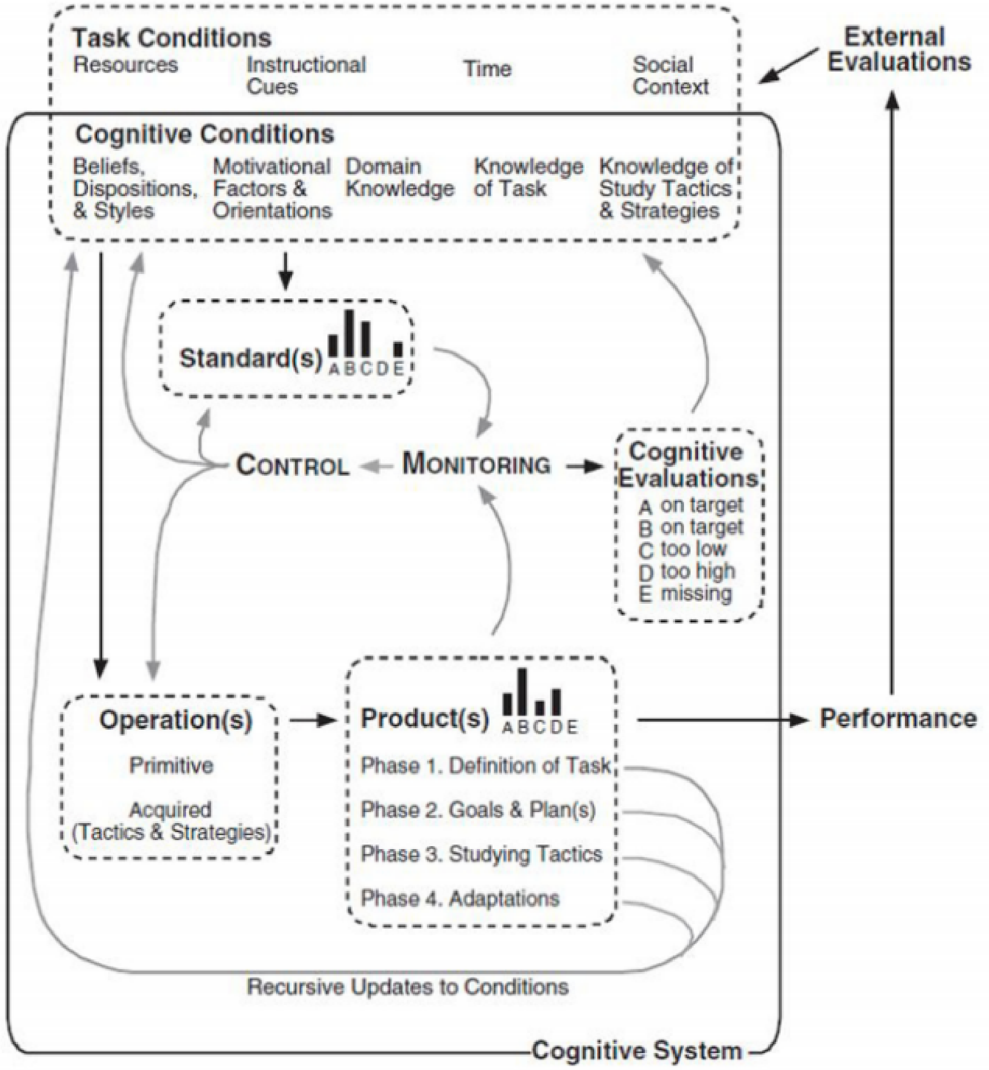

Figure 2.4: Winne's SRL model. *Adapted from Winne and Hadwin (1998)*

Another unique contribution of Winne's model was the definition of various facets of the task that can occur during the phases of regulation. According to the model, the components of the task were defined Winne and Hadwin (1998) as follows: (i) Conditions: resources available to a person and the constraints inherent to a task or environment (e.g., context, time); (ii) Operations: the cognitive processes, tactics and strategies used by the student such as searching, monitoring, assembling, rehearsing and translating, (iii) Products: the information created by operations,(iv) Evaluations: feedback about the fit between products and standards that are either generated internally by the student or provided by external sources (e.g., teacher or peer feedback); and (v) Standards: criteria against which products are monitored. Notably, the model gives only little emphasis on the affective aspects of learning.

Winne's model was adapted for the development of various studies and implementation in computer-supported learning settings Brehmer et al. (2016). A review of studies of SRL based on Winne's model by Azevedo et al. (2007) revealed wider adoption of the framework for exploring aspects of context Bråten et al. (2005), teacher influences Perry et al. (2002), domain knowledge Alexander et al. (2004), cognitive evaluation De Bruin et al. (2005) etc. Based on the model, a web-based learning application called nStudy Winne and Hadwin (2013), for identifying and operating skills of learning, metacognition and self regulation was developed. This approach also allowed recording the trace measures Malmberg (2014) during the learning and facilitated the development of temporal and sequential analysis Azevedo et al. (2010) of learner behaviours for real-time and fine-grained insight on the SRL states of the learner Winne et al. (2011).

Another model of SRL which contributed to a comprehensive understanding of regulatory phases and various internal processes was **Pintrich's model of SRL** Pintrich (2000). According to Pintrich, SRL constituted four phases namely, (i) Forethought, planning and activation; (ii) Monitoring; (iii) Control; and (iv) Reaction and reflection and each of these phases had a cognitive, motivational, behavioural and contextual aspect of the regulation (Figure 2.5). This model shares many facets of regulation with Zimmerman's model of SRL but brings more emphasis on context and motivational dimensions Puustinen and Pulkkinen (2001) than the latter.

	Areas for regulation			
Phases	Cognition	Motivation/affect	Behavior	Context
1. Forethought, planning, and activation	Target goal setting Prior content knowledge activation Metacognitive knowledge activation	Goal orientation adoption Efficacy judgments Ease of learning judgements (EOLs); perceptions of task difficulty Task value activation Interest activation	[Time and effort planning] [Planning for self-observations of behavior]	[Perceptions of task] [Perceptions of context]
2. Monitoring	Metacognitive awareness and monitoring of cognition (FOKs, JOLs)	Awareness and monitoring of motivation and affect	Awareness and monitoring of effort, time use, need for help Self-observation of behavior	Monitoring changing task and context conditions
3. Control	Selection and adaptation of cognitive strategies for learning, thinking	Selection and adaptation of strategies for managing motivation and affect	Increase/decrease effort Persist, give up Help-seeking behavior	Change or renegotiate task Change or leave context
4. Reaction and reflection	Cognitive judgments Attributions	Affective reactions Attributions	Choice behavior	Evaluation of task Evaluation of context

Figure 2.5: Pintrich's SRL model. *Adapted from Pintrich (2000)*

Various other models of SRL were formulated giving emphasis to the metacognitive and motivational aspects of the learner Dunlosky and Metcalfe (2008); Verhallen and Bus (2010); Myers and Crowther (2009), yet a comprehensive model incorporating cognitive, metacognitive, affective and social dimensions of SRL was missing. The Efklide's **Metacognitive and Affective Model of Self-Regulated Learning** Renninger and Hidi (2011) fits into this gap and explains the regulation in two levels of abstraction ie (i) Personal/-macro level and (ii) Task x Person level (Figure 2.6). The Personal level also known as macro-level involves the processes of cognition, motivation, self-concept, affect, volition and metacognition represented distinctly as metacognitive knowledge and metacognitive skills. At this level, the personal and cognitive goals of the learner determine the cognitive processing of the information, interest and value attributions of the task, affective states of the learner etc. The Task x Person level or micro-level level is driven by the task or the facets of learning interaction, which involves four basic functions which are (i) cognition, (ii) metacognition, (iii) affect and (iv) regulation of affect and effort. The MASRL model and the related interventions had made the understandings interactions between cognition, metacognition and affect at the interaction and personal level clearer. A study Efklides and Vlachopoulos (2012) on mathematical ability tasks with high school and university students identified distinct metacognitive knowledge at the person and task levels.

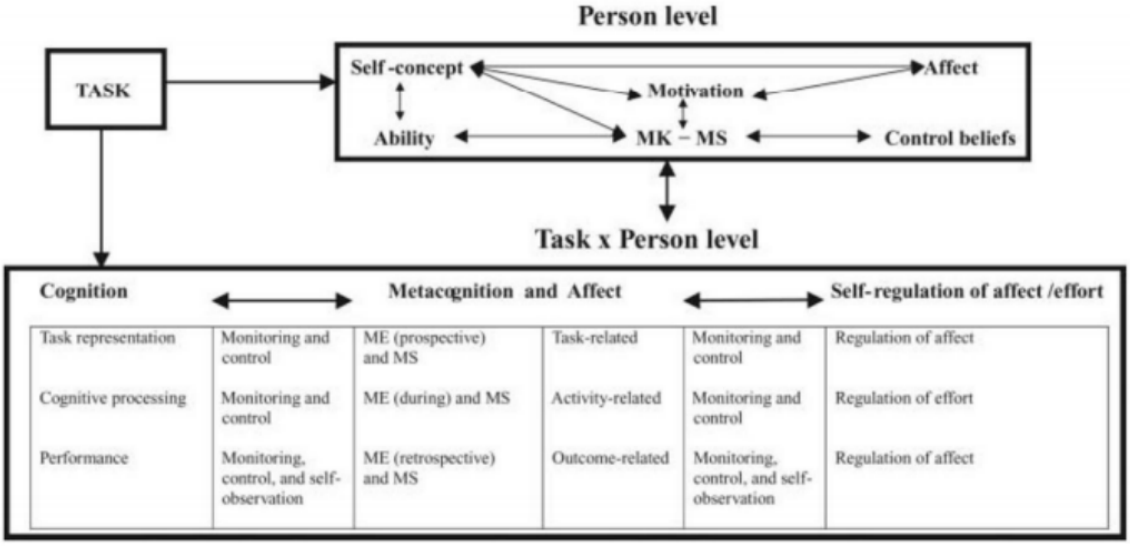

Figure 2.6: Metacognitive and affective Model of Self-Regulated Learning model (MASRL). *Adapted from Efklides and Vlachopoulos (2012)*

2.1 Socially shared regulation model(SSRL)

Skills and competencies expected out of a learner in the 21st-century Brantsch et al. (2008) have transformed greatly since information has become more accessible, abundant and diverse. The new challenge faced by the educators of current times is in preparing the learners to effectively use and assess this information and transform it into relevant knowledge and higher-order skills. The rapid emergence and obsolescence of knowledge in the 21st-century Luna Scott (2015) demand pedagogical methods that can advance creativity, critical thinking, inquiry, collaboration and lifelong learning skills in the learner. The increased emphasis and advancements in the use of information and communication technology(ICT) Sarkar (2012) to develop Intelligent Tutoring Systems(ITS) Nye (2015) and Computer-supported learning environments (CBLE) Moos and Azevedo (2009) have greatly influenced learning interventions and related research in the past few decades.

Collaboration can be defined as a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem Roschelle and Teasley (1995). Various kinds of task or non-task related social interactions such as argumentation, conflict resolution, rapport building, team orientation, mutual regulation involved in collaborative learning interactions are observed to be essential for ensuring effective learning outcomes. The early theories of collaboration in learning Dillenbourg (1999) were grounded in the socio-constructivist approach inspired from Piaget's theories and considered collaboration as an opportunity for individual cognitive development initiated by socio-cognitive conflicts. The Vygotskian socio-cultural perspective John-Steiner and Mahn (1996) on collaboration identified the development in inter-psychological and intra-psychological levels which are characterised by social speech and inner speech respectively. Social speech is a function of group regulation and expression while inner speech serves as a function of self-regulation and internalisation. The shared cognition approach on collaboration relates to the situated learning theory of learning and takes the social and physical contexts of the environment as an integral part of learning. Computer-supported collaborative learning environments have enabled interventions in the social processes during learning by the means of artificial pedagogical agents such as virtual agents or social robots and their roles and behaviours towards the learner. Collaborative groups can be considered as social systems consisting of multiple self-regulating individuals who must at the same time regulate together as a social entity Järvelä et al. (2016).

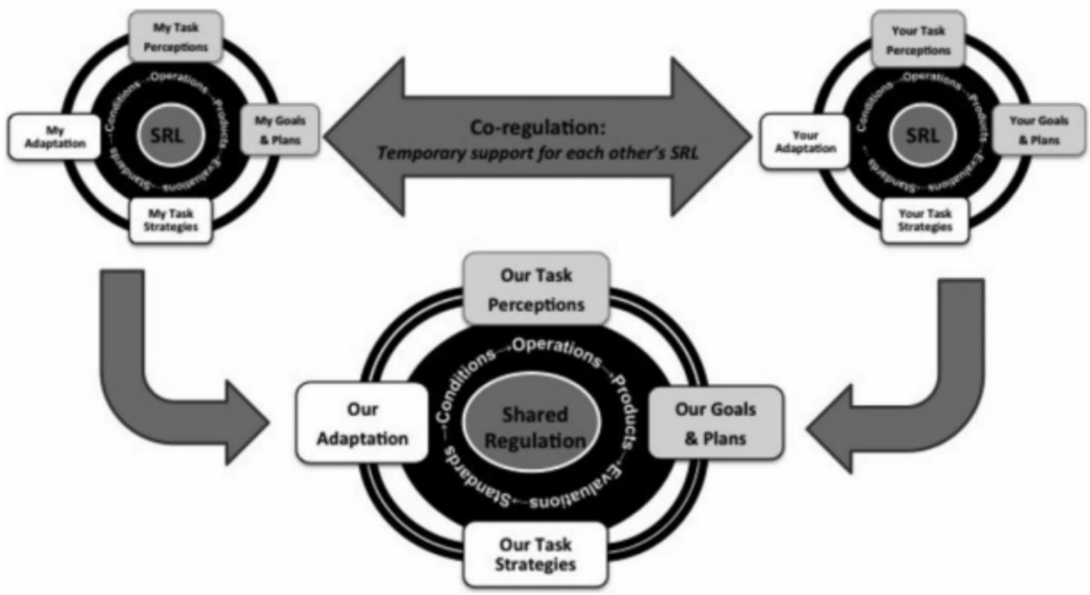

Figure 2.7: Socially shared regulated learning model

The socially shared regulation model(SSRL) proposed by Hadwin, Järvelä, and Miller Hadwin et al. (2018), brings the element of collaboration into the context by explaining the intertwining of individual and social processes in self-regulation Volet et al. (2009b). For a successful collaboration, the group of learners need to coordinate the efforts, establish common ground through negotiations and share resources, perceptions, strategies and goals effectively Castelli et al. (2008). The SSRL model is in great congruence with the present scenarios of learning which are often mediated by ICT tools and happening in computer-supported collaborative learning (CSCL) settings. The model of socially shared regulation makes certain assumptions about the nature of regulation in learning to operationalize the definitions of phases and modes involved. These are :

1. Regulation is a multi-faceted process containing aspects of metacognition, behaviour, motivation and cognition which are not isolated but influential on each other.

2. Regulation assumes human agency as the learner is associated with the capacity to make choices driven by purpose, intents and goals.

3. Regulation is cyclical and takes place over a period of time being shaped by the knowledge, belief and experiences of the learner.

4. Regulation is linked to personal and social experiences influenced by mental models of self, others, task and knowledge from the acquired experiences.

5. Regulation involves timely adoption to new challenges and situations emerging in the group and environment

6. Regulation is socially situated and comprises a complex dynamic exchange of knowledge and beliefs influenced by factors such as personal meaning, outcome utility, task value and past experiences.

The SSRL model Hadwin et al. (2011) identifies three distinct modes of regulation happening in collaborative learning environments namely: (i) self-regulation(SRL), (ii) Co-regulation (CoRL) and (iii) Socially shared regulation(SSRL) (Figure 2.7). According to the SSRL model, self-regulation(SRL) in collaboration involves cognitive, metacognitive, motivational, behavioural and emotional regulation strategies employed by the learner during the interaction with other participants and the learning environment. Co-regulation in SSRL context refers to a transitional process in a learner's acquisition of self-regulated learning, appropriated by strategic planning, execution, reflection and adaptation during the interactions with other learners or group members Hadwin et al. (2011). Socially shared regulation (SSRL) occurs when "deliberate, strategic and transactive planning, task enactment, reflection and adaptation" are taken within a group Hadwin et al. (2018). SSRL refers to processes by which group members regulate their collective activity, which is different to co-regulation of learning, where individuals' regulatory activities are guided, supported or prompted by and with others, especially in collaborative learning contexts. Coregulation is an unevenly distributed form of social regulation where the co-regulator mediates the metacognitive and cognitive activities of the co-regulated, thereby influencing the regulation of his/her learning process while SSRL is considered as an evenly distributed social regulation that arises from interactions and exchanges with a learning group Schoor et al. (2015).

The SSRL model Järvelä et al. (2013) consists of four loosely sequenced and recursively linked feedback loops Panadero (2017) emerging during a collaborative learning interaction (Figure 2.8). During the first loop, groups negotiate and construct shared task perceptions based on internal and external task conditions. Through the second loop, groups set shared goals for the task and make plans about how to approach the task together. In the third loop, groups strategically coordinate their collaboration and monitor their progress. Based on this monitoring activity, the groups can change their task perceptions, goals, plans, or strategies in order to optimize their collective activity. Finally, in the fourth loop, groups evaluate and regulate for future performance Bransen et al. (2021). Thus socially shared regulation involves groups taking metacognitive control of the task

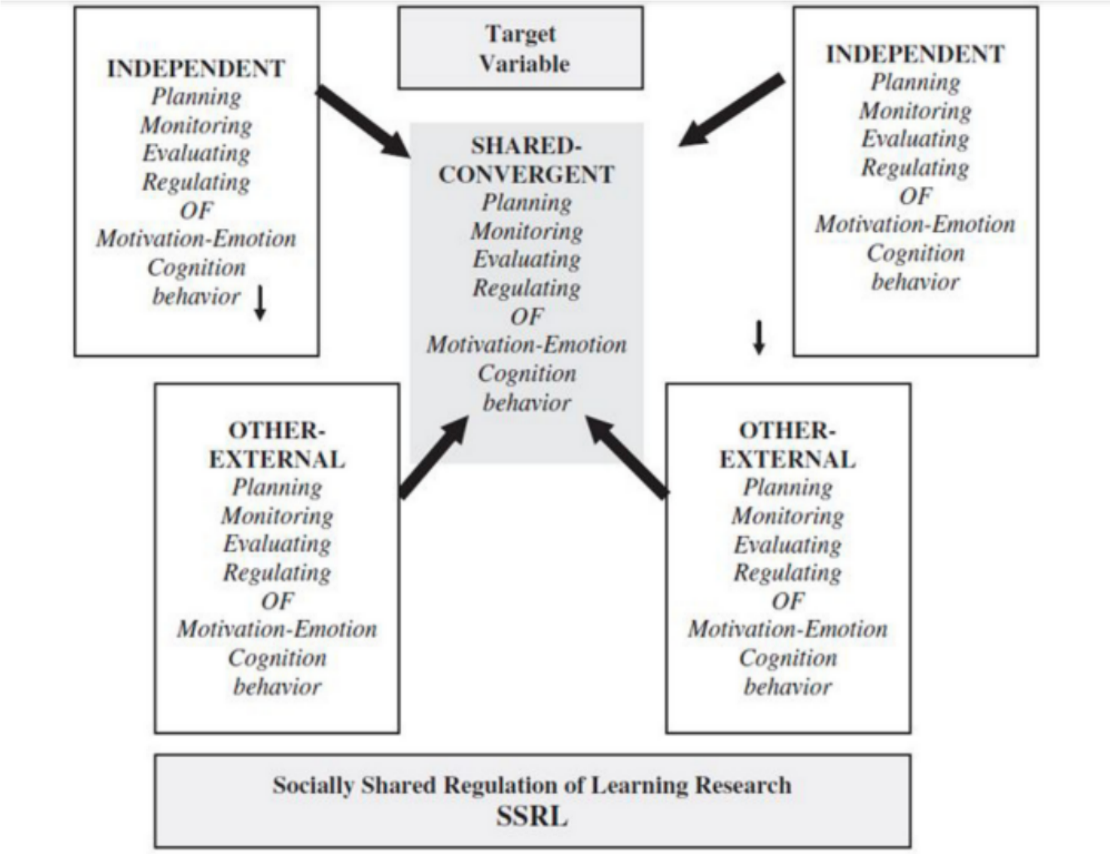

Figure 2.8: Elements of Socially shared regulated learning model. *Adapted from Hadwin et al. (2011)*

together through negotiated, iterative fine-tuning of cognitive, behavioural, motivational and emotional conditions/states as needed Järvelä and Hadwin (2013).

2.1.1 Evidences of SSRL

Empirical studies on socially shared regulation consider individually regulated processes as a part of socially constructed knowledge Hadwin et al. (2011). The evidence of the occurrence of cognitive, metacognitive, motivational and emotional facets of SSRL has been found in various studies and interventions implemented based on the model. The comprehensive framework of SSRL that combines cognitive, metacognitive, behavioural and motivational aspects of learning with collaboration has enabled wider adoption of the model in computer-supported collaborative learning environments and produced promising results in understanding regulation at individual and group levels. In general, the impacts of shared regulatory processes happening in SSRL contexts can be categorised into the following sections: (i) Joint cognitive and metacognitive strategies, (ii) Motivational and emotional regulation and (iii) Learning and performance outcomes

2.1.1.1 Joint cognitive and metacognitive strategies in SSRL

An early case analysis Vauras et al. (2003) that explored how socially shared regulation of motivation emerges in a peer-mediated learning of mathematical problem solving among 4th-grade students, reported mirroring of egalitarian, complementary monitoring and regulation over the task and transfer of learning. The existence of distinct low-level and high-level co-regulation processes was revealed Volet et al. (2009a) from the video analysis of students working on case-based projects where high-level co-regulation was commonly preceded by acts of questioning or explanation. In a comparison of the traditional way of collaboration with a technology-enabled collaboration in medical the decision making context, it was observed that early engagement and co-regulation led to better-shared understanding, effective management and adaptive decision-making behaviours within the highly interactive group Lajoie and Lu (2012). A multiple case study Grau and Whitebread (2012) comprising 8 children organised into two working groups over a period of one academic semester reported an increase in SRL behaviours within learners and relationships with focus on activity and social regulation. Based on an empirical study Järvelä et al. (2013) involving 18 graduate students, working in collaborative teams over an 8-week period, it was observed that supporting fellow team members to successfully regulate their learning was significantly important in achieving team goals. Another study Iiskala et al. (2011) on collaborative mathematical problem solving of dyads of high achieving pupils also suggested the use of socially shared metacognition as a relevant factor for the quality of problem solving and recommends its addition to the conceptual tools of learning research. A case study Hurme et al. (2009) on two groups of pre-service primary teaching with a mathematical problem solving task concluded that emergence of socially shared metacognition as a result of regulation behaviours exhibited by highly metacognitive learning partners contributed to a decrease in the individual's feeling of difficulty. On investigating the motivational aspect of SSRL through a qualitative multi-method study involving adaptive instrument, video-recording and group interviews, Järvelä and Järvenoja (2011) identified various activated regulation strategies involved in collaborative learning such as task structuring, social reinforcing, efficacy management, interest enhancement, socially shared goal-oriented talk and handicapping of group functioning.

Interestingly, a variation of co-regulation called directive other-regulation Rogat and Adams-Wiggins (2014) which involves one student taking control of the group's activity resulted in moderate or low-quality regulation and unbalanced participation as compared to facilitative form which yielded higher-quality task contributions and regulation. Through a study of sequences of self and shared regulation activities Zheng et al. (2019) involved in a STEM task on computer-supported collaborative learning (CSCL) environment, it was revealed that higher-achieving groups were more likely to start with self-executing and end with socially shared monitoring, while the less successful group were most likely to start with executing and end with self-executing.

2.1.1.2 Motivational and emotional regulation in SSRL

Järvenoja and Järvelä (2009) explored the interplay of emotional regulation processes between the individual and group levels as well as the socio-emotional challenges involved in SSRL. The results from this study involving groups of teacher education students in a collaborative learning task indicated existence and sharing of emotional and motivational regulation actively influencing the individuals and group to reach goals. A video based analysis of collaborative groups of university science students reported divergent patterns of engagement related to differences in perception of individual and group goals. Additionally, Rogat and Linnenbrink-Garcia (2011) concluded that negative socioemotional interactions would diminish the quality of social regulation in SSRL scenarios. In a study emphasising recognition and response to socio-emotional challenges in SSRL context Näykki et al. (2014), it was observed that avoidance-focused strategies for restoring emotional balance in the group came at the cost of compromised learning and group performance. The results from study on process discovery Malmberg et al. (2015) indicated that SSRL focus and functions varied temporally from regulating the task and environment towards cognitive and motivational aspects, significantly in higher-performing groups.

On observing regulation and socio-emotional interaction in positive and negative group climate, Bakhtiar et al. (2018) identified four distinct group features where (a) incoming conditions served as a foundation for creating a positive collaborative experience, (b) regulation of emotions during initial planning, (c) negative emotions served as a constraint for shared adaptation in the face of a challenge, and (d) encouragement and motivational statements served as effective strategies for creating a positive climate. Another process-oriented study Isohätälä et al. (2020) to understand socio-emotional layers of SSRL suggested that social interactions promoted more active participation behaviours than cognitive interactions. The behavioural changes in participation were also aligned to the shifts between domain focused and metacognitive activities. In another study using S-REG tool Järvenoja et al. (2020) that traces the emotional and motivational states of the group in different sessions, co-regulation was observed to be occurring more frequently while socially shared regulation episodes lasted longer. Also, the emotional and motivational states were associated with the occurrence of co-regulation at the beginning of learning sessions.

2.1.1.3 Learning and performance outcomes of SSRL

The study performed by Summers and Volet (2010) observes a positive correlation of group performance with individual high-level contributions during group work but not necessarily equal collaborative learning as an outcome of the activity. Another study Janssen et al. (2012) on students engaging in a CSCL environment observed that regulation of social activities positively affected group performance, while social interaction negatively affected group performance. The relationship between productive engagement in cognitive activity and metacognitive regulation in collaborative learning was explored by Khosa and Volet (2014) and they found differences in learning outcome of groups engaging in better social regulation. On investigating the relationship between individual self-regulation, socially shared regulation and group performance, Panadero et al. (2015) reported an influence of SRL on SSRL but no significant effect on the group performance Janssen et al. (2009). On observing the effect of group member familiarity in collaborative groups, it was observed that higher familiarity led to more critical and exploratory perceptions and familiar groups had to devote less time for regulating task related activities. Zheng et al. (2017) reported improvements in participant's learning achievements, group performance and regulation frequency while comparing the experiment group involving SSRL approach to a control group based on traditional collaborative tasks. Janssen et al. (2012) studied task-related and social regulation behaviours in online collaborative learning and identified four broad categories of collaborative activities emerging in SSRL which are, (i) discussion of information, (ii) regulation of task-related activities, (iii) regulation of social activities, and (iv) social activities. Also, it was observed that the learners dedicated a good amount of time and effort for task-related and social activities but their regulation did not positively affect group performance. This can be attributed to the factors such as task difficulty and engagement which would demand higher attention for task and social regulation behaviours.

2.2 Summary and insights

The field of SRL research and its adaptation in the educational domain has seen significant progress over the last two decades. Each model discussed here have contributed to the deeper understanding of SRL and its various implications in the learner. All proposed models identify self-regulation as a cyclical process that occurs in various phases. In general, these phases can be categorised into three Panadero (2017) which are,

1. preparatory phase: which involves subprocesses such as forethought, identification, interpretation, task representation, goal setting, primary and secondary appraisals, social reinforcement etc,

2. performance phase: when the learner applies the planned strategies towards achieving personal and group goals through the task activity through subprocesses of monitoring and control of performance, regulation of motivation, affect and effort, metacognitive awareness of cognition such as feeling of knowledge,

3. appraisal phase: as the learner engages in self-judgement and performance evaluation through subprocesses of reaction and reflection generating cognitive judgements and attributions as well as affective reactions to the generated learning outcome.

The models of SRL differ in terms of the emphasis given to the cognitive, motivational, behavioural and contextual dimensions. Zimmermann's models of SRL Zimmerman (1989) focuses greatly on the individual level and subprocesses on each phase while Boekaert's Dual Processing Self-regulation model Boekaerts and Cascallar (2006) laid a stronger emphasis on emotion and motivation in determining the learning orientations. Winne's SRL model Winne (1996) was characterised by the clear distinction of cognitive and metacognitive sub-processes in relation to various task conditions, while downplaying the emotional and social dimensions. Pintrich's model of SRL Pintrich (2000) was grounded in cognitive and motivational aspects of SRL while the MASRL model Renninger and Hidi (2011) was the first model to distinguish the SRL processes into the personal level and interaction level abstractions. The socially shared regulation model Hadwin et al. (2018) stands out being relevant for the current times as it addresses the cognitive, metacognitive, motivational and emotional aspects of SRL through placing the context in a shared learning interaction involving individual learners of various roles and abilities co-constructing learning goals, monitoring and adapting perceptions and generating shared evaluations and perceptions of learning as an emerging collective group. This configuration is greatly analogous to the real-life interactions happening in modern learning environments and makes it suitable for our research towards developing a regulation scaffolding system for a collaborative learning interaction involving multiple roles of pedagogical agents focusing on self-regulation of the learner.

The key points of this Chapter:

- Regulation of learning entails the processes of goal setting, monitoring progress, analyzing feedback, adjustment of goal-directed actions and/or of the definition of the goal.
- Self-regulation is a cyclical process that involves various phases of planning, performance, monitoring and reflection.
- Earlier models of SRL focused greatly on individual level processes while later models started addressing the emotional and social dimensions of regulation.
- Socially shared regulation in learning (SSRL) explores regulation in the context of collaboration and occurs when “deliberate, strategic and transactive planning, task enactment, reflection and adaptation” are taken within a group of learners.

Part III

Related Work

Chapter 3

Related Work

Contents

This chapter presents an overview of the evolution and characteristics of artificial pedagogical agents and their influences on cognitive, metacognitive and motivational aspects of learning. Different theories motivating the use of pedagogical agents as well as various levels of agent design features are discussed, presenting evidence for the influence of these agents on learning and motivation. We then describe how pedagogical agents have been adopted in the research on self-regulated learning and focus specifically on the aspect of socially shared regulation to identify the challenges and limitations in the field that motivates the development of a regulation scaffolding system based on pedagogical agent roles and behaviours presented in our research.

3.1 Evolution of pedagogical agents

Over the past century, various learning theories and methods have transformed the way learners interact with their environment and other learning partners as well as the approach towards various learning strategies. Scaffolding is the support or feedback that is given in a timely manner to help a learner achieve a goal that they may not have without that support Jones and Castellano (2018). According to Vygotsky's theory of social learning Vygotsky (1980), learning involves the expansion of the zone of proximal development of the learner which is defined as the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem-solving under guidance or collaboration with more capable peers. Such scaffolding often involves the use of semiotic and environmental tools that can augment the mental functions of attention, sensation, perception and memory to assist the learner.

3.1.1 Computer-assisted scaffolding

The use of educational tools and scaffolding systems became more prevalent as the notions of social and situated learning became prominent, giving more emphasis to the learning interactions based on problems, projects and inquiry Bell (2010). Advancements in Information and Communication Technologies(ICT) led to the evolution of Technology Enhanced Learning Environment(TELEs) that leveraged the notion of 'learning by doing' where learners are mediated by technology artifacts and tools of learning. Various approaches were seen in the implementation of TELEs and studies have shown that an appropriate delivery of ICT can increase the educational quality and transfer learning to real-life situations van Weert et al. (2005). The interventions created using TELEs can be broadly categorised to three Kirkwood and Price (2014) : (i) replication of existing teaching practices, (ii) supplementing existing teaching, (iii) transforming teaching and/or learning processes and outcomes. In general the scaffolding possible in a TELE-based learning environment could be classified as follows Hill and Hannafin (2001):

- Conceptual scaffolds: that allow the learner to internalize and visualize the patterns and concepts involved and establish connections with their prior knowledge and experiences.
- Meta-cognitive scaffolds: that provide support for learners to evaluate, assess and reflect on their actions and outcomes during the learning process.
- Procedural scaffolds: which are instructions or feedback provided to guide the learner in the desired learning pathway that ensures utilization of resources and maximize productivity in learning.

- Strategic scaffolds: that supports the learner in selecting and managing the learning goals and actions to achieve them based on the performance and the feedback available.

It has been observed that technology enabled learning environments enable students to access information efficiently and facilitate self direction and self regulated learning Sanchez and Alemán (2011). Based on a constructive learning approach, Levin and Wadmany (2006) observes that ICT intervention helps the students to focus on higher-level concepts rather than less meaningful tasks. The study conducted by McMahon (2009) showed that there were statistically significant correlations between studying with ICT tools and the acquisition of critical thinking skills.

3.1.2 Computer-Based Learning Environments(CBLEs)

Computer-Based Learning Environments(CBLEs) such as multimedia and web-enabled learning environments Devolder et al. (2012) were characterised by non-linear and non-sequential information delivery and the use of multiple representation formats for knowledge and information such as text, diagrams, graphics, animation, video, audio etc Mayer (2001). These open-ended learning environments Iiyoshi and Hannafin (1998) gave the learners more control over their actions and thus enabled them to choose, organize, analyze and process the resources based on their learning goals and orientations. These systems were grounded on constructivist learning and hence focused on the learner to direct the entire process and leveraged technology as an active tool for manipulating information and creating knowledge representations. This often resulted in the scaffolding mechanisms becoming too static and generic as attention and timeliness related factors are often disregarded and demanded a system capable of delivering appropriate scaffolding dynamically by diagnosing, calibrating and adapting to a particular learner in a specific context Molenaar and Roda (2008).

Intelligent Tutoring Systems(ITS) Kulik and Fletcher (2016) emerged to fill the gap of adaptive learner scaffolding which was missing in the CBLE and TELE based interventions which often centred on the learner's inquiry and actions. Intelligent Tutoring Systems (ITS) were information-structured tutors Carbonell (1970) that relied on organized and domain-specific knowledge databases as well as computational and dialogue-generating tools to establish tutorial interactions with learners. According to Kulik and Fletcher (2016), Intelligent Tutoring Systems (ITS) include three elements which are: (i) an explicit domain knowledge model that contains the foundations, concepts, and rules that experts understand and use in solving problems in the domain; (b) a dynamic student model, which keeps track of the student's state of knowledge with regard to the domain; and (c) a pedagogical module, which chooses tutoring strategies and actions to apply in specific situations for specific students. Later, an additional element of the user interface that facilitates the communication with the learner was also added to the ITS framework.

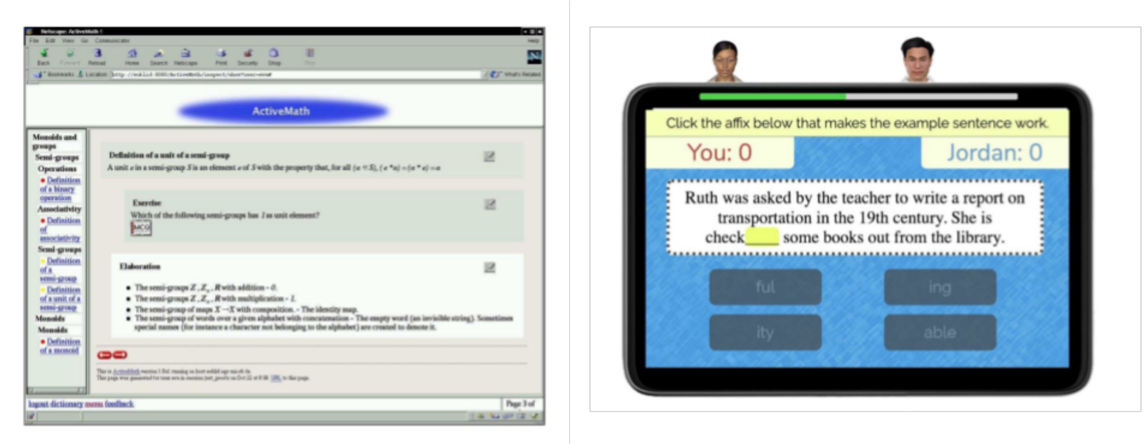

Figure 3.1: Examples of Intelligent Tutoring Systems (ITS). (i) ActiveMath Melis et al. (2001) and (ii) AutuTutor Graesser et al. (2005)

SCHOLAR Carbonell (1970), which is considered as one the first ITS systems, followed a three-model architecture consisting of an expert knowledge module, student model module and tutoring module that focused on reviewing the student's geographical knowledge Woolf (2010). Various ITS systems such as CAPIT Mayo et al. (2000), ITSPOKE Litman and Silliman (2004), ActiveMath Melis et al. (2001), KGTutor Zhuge and Li (2004), MathTutor Cardoso et al. (2004), JavaTutor Wiggins et al. (2015), ArduinoTutor Albatish et al. (2018) etc were developed over the years that followed methods such as condition-action rule-based reasoning, case-based reasoning and AI techniques such as bayesian, fuzzy, data mining and ANN based learner modelling Almasri et al. (2019). AutoTutor Graesser et al. (2005) is a notable intelligent tutoring system with mixed-initiative dialogue that simulated a human tutor capable of establishing a conversation with the learner in natural language (Figure 3.1). Though these systems excelled in providing task and knowledge guidance, an element of social and motivational guidance was greatly missing in these learning interactions which inspired the development of Computer-Supported Collaborative Learning (CSCL)(Paviotti et al. (2012); Mousavinasab et al. (2021)).

3.2 Theories of pedagogical agents

Pedagogical agents can be defined as intelligent artificial learning partners (single or multi) that can support the student's learning and use various strategies in an interactive learning environment Martha and Santoso (2019). The emergence of intelligent pedagogical agents can be connected to various theories and frameworks. The Computers as Social Actors(CASA) paradigm Nass and Moon (2000) Reeves and Nass (1996) considers computers as social entities and suggests that humans treat media and computers like real people applying scripts for interacting with humans to interactions with social technologies. Such perspectives have triggered the transformation of Intelligent Tutoring Systems(ITS) into more capable and interactive agent representations to aid learning. Cognitive apprenticeship is a process through which learners learn from a more experienced learning partner through cognitive and meta-cognitive processes such as scaffolding, articulation, exploration, modelling and reflection Dennen and Burner (2008). Following are various key theories that form ground to the literature on pedagogical agent research:

- Social-cognitive theory: Theories of social-cognition Bandura (2005) considers teaching and learning as social activities greatly influenced by the learning partners and environment. As the learner engages in a learning activity, there is a dynamic interaction with other participants, tools, context and artificial pedagogical agents that can enhance such socio-cognitive affordances required for an effective learning interaction.

- Distributed cognition: In this perspective, human cognition is not just limited to the learner's mind and is distributed among the individuals, tools and artifacts in the learning environment Hutchins (2000). Hence pedagogical agents can be designed to share and assist learner's cognition and can function as a cognitive and social tool for scaffolding Lin et al. (2015).

- Social agency theory: According to Louwerse et al. (2005), social cues like facial expressions and voice features of agent can motivate the learners to interpret them as social actors and can prime social conversation schema in learners. Design and implementation of pedagogical agents based on social cues have proved to improve learning (Craig and Schroeder (2017); van der Meij et al. (2015)), facilitate meaningful interactions (Liew and Tan (2016);Suki and Suki (2017)) through scaffolding and guidance Terzidou and Tsiatsos (2014).

Theories of social-constructivism Cash (2013) suggests that social interactions and conflicts between the learning partners could lead to cognitive reorganizations and development in learning. Computer-Supported Collaborative Learning (CSCL) sets construction of shared understandings and inter-subjective meaning-making as the key objectives of a collaborative learning interaction. Distributed cognition Lehtinen et al. (1999) refers to a process in which cognitive resources are shared socially in order to extend individual cognitive resources or to accomplish something that an individual agent could not achieve alone. This distribution can occur through exercises of cooperation as well as collaboration which are distinctly different in terms of learner participation and goals. In cooperation Stahl et al. (2006), partners split the work, solve sub-tasks individually and then assemble the partial results into the final output while collaboration is a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem Roschelle and Teasley (1995).

Various collaborative tools and approaches such as discussion boards, simulations, games, immersive interactions were developed in CSCL research towards exploring cognitive, meta-cognitive, motivational and emotional aspects of learning. Collaborative tools called CIF and MoCAS Serrano-Cámara et al. (2014) were used to understand the motivational influences of collaborative learning and suggest higher levels of intrinsic and extrinsic motivation among the students compared to traditional pedagogical approaches. CSCL systems enabled student groups to externalize their knowledge representations in the form of diagrams and graphs for teaching and learning mathematical problem solving and provided evidence for supporting effective reflection and mutual interactions among the learners Lehtinen et al. (1998). Collaborative learning also involves challenges O'Donnell and King (2014) that arise during group interaction and peer collaborations and hence calls for careful structuring and orchestration to ensure productive interaction Dillenbourg et al. (2009).

3.3 Pedagogical agent research characteristics

The initial phases of research on pedagogical agents were focused on the technological perspective, giving more emphasis to the characteristics such as intelligence Lelouche (2000), believability Lester and Stone (1997), likeability Moreno et al. (2002), perception of animated appearance Johnson (2001a), affective behaviours Okonkwo and Vassileva (2001) and learner engagement Conati and Zhao (2004) Johnson et al. (1998) etc. Studies on persona effect Lester et al. (1997a) suggested that the mere presence of pedagogical agents could facilitate learning and student's perception of their learning which shifted the attention to learning outcomes and pedagogical behaviours Moreno (2005). The research and literature on pedagogical agents raise various questions such as

- (i) How pedagogical agents could be designed and what are the various appearance and embodiment aspects involved?
- (ii) What are the various roles assigned to these agents in a learning environment?
- (iii) How pedagogical agents can influence different aspects of learning, student behaviours and perceptions?

The following sections of this chapter present an overview of these aspects of pedagogical agents and their implications.

3.3.1 Levels of agent design

According to Domagk (2010), the design features of pedagogical agents comprise of various levels of abstractions which can be categorised as (i) global design level, (ii) medium design level and (iii) detail design level as shown in Figure 3.2. On a global level, pedagogical agents can be categorised as human-like and non-human characters implemented through static images, videos or animations Lusk and Atkinson (2007). In terms of design, pedagogical agents were implemented through elements such as text, voice, 2-D character, 3-D character and physical entities like robots and often involves a combination of multiple modalities Baylor and Ryu (2003). The medium level involves technical aspects such as appearance, behaviours, emotional expression, conversational and animation methods etc (Dirkin et al. (2005); Dunsworth and Atkinson (2007)) and choice of character features like pedagogical role, agent competence level, social attitudes etc Baylor (2003a). The detail level design involves features such as age, gender, voice, clothing etc that are often guided by the decisions on the global and medium levels of design Domagk et al. (2006).

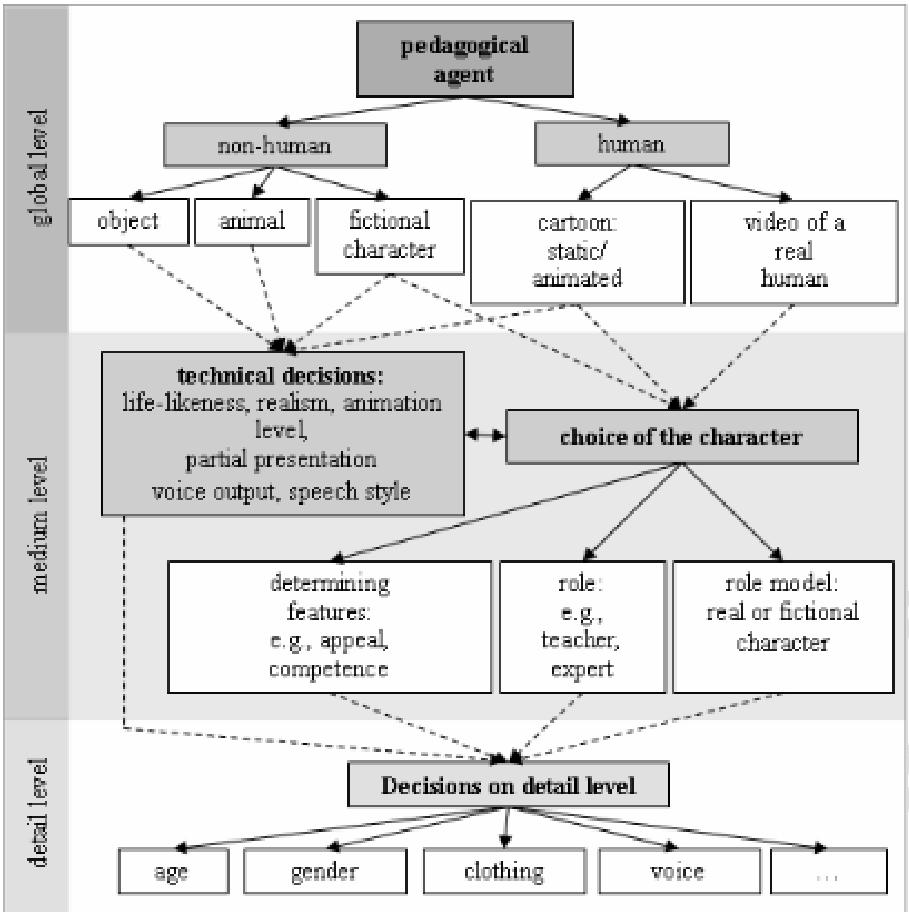

Figure 3.2: Pedagogical agents-levels of design (PALD). *Adopted from Heidig and Clarebout (2011)*

The principle of modalities Clark and Mayer (2016) suggests that learners will learn better when information is delivered by the agents through speech than on-screen text. Technically the conversational agents could be categorised as (i) dialogue systems that provide conversational guidance using natural language Pareto et al. (2012) and (ii) embodied conversational agents which are interactive artificial agents capable of verbal and non-verbal behaviours and feedback Cassell (2001). Earlier implementations of embodied pedagogical agents such as 'Herman the Bug' Stone and Lester (1996) (Figure 3.3) and 'Peedy: The parrot' Ball et al. (1997) adopted non-human features while animated agents like 'ADELE' Johnson (2001b) and 'Dr.Phyz' Mayer et al. (2003) had anthropomorphic features. The aspect of embodiment facilitated various behaviours such as interactive demonstrations, navigational guidance, non-verbal feedback, emotional expression etc to establish adaptive pedagogical interactions. For example, the agent 'STEVE' Johnson and Rickel (1997) utilized head nodding as back-channel feedback to regulate conversation with the learners. Embodied agents can also effectively elicit gaze and deictic gestures for the acts such as pointing and looking at objects in the environment to guide the attention of the learner Johnson et al. (2000). Studies conducted by Lusk and Atkinson (2007) and Baylor and Ryu (2003) reported higher engagement and learning transfer in groups interacting with fully embodied pedagogical agents.

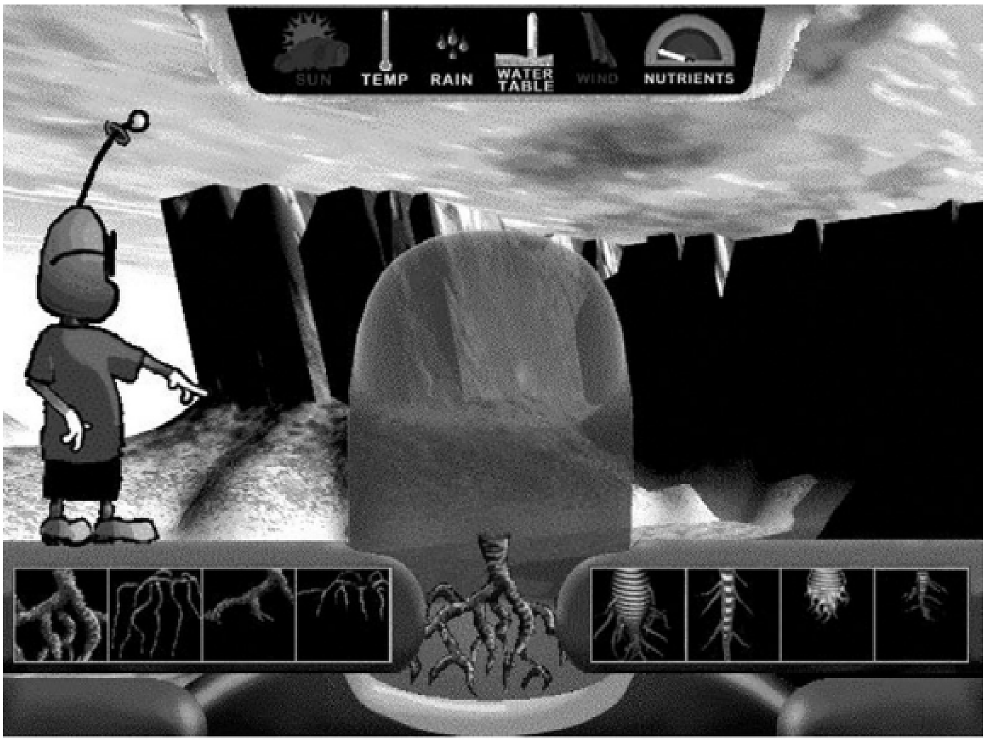

Figure 3.3: The pedagogical agent "Herman the Bug" in the learning environment "Design-a-plant" Lester and Stone (1997)

3.3.2 Agent embodiment

On the global design level, the aspect of embodiment can take virtual and physical forms which are distinct in terms of visual and auditory presence and situatedness (Park (2015); Edwards et al. (2018)). Virtually embodied pedagogical agents such as Baldi, Timo Bosseler and Massaro (2003), Thinking head Milne et al. (2010), Talking head Moundridou and Virvou (2002) , Genie Perez and Solomon (2005) etc were used in various studies on factors such as motivation Choi and Clark (2006), likeability Domagk (2010), engagement Baylor and Ryu (2003), learning transfer and retention Gholson and Craig (2002) etc. Ryokai et al. (2003) developed 'Sam', an embodied conversational peer agent capable of engaging in a collaborative storytelling task with children. The results indicated that improvement in children's linguistic and narrative skills of the learners Ryokai et al. (2002). Kim et al. (2006) looked at the aspect of agent competency and response using another agent called 'Mike' and found a significant impact of agent's proactive behaviour on learner's recall and positive attitude towards the agent (Figure 3.4).

On comparing animated teaching avatars to interactive 2D visualizations, Adamo-Villani and Dib (2016) reported higher learning gains and engagement in learners who interacted with the animated agent. Although virtually embodied agents can enhance learning in many ways, it is also observed to hinder learning and distract the learner especially owing to split-attention effect Ayres and Sweller (2005) which states that demand for distribution of attention between several sources of information could increase the cognitive load (Baylor and Ryu (2003); Craig et al. (2002)). Emphasis on the realism Ruttkay and Pelachaud (2006) and emotional expressiveness Brna et al. (2001) of agents thus became more prominent aiming to make the interactions more intuitive and less cognitively demanding Bercht and Viccari (2000). Kim et al. (2007) explored the influence of emotion and gender on the learner to find that empathetic responses had a positive impact on learner interest and self-efficacy. Veletsianos (2009) reported that expressive agent leads to better retention than non-expressive agents. Another study by Baylor and Kim (2009) on effects of instruction, gesture and facial expression reported that the presence of facial expressions improve attitudinal learning while presence of the gestures improves procedural learning.

Figure 3.4: Pedagogical agents "Mike" (Left, Kim et al. (2007)), "Tom" (Middle: Likeabile, Right: dislikable Domagk (2010))

Physically embodied pedagogical agents are often present in the learning environment as fully/semi-autonomous social robots or programmable educational robot systems Catlin and Woollard (2014); Chevalier et al. (2020) (Figure 3.5). In contrast to the virtual agents, the physically embodied robots enable active engagement through physical and tangible interactions encouraging better social behaviours Kennedy et al. (2015) and increased learning gains Kidd and Breazeal (2004) especially in tasks that require direct physical manipulation of the learning tools and resources Köse et al. (2015). Various studies have been done using the humanoid robot, Nao, in roles such as tutor and peer or as a learning tool Blancas et al. (2015) Causo et al. (2016). Chandra et al. (2016) used the robot to understand learner's assessment in peer-tutoring and peer-learning scenarios revealing significantly more corrective behaviours and self-disclosure attributing to the presence of the robot. Studies such as Law et al. (2020); Jamet et al. (2018); Lemaignan et al. (2016) adopted the pedagogical method of learning by teaching in Nao robots on various task such as spatial arrangement Johal et al. (2016), improving handwriting Hood et al. (2015b), computational thinking Keane et al. (2016) etc. Leite et al. (2015) used another robot called 'Keepon' Kozima et al. (2009) in a storytelling task to improve learner's emotional intelligence and recall skills through interactive role-playing activities. Likewise, the humanoid robot Robovie Ishiguro et al. (2001), was used in studies exploring learner's social attributions and interest in presence of a physical pedagogical agent and suggested that learners, especially children, considered the robot as a social being and associated mental states with the robot's behaviours and actions Kahn Jr et al. (2012).

Figure 3.5: Examples of social robots for learning. (i) iCat robot teaching young children to play chess Pereira et al. (2008) (Left) and (ii) Keepon robot tutoring an adult in a puzzle game Leyzberg et al. (2014) (Right)

Other relevant examples of social robots being used with pedagogical intentions were Papero Osada et al. (2006), Tiro Han and Kim (2009), iCat Mubin et al. (2013a), Irobi Han (2012) etc. A comparison study with the Robovie and iCat robots in terms of their animacy and intelligence perceptions suggested that more animated facial features could attract more learner's attention Bartneck et al. (2009a). Stower and Kappas (2021) integrated the social robot Nao with the educational robot Cozmo Pelikan et al. (2020) and Cubetto Anzoátegui et al. (2017) for designing a learning task on computational thinking skills. Though physically embodied pedagogical agents in the form of social and educational robots enhance the learning environment, they demand additional expenses in terms of equipment, maintenance and distribution as compared to virtual agents that are often in the form of software systems delivering one-on-one support through screen-based or immersive learning platforms Belpaeme et al. (2018).

3.4 Roles of pedagogical agents

Various instructional roles such as expert, tutor, mentor, motivator, learning companion that supported the social-cognitive aspect of learning in technology-enabled learning environments have been developed and proven to be effective in enhancing learning. A review on the research-based design of pedagogical agents by Kim and Baylor (2016) has observed that agent roles with expertise such as expert or mentor have improved learning outcomes while the motivator role had more influence over increased self-efficacy. In a broad sense, based on the knowledge level, an agent can be introduced in a learning environment as a More Knowledgeable Other (MKO) Abtahi (2014) such as an expert/mentor or as a peer learner having the same or relatively less knowledge on the learning topic.

Pedagogical agents in studies such as Pareto et al. (2011); Kizilkaya and Askar (2008); Sjödén and Gulz (2015); Schwartz et al. (2009) etc were implemented in the roles of more knowledgeable agents such as instructor, tutor, guide etc. Baylor and Kim (2003) explored the roles of expert, mentor and motivator in terms of image, animation, voice and affect and reported the effectiveness of distinct roles and behaviours (Figure 3.6). The expert role was designed to exhibit mastery in the learning domain and featured limited non-verbal cues in the form of deictic gestures, authoritative and formal speech etc. The motivator role focused on the learner's efficacy and engagement Tärning et al. (2019) and was associated with behaviours such as suggestions and encouragement for the learner to progress in the task. The role of the mentor agent was characterized by instruction and guidance behaviours to demonstrate competence to the learning as well as emotional expressions and friendly speech for facilitating motivational influences. Murray and Tenenbaum (2010) reported improvements in self-efficacy and learning of the participant in a long term interaction study spanning 5 weeks involving a motivator agent. On examining the effect of the motivational pedagogical agent on learning and task perceptions, van der Meij et al. (2015) observed gender differences in self-efficacy beliefs. You et al. (2006) deployed a humanoid robot in the role of a teacher assistant in a language learning scenario and reported a positive attitude for the classroom toward the robot's behaviours and performance.

Roles of pedagogical agents as collaborative assistants, peer learners, learning companions etc were also used in various scenarios. Osman and Lee (2014) studied the impact of collaborative assistant agents in a multimedia learning environment for teaching electrochemistry concepts and representations and observed significant differences between the control and treatment groups in learning outcomes. Terzidou et al. (2016) integrated collaborative pedagogical agents in an OpenSim based serious game environment for tertiary education and found positive impacts on group performance. On comparing the roles of

Figure 3.6: Pedagogical agents used in the study by Baylor and Kim (2003): Expert (left), motivator (middle) and mentor (right)

tutor and peer through a Wizard of Oz study with Nao robot, Zaga et al. (2015) observed that the peer agent motivated the learners more to complete the task and gathered more attention compared to the tutor agent. This could be attributed to the fact that peer-like agent behaviours are less intimidating and formal than the tutor interactions, hence making it easy for the learners to associate themselves easily with the peer agent. Learning companions Lubold et al. (2016) are also peer-like roles often assigned to the agents to facilitate motivation without actively engaging in direct tutoring. The CoWriter project Hood et al. (2015a) used a robot agent in the role of novice eliciting the method of learning by teaching Chase et al. (2009) for improving the handwriting skills of children (Figure 3.7). Moreno et al. (2010) used a virtual peer agent to support the learner through visual information and attention guidance through deictic gestures that considerably reduced the cognitive load of the students. Recommendations from the research regarding the roles of pedagogical agents and the influence of cognitive load and split-attention effect in the impact on learning gain and agent perceptions suggest careful orchestration of learning interactions involving multiple agent roles Martha and Santoso (2019). It was observed by Baylor and Kim (2003) that having two separate pedagogical agents representing two different roles had a significantly more positive influence on the learning and perception of the agents which can be attributed to the influence of multiple agents on cognitive load Dinçer and Doğanay (2017).

3.5 Impact of pedagogical agents

Pedagogical agents in the form of virtual characters or robotic embodiment have shown potential for impacting the motivation, engagement and performance of the learners through various studies and interactions. Lusk and Atkinson (2007) states that "the agents can enrich and broaden the communicative relationship between the learners and computers as well as provide motivational and affective instructional features that actively

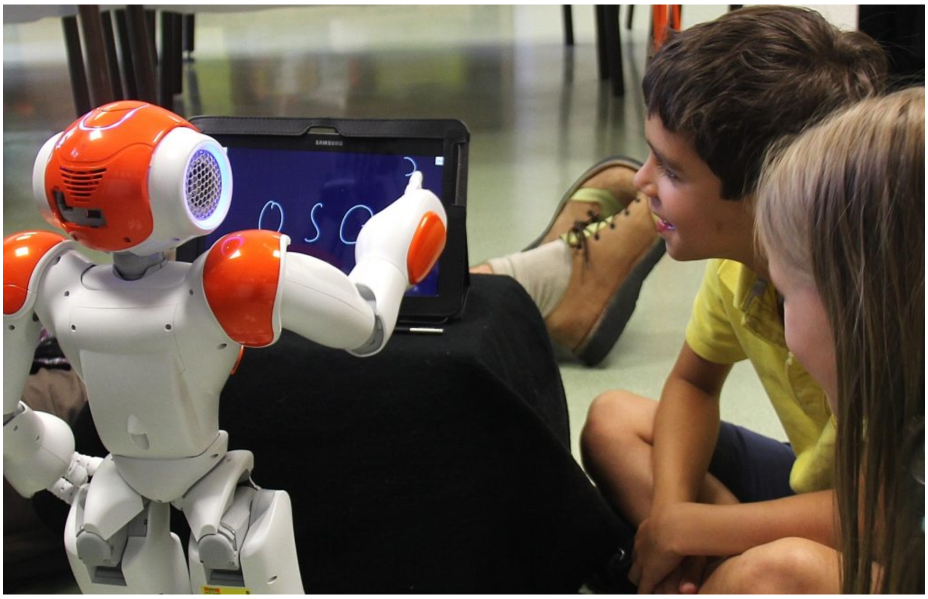

Figure 3.7: Nao robot supporting children to improve their handwriting skills Hood et al. (2015a)

engage students". The learners are often observed to be developing social and emotional associations with the agents that influence their sense of responsibility, motivation and activity perceptions Gulz and Haake (2005) Krämer and Bente (2010) Liew et al. (2017).

3.5.1 Social and motivational outcomes

A coordinated display of verbal and non-verbal cues such as gestures for attentional guidance, affective speech and expressive behaviours can establish an effective social presence in a learning interaction Sklar and Richards (2010) Dunsworth and Atkinson (2007). Dincer and Doğanay (2015) compared the impact of pedagogical agents on academic success and motivation among secondary school students between four groups that received support from a fixed pedagogical agent, selectable multiple agents, without agents and in traditional way respectively and reported positive impacts in groups with pedagogical agents. The study also suggested that the personalisation of agent features based on learner preferences can further improve motivation and learning.

On investigating the effect of a Teachable agent in a math game context, Sjödén and Gulz (2015) observed significant effects on the choice and performance on conceptual math problems although not on overall test scores. Terzidou and Tsiatsos (2014) introduced an OpenSim based agent on a collaborative serious game and concluded that the agent's presence and assistance strongly improved the performance of the learners. However, the evidence supporting the claim that the social presence provided by the agents or the persona effect could improve the learning interaction is mixed. For instance, Frechette and Moreno (2010), on examining the impact of the presence and non-verbal cues found no significant effect on the learning and a preference towards static agent character design. Similarly, Choi and Clark (2006) observed that agent's visual appearances and social behaviours did not motivate, interest or tutor learners better than a simple arrow and voice-based feedback thus supporting the claim that the delivery medium alone cannot improve learning and it needs effective instructional methods as well.

In an attempt to use embodied conversational agents for assessing interpersonal competency skills Hubal et al. (2008) found differing tendencies among adolescent and adult participants suggesting that the technology by itself wouldn't be sufficient to engage the participants. Dirkin et al. (2005) compared the four conditions of text only, voice only, voice with image, and fully capable social agent to study learner perceptions to find evidence supporting persona effect but surprisingly the text-only condition equalled the social agent in terms of perceived social presence. Although such contrasting findings are often attributed to differences in quality and behaviours of agents used in various studies and their contexts, the existing evidence shows potential for pedagogical agents for greatly influencing the learner motivation and engagement.

3.5.2 Learning and performance outcomes

The impact of interactions involving pedagogical agents in learning and performance outcomes have also been examined through various studies Murray and Tenenbaum (2010) Pareto et al. (2011) Liew et al. (2017). Compared to the conventional methods of instruction and tutoring support, pedagogical agents provide better scaffolding leading to improved recall, comprehension, retention and self-efficacy Theodoridou (2011) Lane et al. (2013). Kim and Wei (2011) looked at the variables of task-specific self-efficacy, attitudes and learning gain among school children based on the learner attributes and observed improvement in performance and learning retention. Another recent study Hayashi (2020) on gaze awareness and metacognitive suggestion by a pedagogical conversational agent reported a correlation between successful coordination through gaze feedback and learning gains.

Pedagogical agents were also employed with an intention to reduce the cognitive load by helping the students to distinguish between relevant and irrelevant information through behavioural and verbal cues, resulting in higher learning outcomes Yung and Paas (2015). On interacting with the affective pedagogical agent, Jessie, a group of learners with Autism Spectrum disorder (ASD) showed significant improvement in learning Mondragon et al. (2016). In a similar study among approximately one hundred school children engaging in a math-based learning task, Woolf et al. (2010) observed that the low-achieving students with learning difficulties improved their performance and learning outcome and also showed reduced anxiety after interacting with an affective pedagogical agent. Ramachandran et al. (2019) used an interactive robot tutoring system to observe the learner behaviours and motivation during learning interactions over multiple sessions and identified a link between internal motivation, observable behaviour and learning outcomes in the context of robot-child tutoring. However, the empirical evidence regarding the pedagogical agent interactions and learning outcomes does not conclude an assured positive outcome in all scenarios. For example, in a study Herberg et al. (2015) on the watchfulness of the robotic learning partner reported hindering of performance in a language learning task when the agent was looking away from the learner more often. Similarly, Sträfling et al. (2010) found no significant impact on the learning outcome on comparing a realistic anthropomorphic agent with a cartoon-like agent on a task of tutoring learning strategies but observed differences in agent preferences and self-disclosure behaviours. Results from Domagk (2010) suggested that pedagogical agents may promote transfer performance, but only if they are appealing in their appearances and behaviours. A subsequent study Domagk et al. (2010) also indicated that the presentation of unappealing social cues can harm transfer and learner engagement.

In general it can be concluded that the design and implementation of learning interactions involving pedagogical agents have the potential for impacting the learner's motivation aspects such as self-efficacy, engagement, task and agent perceptions etc through a careful orchestration of independent variables such as feedback, expression and various behavioural cues etc.

3.6 Self-regulation and pedagogical agents

The research and development in the domain of pedagogical agent research is greatly motivated by the social-cognitive framework of learning Schunk (2012). According to Kim and Baylor (2006), pedagogical agents can act as a socio-cognitive tool for enhancing computer-based learning through building social relationships with the learner, modelling new beliefs and attitudes and sharing empathy. Social cognitive theory considers self-efficacy as a primary diver of learner motivation and identifies self-regulation as a derivative of self-efficacy and intrinsic motivation Cook and Artino Jr (2016). Self-regulated learning emerged as a core conceptual framework in pedagogical agent research which can be used to address the cognitive, metacognitve, motivational, behavioural and emotional aspect of learning. As compared to the implementation of pedagogical agents focusing on cognitive and affective aspects of learning, the number of works focusing on the meta-cognitive aspect of self regulation is less. Clarebout and Elen (2006) studied the impact of adaptive pedagogical agents in open learning environment on self-regulation of the learners. The study compared the control condition to two experimental conditions (i) a group with adaptive agent interventions and (ii) another group where the agent interferes on fixed time intervals. The results show that the group with timed interventions performed better in self-regulatory processes while adaptive interventions did not ensure improvement in performance.

Figure 3.8: (i) The four pedagogical agents in MetaTutor Azevedo et al. (2009) (Left), (ii) A Screenshot of MetaTutor interface (Right)

MetaTutor Azevedo et al. (2009) was one of the first comprehensive hypermedia learning environments designed focusing on enhancing self-regulated learning (Figure 3.8). The Metatutor allowed the learners to engage in self-regulatory processes through collaborative activities that required them to make instructional decisions based on instructional goals such as seeking, collecting, organizing and deriving knowledge from the resources available in the hypermedia environment. The purpose of MetaTutor project was to examine the effectiveness of animated pedagogical agents as external regulatory agents for detection, tracing, modelling and scaffolding of regulatory processes involved during learning about complex science topics. Hence, the MetaTutor served as a common platform for various studies on self-regulated learning with pedagogical agent assistance. Azevedo et al. (2012) studied the effectiveness of pedagogical agents in providing varying degrees of feedback and prompts for facilitating effective learning strategies. The system consisted of four distinct pedagogical agents (Gavin, Pam, Mary and Sam), displayed in the upper right-hand corner of the learning interface named as the SRL palette which the learners may use to instantiate interaction with the agents. The study compared three conditions: prompt and feedback(PF), prompt-only(PO) and no prompt(NP) condition. The PF condition involved timely prompts delivered by multiple agents and immediate feedback on the learner responses and actions. The PO condition had timely prompts without any feedback and NP condition learned without any assistance from the agents. The results indicated that the learners in PF condition had higher learning gain as well as metacognitive monitoring and regulation evident from the log-file data. Harley et al. (2012) looked at the aspect of emotional responses emerging from the learners while engaging in self-regulated learning with pedagogical agents. The study involves a sub-goal setting task in interaction with the pedagogical agent during which the emotions of the learners were estimated. The results suggested prominence of neutral and sadness emotions in learner's experience during the task. It was observed that the learners experienced sadness in response to their proposed sub-goals being rejected by the agent which indicates the presence of a social relationship between the agent and the learner.

Bouchet et al. (2013) explored the aspect of adaptive self-regulated prompting using MetaTutor by comparing three conditions: non-adaptive prompting (NP), frequency-based adaptive prompting (FP) and quality-based adaptive prompting (FQP). In NP condition, the learners received a constant and moderate amount of prompting (1 every 10 min.) while FP and FQP conditions received more prompts initially (3.5 every 10 min.) but the probability of each prompt category (monitoring and strategy) increased after each prompt and each self-initiated enactment of SRL processes. In the FQP condition, the probability of each prompt further increased if the learner did not comply to a mandatory prompt or if the learner's responses are not accurate. The results indicated that the learners were unable to perceive the differences in the prompting frequencies although it had a significant impact in generating positive outcomes in learning and SRL behaviours across the groups. Notable the learner's self-report of satisfaction fell short with increased prompting. This can be attributed to the impact on the learner's perception of agency and self-efficacy and suggests optimisation of prompting frequencies that allow the learner to feel motivated in the learning interaction.

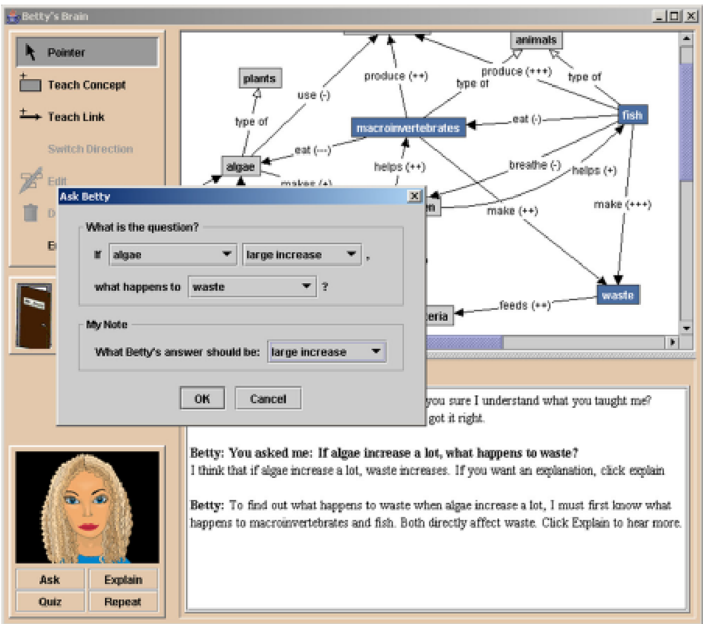

Figure 3.9: Betty's brain system with a causal map, animated agent and a query window Biswas et al. (2010)

Another notable implementation of pedagogical agents in the context of self-regulation was, Betty's Brain system Leelawong and Biswas (2008), that used domain-independent Teachable Agents that the learners can tutor using a visual representation (Figure 3.9). The design of Betty's Brain system was guided by socio-constructivist theories of learning Kanselaar (2002), peer-assisted tutoring Topping and Ehly (1998) and reciprocal teaching

Rosenshine and Meister (1994). The system assumed the human learner in the role of teacher and the computer agent as the student and the roles were consistent during the period of interaction and relied on emphasizing the factors of explicit teaching, shared representations and shared responsibility in learning.

The system had three components: (i) concept map representations to teach the agent, Betty, (ii) query module to ask the agent questions and understand how much it has learned, and (iii) a quiz module to understand how much the agent performs on the questions the human learner haven't considered. The system also incorporated an additional agent character, Mr.Davis, in the role of a mentor who answers the learner's questions on learning, teaching and regulation strategies and occasionally intervenes with specific help during the interaction. The researchers compared three systems in the study: (i) Learning by being Taught(ITS) system in which the mentor agent directed the learners in constructing concept maps, (ii) Learning by Teaching(LBT) system in which the students were asked to teach Betty by creating concept map on their own and had Betty agent answer the questions generated by Mentor agent at the end of each session and (iii) Learning by Teaching with self-regulated learning (SRL) system where the learners taught the Betty agent by creating concept maps along with composing the questions to be asked by the mentor agent to Betty agent. The results indicated learning to be improving over time in all three conditions while the LBT and SRL conditions had a higher number of valid concepts mastered by the learners. In a subsequent study on knowledge retention, it was observed that the SRL group used a more balanced approach in monitoring and debugging phases by asking more causal questions than the ITS and LBT groups and retained self-regulation behaviours even when all the metacognitive scaffolds and feedbacks were removed. The agents in Betty's Brain system were assigned the roles of student and mentor while the human learner took the place of a teacher. Interestingly, even with minimal character representations through static images and dialogue, these agents were able to develop effective relationship with the learner and provide regulation scaffolding.

Jones and Castellano (2018) explored the use of social robotic tutor in personalised tutoring support in a long term study among primary school children based on a geography task of map reading skills (Figure 3.10). The implementation was based on Open Learner Model(OLM) Bull and Kay (2010) that allows the learner to view the model that the system holds about them. The OLM provide the learner with all relevant information on their performance for them to motivate reflections and self-regulatory processes. Along with prompting of strategies and performance feedback, the robot tutor also provided a summary of developing skills for the learner by considering the previous interactions with each learner. The study looked at two conditions: (i) Domain tutoring without SRL support along with access to OLM tools and (ii) Domain tutoring with adaptive SRL from the autonomous robotic tutor based on the task performance along with OLM tool support. The results indicated no significant difference in learning gain and performance between the two groups but the adaptive SRL group displayed more regulation behaviours such as

Figure 3.10: Nao robot highlighting OLM to a student in a map reading task Jones and Castellano (2018)

spending more time on questions and attempting difficult questions. Also, the data suggested effective transfer of SRL skills improved within the activity to a different task and changes to the self-report of learner's attitudes on self-regulation. Vrochidou et al. (2018) proposed a game-based learning activity involving a social robot, Nao, as a self-regulating didactic mediator in a structured school environment. The results from the study indicated that the presence of a self-regulating entity increased the engagement in the activity and improved the children's computational and logical thinking skills. Another long-term unsupervised deployment of Robot Extended Computer Assisted Learning (RECAL) system with 61 children working with a social robot in their own classroom, Davison et al. (2020) collected qualitative data to understand the usage patterns and self-regulated learning processes developing throughout the learning interaction. The interaction setup consisted of a 50 cm tall humanoid robot, Zeno R25, with expressive facial capabilities and two tangible learning tasks based on Arduino and embedded sensors (Figure 3.11). The results from the study show that children were able to successfully regulate themselves during various levels of the task and the interest in the activity declined over time and resurged when a new learning content was introduced.

3.6.1 SSRL based systems

Socially shared regulation of learning(SSRL) has emerged as a growing framework for self-regulated learning research in the collaborative setting during the past decade only. Being the recent trend in the domain, the number of studies utilizing artificial pedagogical agents such as animated agents and social robots are rare to none. Most of the explorations regarding SSRL has been focusing on groups of learners in various collaborative contexts regulating as a collective sharing task perceptions and goals. Hadwin et al. (2011) identified socially shared regulation in learning to be "emerging through a series of transactive

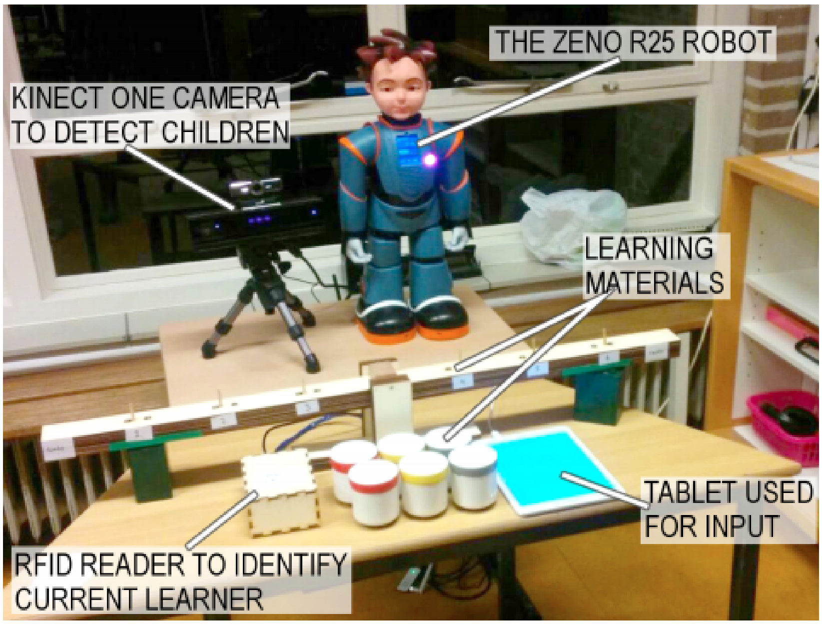

Figure 3.11: Self-regulated learning interaction setup with Zeno R25 robot Davison et al. (2020)

exchanges amongst group members when deliberate, strategic planning, task enactment, reflection and adaptation are taken within the group".

Harley et al. (2017) explored how learners can collaboratively regulate their learning with pedagogical agents to increase their academic achievement. The study examined the interaction between the agent, Pam, and the learner to establish sub-goals for learning with MetaTutor platform and involved two scaffolding conditions of prompt and feedback(PF) and control. The results indicated that the learners followed the prompts and feedback from the agent most of the time in setting the sub-goals and lead to higher proportional learning gains as compared to the control group. The interactions with the learner and the agent during the goal-setting phase was identified to be unidirectional that can be better classified as externally-regulated learning which aligns with the characterization of SSRL Järvelä et al. (2013).

Molenaar et al. (2012) tested the effect of dynamic scaffolding of social regulation with an attention management system in dyads of middle schools students in a computer-based learning environment based on Ontdeknet platform Molenaar (2003) (Figure 3.12). The students in the scaffolding condition received dynamic cognitive and metacognitive scaffolds based on their performance. The students were informed that the embodied animated agent was assigned the role of a tutor who oversees the entire activity and in the control condition, the agent was limited to the mere presence in the environment without providing any direct interaction with the learners. In the scaffolding condition, the cognitive scaffolds were provided when the students asked for help or when the system monitored an idle user. The metacognitive scaffolds were divided into orientation,

Figure 3.12: Embodied agent providing regulation cues in a learning environment Molenaar (2003)

planning and monitoring phases and were delivered based on the attention focus of the students. The orientation scaffolds were delivered when the students move their attention to a sub-task and planning scaffolds were given just before the execution of sub-tasks. Upon saving a sub-task, the dyads were shown a monitoring scaffold on the screen based on their progress and need for help. Also, the study measured the dyad's performance and the individual student's knowledge through a curriculum-based knowledge test and a perception questionnaire. The results from the interaction indicated that the dynamic scaffolding had positive effect on the dyad's performance although there was no improvement in the domain knowledge. The researchers provide an argument that the metacognitive scaffolding does not necessarily affect the quantity of knowledge but only leads to improved quality of knowledge.

On examining the sequential patterns of self and socially shared regulations of STEM learning in a collaborative learning based virtual environment, Zheng et al. (2019) revealed that the timing of socially shared monitoring processes can have greater influences on the adaptive scaffolding on a group of learners. The existing body of research that combines pedagogical agents to promote self-regulation or socially shared regulation in particular demands more explorations aiming at formalising the elements of learning environment as well as understanding various agent-learner interactions emerging during the regulation phases.

3.7 Limitations and Challenges

As compared to the number of studies and systems based on pedagogical agent-based learning interventions, the explorations focusing on the meta-cognitive learning aspect of self-regulated learning is considerably less. The existing works that leveraged pedagogical agents for promoting self-regulation in learners differ greatly in the characterization and implementation of the agents as well as the theoretical framework of self-regulation that they are grounded upon. SRL based systems such as Metatutor Azevedo et al. (2009) and Betty's Brain (Leelawong and Biswas (2008); Biswas et al. (2010)) had 2D animated agents embedded in the the learning environment while some studies used social robots as learning partners promoting self regulation Jones et al. (2018); Vrochidou et al. (2018). Many such studies also limited the pedagogical agents to their presence in the environment Mudrick et al. (2014) and non-reciprocal engagement in regulatory processes that relied mostly on providing prompts and feedback during learning. This often resulted in an unevenly distributed regulation which is far from the learning interactions happening in real world scenarios such as learning groups and classrooms Bransen et al. (2021). Also the models of SRL that support these systems vary in their assumptions about the learner as well as in the approaches toward the learning progress Boekaerts and Niemivirta (2000). SRL systems based on Top-Down approach or growth pathway consider learning goals to be more relevant for the students and emphasize more on the personal beliefs and mental processes of the learner. The Bottom-Up approach or well-being pathway based systems have been behavioural and relied more on the actions and environment to promote regulation in which students activate their goals to protect their self-concept and motivational beliefs.

Another distinction among the existing systems of SRL is regarding how they conceive the learner actions and responses in terms of their prior knowledge and skills. According to Zimmerman and Kitsantas (2005), it is necessary to have some cognitive, motivational and emotional processes that have become an automatic response pattern so that the learners can actively employ regulation strategies with less cognitive load. This includes processes such as accessing prior knowledge, goal activation, reflective thinking, emotional regulation etc. SRL systems such as Betty's Brain used peer-assisted tutoring Topping and Ehly (1998) and reciprocal teaching Rosenshine and Meister (1994) assuming the learner to be capable of self-regulating themselves and the learning partners during interaction while SRL prompt and feedback systems like Bouchet et al. (2013) and Harley et al. (2017) relied on agents triggering and mediating the regulation processes.

The main challenges in research regarding the use of pedagogical agents in promoting self-regulation are related to the role of learning environment, agent characteristics, measurement and interpretation of the meta-cognitive outcomes of the interactions. Regarding the learning environment, the scope of regulatory processes can range from an individual focus to socially influenced groups such as collaborative teams and classrooms. Boekaerts and Niemivirta (2000) states that the learner's interpretation of context activates different goal pathways which can influence the roles they adopt during the learning process. For instance, self-regulated learning is focused on the self and the individual processes involved in regulating learning and performance. Co-regulated learning brings the focus on the interaction between the learner and the context that involves emotional, motivational, cognitive and meta-cognitive mediation through social interactions with others in the environment. Depending on the roles assigned for these learning partners and it's conceptions by the learner, a spectrum of hierarchical relationships are possible in a learning interaction through various roles such as peer, mentor, tutor etc. Socially shared regulation of learning emerges when groups of learners regulate their collaborative learning, directed towards jointly constructed goals for the team within the context. Hence, along with studying the impact of pedagogical agent features on the learning outcomes, it becomes important to examine the agent-learner interactions in various contexts of environments and their potential social influences on self-regulation behaviour.

Pedagogical agent features such as embodiment, realism, instructional roles and behaviours can have a significant impact on learning and motivational outcomes Baylor and Kim (2004). A review Heidig and Clarebout (2011) on the impact of pedagogical agent design and associated functions on learning outcomes and motivation presented mixed results mentioning cases with benefits as well as hindrances to the learning. Differences in the design, as well as functions of agents ranging from animated talking head Moundridou and Virvou (2002) to humanoid robots Mubin et al. (2013b) and relatively less number of studies focused on the meta-cognitive aspects of learning and motivation in learning makes it difficult to draw a conclusion on the effective characteristics required for a pedagogical agent. Hence it remains as a challenging task to design the agent features and expand their representations to forms such as animated 3D characters, social robots etc. Considering the minimal 2D agent representations used in existing SRL systems, there is a great scope for experimentation with animated virtual characters and robots in various roles of learning partners.

Another key challenge in the self-regulated learning field is the difficulty in quantifying the learning and regulation outcomes through reliable tools of measurement Panadero et al. (2018). A number of assessment methods such as thinking aloud protocols Greene et al. (2011), self-reporting questionnaires, structured interviews Andrade and Dugan (2011) that rely heavily on the learner's perspective dominated the research and analysis regarding self-regulated learning until online measures based on learner's activity and performance emerged. This also shifted the conceptualization of SRL from a trait-based perspective to a process-based perspective enabling sequential and temporal analysis of learning and regulation patterns for assessment Panadero et al. (2016). The online measurement also helps in reducing the impact of assessment on the learner's SRL and more concrete definition of the learning promoting activity traces and behavioural observations of the learner. Reactivity of the learner, which is defined as the changes that occur in an individual's behaviour due to meta-cognitive monitoring, accounts to the impact of SRL measurement on the regulation itself. Thus the instruments of measurement for SRL often translates into interventions causing reactivity effect from self-observations. This can be considered as a challenge as well as an opportunity towards overlapping phases of intervention and measurement during learning. The emergence of computer based tutoring and scaffolding extended the scope of designing tools which are hybrid measurement-intervention methods capable of promoting SRL. SRL tools such as Radar, OurPlanner and OurEvaluator Panadero et al. (2013) leveraged this aspect to enable group of learners to reflect the cognitive, metacognitive and emotional status of their fellow learners and jointly construct task related goals in context of socially shared regulation in learning. The presence of pedagogical agents can help in attaining better informal gathering of learner's self-conceptions through dialogue-based interactions and non-verbal cue enabling a natural learning interaction that minimises reactivity effect.

3.8 Conclusion

The recommendations from the current research and implementation in self-regulation and specifically socially shared regulation in learning demands a coherent framework using computer-supported collaborative learning and artificial pedagogical agent that can deliver controlled and adaptive scaffolding to the learners based on their performance and social attitude towards the learning partners. This thesis aims to leverage the benefits of artificial pedagogical agents of various roles and corresponding pedagogical strategies for orchestrating a collaborative learning environment for promoting socially shared regulation scaffolding in learning. The proposed framework of multi-agent learning interaction based on agent roles would address the individual self-regulation in context of SSRL. Most of the studies in SSRL involves groups of learners ranging from dyads to big groups such as batches of students while very little attention has been focused on the contributions of each individual learner towards the shared regulation Hadwin et al. (2010).

Collaborative groups can be considered as social systems consisting of multiple self-regulating individuals who must at the same time regulate together as a social entity Järvelä et al. (2016). A collaborative learning environment with multiple pedagogical agents of various roles can thus help in orchestrating an interaction which is synonymous to the real-world learning interactions. Another important aspect of SSRL research is the learning task that the groups should engage during the learning. The tasks used in existing studies have varied from scientific discovery based task to collaborative sub-goals setting task for groups of learners Beckman et al. (2021). The structuring of the learning task and the degree of coordination required for the shared activities are crucial in promoting self-regulation in SSRL context. A multi-agent learning interaction thus demands the design and implementation of a learning task which is in-line with the sequential flow of regulatory phases involved in self-regulation. Hence, this thesis will explore self-regulated learning in the context of collaborative learning involving shared regulatory processes using multiple agents assigned to different pedagogical roles and associated behaviours.

The key points of this Chapter:

- Pedagogical agents can be defined as intelligent artificial learning partners (single or multi) that can support the student's learning and use various strategies in an interactive learning environment.
- Design features, embodiment and social roles associated with the agents can greatly influence the perceptions, performance and motivation of the users.
- Multi-agent learning interaction in the context of socially shared regulation involving different pedagogical roles appears to be a relevant direction for exploring self-regulated learning.

Part IV

Shared Learning Interaction Design

Chapter 4

Dimensional framework of pedagogical agent roles in SSRL context

Contents

4.1 Introduction

Computer-supported collaborative learning environments have enabled interventions in the social processes during learning by the means of artificial pedagogical agents such as virtual agents or social robots and their roles and behaviours towards the learner. Pedagogical agents can be described as intelligent artificial learning partners that can support the student's learning and use various strategies in an interactive learning environment. According to Stone and Lester (1996), a pedagogical agent should essentially exhibit the properties of contextuality (providing explanations and responding appropriately in the social and problem-solving context), continuity(maintaining pedagogical, verbal and behavioural coherency in actions and utterances) and temporality(timely intervention in learning to communicate concepts and relationships) to be effective in a learning interaction. Pedagogical agents can assist learning by providing instructional support such as feedback, guidance and cues for attention focusing and reflection etc. Various functions emerging in a learning interaction with an agent can be categorized as follows based on the framework of teaching functions proposed by Leutner and Klauer (2007):

- Motivation: eliciting learner's confidence and interest through communicating the relevance of the learning topic and the activity.
- Information: drawing the learner attention to the learning content enabling the learner to activate the prior knowledge and integrate new information into the knowledge structure.
- Information processing: providing explicit information on the conditions, relationships and outcomes of the learning content, helping the learner to extract similarities and differences in the knowledge structure.
- Storing and retrieving: guiding the learner in activating the prior knowledge and reviewing the existing cognitive structure to accommodate the acquired knowledge.
- Transfer of information: helping the learner to apply the new knowledge and transfer it into other contexts and problems.
- Monitoring and directing: guiding the learner in understanding the status of learning and guiding them towards the learning goals

Empirical studies on pedagogical agents and their implications on learning outcomes and motivation observe that the agents may offer support on at least one of these teaching functions and if not, the presence of an agent can potentially hinder the learning process by distracting the learner from the learning task. Baylor et al. (2004) explored the impact of pedagogical agents through differing motivational support(presence and absence) and affective state(positive and evasive) in a study based on math anxiety in college students. The results indicated that the presence of agents with motivational support had a significantly positive impact on the self-efficacy and perceived agent helpfulness factors in the learner. On examining the effects of visual signalling and visual presence of an animated pedagogical agent, Johnson et al. (2015) observed that delivery of visual cues relevant to the learning content through an agent can positively impact learning and lower the learner's perception of difficulty. Harley et al. (2017) looked at the learner-agent interactions in a sub-goal setting task with MetaTutor, an intelligent tutoring system and observed that the prompts and feedbacks provided by the agent aided the learners in collaboratively setting learning goals. The learners were willing to engage in and benefit from the agent support when immediate, directional feedback was provided.

4.1.1 Regulation in learning

Pedagogical agents are considered as an effective socio-cognitive tool for building social relationships, shared goals and beliefs to promote better performance and positive attitudes in a learning environment. In social-cognitive theory, self-efficacy is emphasized as a key driver of motivated actions and is closely associated with the processes of self-regulated learning Cook and Artino Jr (2016). Regulation of learning Allal (2010) entails the processes of goal setting, monitoring progress, analyzing feedback, adjustment of goal-directed actions and/or of the definition of the goal. Regulated learning can be of four kinds, described as follows:

- Self-Regulated Learning(SRL), where a student uses self-assessment, goal setting, and the selection and deployment of learning strategies to reach the learning goal.
- Externally Regulated Learning(ERL), which involves a human or virtual tutor prompting an individual learner to deploy key SRL processes during their learning, which may, in turn, enhance their SRL.
- Co-Regulated Learning(CoRL), involves a peer learner supporting and influencing each others regulation of learning, typically in an interdependent and reciprocal manner.
- Socially-shared regulated learning (SSRL), which involves multiple learners regulating themselves as a collective unit, using consensus building and negotiation to co-construct and make decisions about group task goals, definitions, beliefs, strategies, and knowledge.

In the context of collaborative learning, socially-shared regulation has emerged as the key factor as it considers regulation processes involved in groups of learners. The socially-shared regulation model of learning regulation Hadwin et al. (2011), combines the foundational theories of self-regulation, which were mostly centred on individual processes, with the social and interaction aspects of collaborative learning. The SSRL model consists of four loosely sequenced and recursively linked feedback loops Panadero (2017) emerging during a collaborative learning interaction. During the first loop, groups negotiate and construct shared task perceptions based on internal and external task conditions. Through the second loop, groups set shared goals for the task and make plans about how to approach the task together. In the third loop, groups strategically coordinate their collaboration and monitor their progress. Based on this monitoring activity, the groups can change their task perceptions, goals, plans, or strategies in order to optimize their collective activity. Finally, in the fourth loop, groups evaluate and regulate for future performance. Emerging empirical evidence suggests the effectiveness of SSRL based scaffolding support in collaborative learning. Based on an empirical study involving 18 graduate students, working in collaborative teams over an 8-week period,Järvelä et al. (2013) observed that supporting fellow team members to successfully regulate their learning was significantly important in achieving team goals. Another study Iiskala et al. (2011) on collaborative mathematical problem solving of dyads of high achieving pupils also suggested the use of socially shared metacognition as a relevant factor for the quality of problem-solving and recommends its addition to the conceptual tools of learning research. The reviews and recommendations on the design and impact of pedagogical agents over that last decade Martha and Santoso (2019) suggests broadening the scope of motivational theory beyond socio-cognitive frameworks of pedagogical interaction design through collaborative learning and shared conception of goals and beliefs among learning partners.

4.1.2 Roles of agents

Social relationships emerging between the learning partners through information exchange, joint construction of learning goals and verbal and non-verbal interactions play a decisive role in a learning environment Alonso et al. (2015). According to Haythornthwaite (2001), learning can be described as a social relationship through which learners exchange, share, provide and receive different experiences of individual and collective knowledge building. In a learning interaction involving pedagogical agents, the beliefs and attitudes related to the social relationships may differ based on the roles enacted or assumed by the agent. For instance, Baylor and Kim (2005) presented three pedagogical agent performing different roles of motivator, expert and mentor characterized by distinct appearance, animation, voice and affective features. A study on the role perception and impact of these roles revealed that motivational agents(Motivator and Mentor) promoted more self-efficacy and engagement in the learners while information agents(Expert and Mentor) improved the transfer performance than the motivator agent. Overall, the mentor agent that combined both information and motivational support was observed to be beneficial for motivation and performance in the learning groups. In further studies based on split persona effect, Baylor and Ebbers (2003) compared a single mentor agent(motivation + information) to two separate agents (expert and motivator) based on the functionality, observing greater learning in the two-agent condition (Figure 4.1). This finding was attributed to cognitive load theory, which suggests that the presence of two agents with distinct features could make it easier for the learner to attribute responses and behaviours associated with an agent, thus reducing the cognitive load involved in the process. Also, the increased collaborative interactivity could have resulted in activation of better agency in the learner. These observations suggests the benefit of distinct roles and associated behaviours in orchestrating the learning interactions in various contexts.

Theories of learning based on discovery based open-ended learning environments and peer assisted tutoring Topping and Ehly (1998) and reciprocal teaching Rosenshine and Meister (1994) have led to the development of peer-like agent representations such as teachable agents and co-learner agents Pareto et al. (2012). As active or passive learning

Figure 4.1: Agent personas used by Baylor (2003b)

partners, the peer-like roles of agents can lower the learner anxiety and accompany the learner in learning through more friendly and less intrusive behaviours compared to overt instructor roles Chase et al. (2009). Implementation of pedagogical agents as learning companions (PALs) Kim et al. (2006) explored the aspect of agency in learning through various levels of peer behaviours. Agents as passive peers in an environment can enhance the personal agency which involves control and regulation over the learning task. Proxy agency is a form of socially mediated agency, which enables people to get resources from others to attain goals. Active peer agents that transmit knowledge and skills could increase modeling effects by sharing similar attributes with learner Kim et al. (2007). Peer agents as collaborative learning partners can promote collective agency which is a predicate of group action. Kim (2013) implemented a virtual peer agent in an online reading lesson to promote text comprehension and perceptions and observed that the learners who interacted with the virtual peer performed better than those who received only content support. The Co-Writer project Chandra et al. (2018) used the idea of "learning by teaching" to teach handwriting to a Nao robot where the robot assumed the role of a novice. The results from the study indicated that the learners were indulgent with the robot's mistakes and often took initiative in providing feedback to the peer Johal et al. (2016). On comparing the effects of expert-like and peer-like agents on learner perceptions, task-related attitudes and performance, Liew et al. (2013) observed that the learners assign higher trust to the information provided by the expert-like agent while they associate higher activity interest with peer-like agent.

Design and definition of the agent roles are crucial especially in multi-agent learning environments as the learner's expectations have to match the agent functionalities Sunal et al. (2003). For instance, Yadollahi et al. (2018) observed deictic gestures of a robot peer agent in a reading task to be distracting for children with lower reading proficiency, preventing them from comprehending the text and mistakes during the activity. Chen et al. (2020) experimented on adaptively switching the roles of tutor and tutee roles in a collaborative word-learning activity and found improved vocabulary acquisition in tutor's instruction session and higher affective engagement related to tutee sessions (Figure **??**). The appropriation of the agent roles thus depends greatly on the learning context and

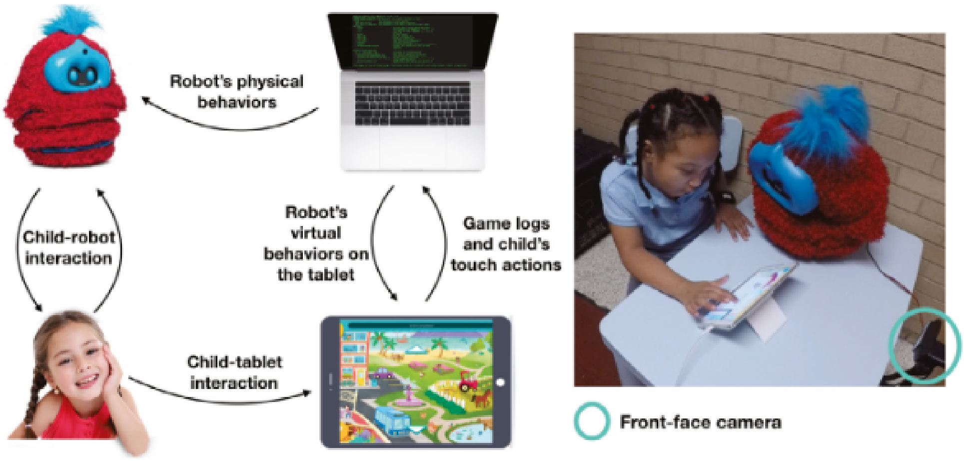

Figure 4.2: Collaborative learning activity with a Tega robot Chen et al. (2020)

the learner goals. An expert agent would be suitable while introducing a new learning topic or demonstrating a new procedure within a well-defined learning domain. The motivator agent may be more effective in constructivist learning environments where the learner motivation and interest are important. A mentor agent could be ideal when both motivational and information support is required for the learner. Peer-like agents can be effective in activating monitoring and planning processes in the learner, which can improve the agency and regulation in learning. This outlines the need for a clear definition and distinction among the agent roles and their associated behaviours in the context of regulation for an effective orchestration of multi-agent learning systems.

4.2 Relational Framework

According to the Computers as Social Actors (CASA) paradigm Nass and Moon (2000) Reeves and Nass (1996) humans considers computers as social entities and treat media and computers like real people applying scripts for interacting with humans while engaging with social technologies. The emphasis of socio-emotional relationships in the field of Human-Computer Interaction derives from the works on natural multimodal interfaces such as embodied conversational agents Cassell (2001) Pelachaud (2005) and social robots Breazeal (2002). Bickmore and Picard (2005) defines relational agents as computational artifacts designed to build long-term, socio-emotional relationships with their users. Pedagogical agents are those relational agents that establish social relationships with the users with an intention of generating learning outcomes or providing scaffolding Wu and Looi (2012). In social psychology, the meaning of relationships, their representations and evolution over time are explored through various relationship models as follows:

- Dyadic models: that defines relationship as inter-dependant interaction between two people such that a change in the state of one will produce a change in the state of the other.
- Provision models: that are based on what one person provides for the other in terms of factors such as trust, socio-emotional support etc
- Economic models: which are based on perceived outcomes such as benefits, cost, investments and alternatives emerging in relationships.
- Stage models: that assume fixed stages such as initial rapport, mutual self-revelation, mutual dependency and personal fulfilment in building a relationship.
- Dimensional models: which represents the characteristics of a given relationship to a point in a small-dimensional Euclidean space.

Dimensional models have been used commonly for representing social relationships in human-computer interaction involving entities such as embodied conversational agents and social robots Argyle (2013). Bickmore and Cassell (2001) explored the effect of social dialogue by an embodied conversational agent in user trust through the dimensions of familiarity, power and solidarity. Familiarity accounts for the way in which relationships develop through the reciprocal exchange of information, beginning with relatively non-intimate topics and gradually progressing to more personal and private topics. The growth of a relationship can be represented in both the breadth and depth of information disclosed. Power refers to the ability of one individual to control the resources of another. Solidarity is defined as "like-mindedness" or having similar behaviour dispositions (e.g. goals, gender, etc.).

The socially shared regulation model (SSRL) proposed by Hadwin, Järvelä, and Miller Hadwin et al. (2018), brings the element of collaboration into the SRL context by explaining the intertwining of individual and social processes in self-regulation Volet et al. (2009b). Socially shared regulation involves "deliberate, strategic and transactive planning, task enactment, reflection and adaptation" are taken within a group Hadwin et al. (2011). Such an interaction dynamics provides a great scope for various degrees of socio-cognitive exchanges and social and pedagogical functions and role attributions to the group members. We present a dimensional framework for the pedagogical roles in a SSRL learning context involving multiple learning partners based on social attitudes and regulation behaviours associated with the agents.

4.2.1 Social Attitude

According to Scherer (2005), social attitudes can be defined as "affective style that spontaneously develops or is strategically employed in the interaction with a person or a group of persons, coloring the interpersonal exchange in that situation". An interpersonal stance corresponds to an attitude, spontaneously or strategically expressed, that conveys the relationship of a person to the interlocutor Jaffe et al. (2009). Social roles and associated attitudes evolve as a function of the context and goals associated with the agents Baur et al. (2016). The representation of attitudes by Argyle Argyle (2013), commonly referred

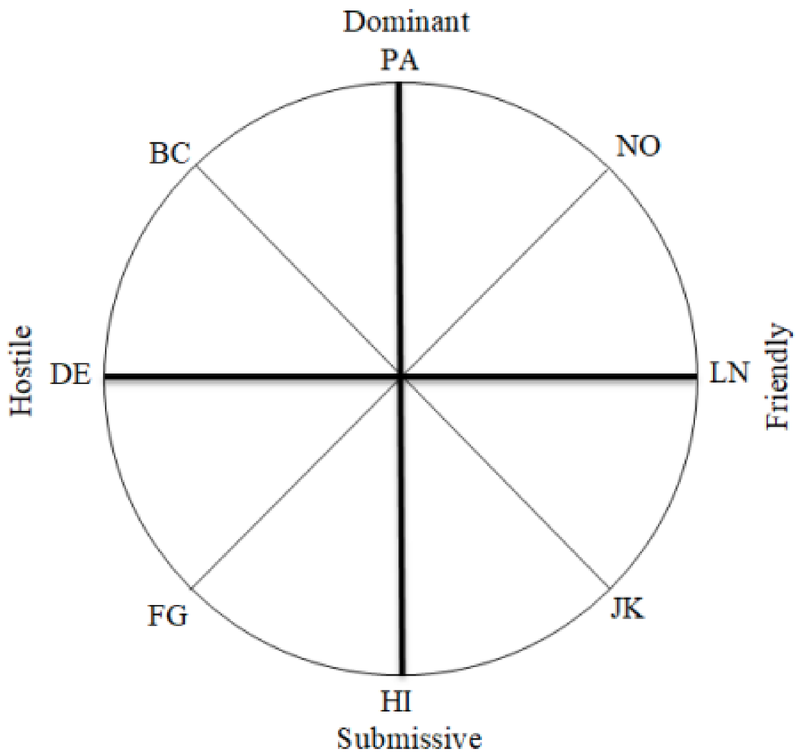

Figure 4.3: Interpersonal Circumplex (IPC). *Adopted from Argyle (2013)*

to as the Interpersonal Circumplex (IPC) (Figure 4.3), plots interpersonal or social behaviours using two orthogonal axes denoting the dimensions of agency and communion. Agency dimension encapsulates the ideas of dominance, power, status and control while communion suggests behaviours of love, affiliation, friendliness etc Gurtman (1992).

Various studies have explored the modelling, expression and perception of agent attitudes based on different combinations of agency and communion features. Straßmann et al. (2016) looked at the effect of an intelligent virtual agent's non-verbal behaviour with regard to dominance and cooperativity. The results revealed that symbolic gestures such as crossing the arms, stemming the hands on the hip, effectively influenced dominance perception in users while cooperativity was strongly influenced by facial expressions. Cafaro et al. (2012) studied the user's judgement of interpersonal attitude along with hostility and friendliness factors and the personality (extraversion) of a virtual agent in first encounters based on non-verbal signals of smile, gaze and proximity and found the relevance of proximity on judgements about extraversion. Youssef et al. (2015) presented an architecture for a socially adaptive virtual agent in the context of dyadic conversations that enabled adjusting the attitude and relationship based on the user behaviour. On evaluating the agent in context of a job-interview simulation, it was observed that the emotional expressions had an impact on the user's experience while the attitude expression's impact was stronger after a long period of time. In context of expression of interpersonal attitudes in group conversations, Ravenet et al. (2014) presented a computational model that allows a virtual agent to exhibit a variety of non-verbal behaviours based on gestures, facial expressions and proxemics (Figure 4.4).

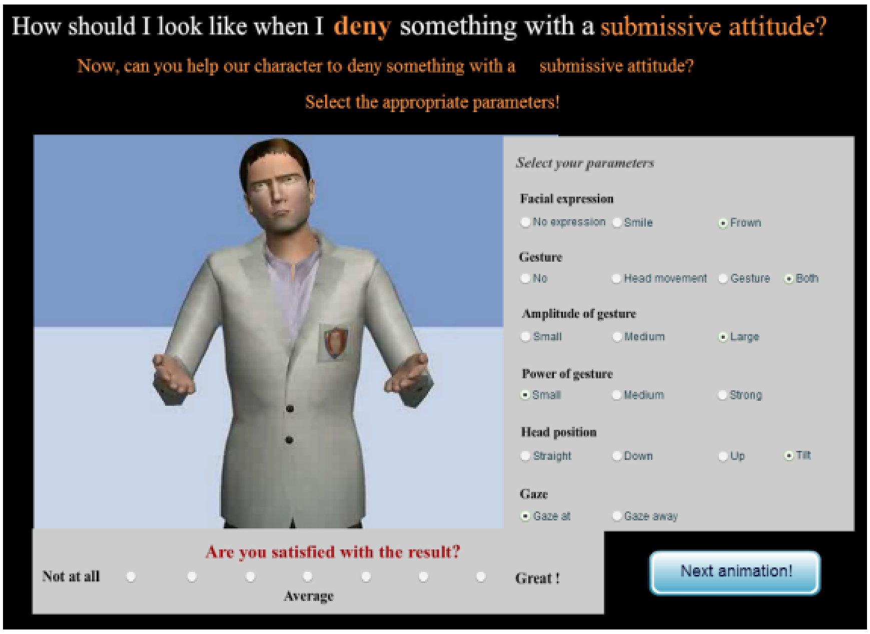

Figure 4.4: An online graphical application designed to annotate the behavior of the ECA for a given attitude Ravenet et al. (2013)

Pecune et al. (2016) presented a social decision-making model based on social goals and situational goals of a virtual agent based on the dimensions of liking and dominance and applied it in a learning scenario involving a virtual tutor and virtual student agent. On varying the degree of social supportive behaviour in a robotic tutor based on the behavioural dimensions of role model, non-verbal feedback, attention guidance, empathy and communicativeness, Saerbeck et al. (2010) observed positive effect of the robot's behaviour on learning performance of participants. Ojanen et al. (2005) developed an assessment model which aims to fit children's social goals to the circumplex model and examine the links between goals and peer-reported behaviours such as aggression, prosocial behaviour, withdrawal etc and suggested conceptualizing social goals emerging in learning through dimensions of agency and communality.

Measure	IMI-C	IAS-R
LM	Friendly	Warm-Agreeable
NO	Friendly-Dominant	Gregarious-Extraverted
PA	Dominant	Assured-Dominant
BC	Hostile-Dominant	arrogant-Calculating
DE	Cold-hearted	Cold
FG	Hostile-Submissive	Aloof-Introverted
HI	Submissive	Unassured-Submissive
JK	Friendly-Submissive	Unassuming-Ingenuous

Figure 4.5: Representative adjectives of each IPC octant for IMI-C and IAS-R inventories

For our proposed role-framework in SSRL context involving multiple learning partners aimed at providing distinct regulation scaffolding, we have chosen the dimensions of dominance and friendliness to represent the social attitudes associated with the roles of pedagogical agents in interpersonal circumplex space. The IPC is generally split into eight octants or scales that are alphabetically labeled counterclockwise: PA, BC, DE, FG, HI, JK, LM and NO where each octant can be represented by a set of adjectives (Figure 4.5) defined as per IPC inventories such as IMI-C and IAS-R Wiggins et al. (1988).

4.2.1.1 Dominance dynamics

Dominance refers to one individual's ability to control the access to resources of another Kasap et al. (2009). In a learning environment, the dominance factor can determine the hierarchy of authority and dependence related to the learning goals. According to Castelfranchi et al. (1992), an agent is dependant on another one if the latter can help the former to achieve one of its goals. A dependent relationship among two agents thus arises from the lack of an enabling condition for pursuing a goal. In the context of shared regulation and learning, relevant knowledge and dependability can be considered as an enabling factor establishing the dominance level of an agent. The degree of agency for an agent can vary from submissive to dominant. The dominant attitude of an agent is mainly characterized by behaviours such as authoritative and monotonous engagement with the learners while submissive traits include acts of approval, acknowledgement and compliance.

4.2.1.2 Friendliness dynamics

The dimension of friendliness ranges from hostility to affection based on the relatedness of communion which is defined as "an orientation toward other people, focus on relationships and contacts with others" Abele and Wojciszke (2007). The degree of friendliness expressed by the agents in a learning context can influence the role perceptions and approaches of the learner. For instance, a friendly agent is often observed to promote self-disclosure and reciprocity in learners Lee and Choi (2017) while socially in-congruent and potentially distracting behaviours can hinder learning and task engagement Blancas-Muñoz et al. (2018). In a collaborative learning context, friendliness can be characterized by acts of encouragement, motivation, helping etc while behaviours emerging from conflicting social or learning goals and expressions of disapproval or aggression can promote hostile attitudes.

4.2.2 Regulation modes

Self-regulation of a learner can be supported by distinct kinds of regulation behaviours exhibited by the agents. The interpersonal regulation can happen in pairs or groups that engage in intentional, goal-directed meta-cognitive processes and establish strategic influences over the behaviours, decisions and actions of the learning partners. The source of regulation scaffolding and the associated roles and behaviours can determine the dynamics of regulation evolving in a collaborative interaction. Externally-regulated learning (ERL) emerges from a human or virtual tutor prompting an individual learner to engage in regulation processes through instruction and information exchange. Co-Regulated learning (CoRL) differs from ERL as it involves learning partners of comparable knowledge levels supporting and influencing one another's regulation of learning. Thus a critical aspect of co-regulation is intersubjectivity which involves sharing beliefs, goals and activities in a common regulatory space that involves combining knowledge and agency over the task Hadwin et al. (2011). The source of regulation scaffolding can be defined along the dimension of competence and feedback associated with the agent. In SSRL context, this becomes relevant as there can be multiple learning partners having different knowledge capacities and learning intentions.

4.2.2.1 Competence dynamics

Competence entails the possession of knowledge, skills and capability that can translate to qualities such as capable, intelligent and confident Fiske et al. (2002). Performance is conceived as the observable solution behaviour of a person on a set of domain-specific problems. Knowledge associated with an agent can be thus be modelled in terms of competence and performance Korossy (1999). In a learning environment, based on competence and performance factors the agents can be categorised as More knowledged Other (MKO) and capable others (CO) (peers of less or comparable knowledge levels). More knowledged agents in a learning environment can be portrayed as informative, credible and dependable learning partners while peer-like agent behaviours would involve acts inquiry, help-seeking and self-monitoring. Lesser competent agents are also more likely to generate mistake, initiate negotiations and conflicts in a learning interaction Chen et al. (2020).

4.2.2.2 Feedback dynamics

Scaffolding Jones and Castellano (2018) is the support or feedback that is given in a timely manner to help a learner achieve a goal that they may not have without that support. The feedback provided can be explicit or implicit depending on the way it is delivered to the learner. Explicit feedback refers to that which may be processed instantaneously during spontaneous comprehension or production Akakura (2012) which can constitute direct hints, suggestions or information exchanges during the learning process. Implicit feedbacks are suggestions or scaffolds that are not direct which requires additional cognitive and motivational efforts for translating into regulation or learning outcomes. These would involve behaviours such as raising questions, thinking aloud, presentation of conflicts and alternative solutions etc.

Implicit feedback can be associated with discovery learning while explicit feedback translates to heavily guided learning which are two extremes of inquiry spectrum Podolefsky et al. (2013). These extremes differ greatly in terms of the goals and roles in a learning environment as discovery approach is more learner-driven and evolving experience while explicit guidance based learning can be termed as static and progressing in pre-determined learning paths (Figure 4.6).

Discovery		Heavily Guided
Engagement, messing about, question asking	**Process of Learning**	Procedure following, question answering
High, individualized	**Variability of Learning Process**	Low, homogenous
Student, peers	**Agent in Learning Process**	Experts, teacher
Creator, explorer	**Role of Student**	Follower, (re-)constructor
Guide, co-participant	**Role of Teacher**	Provider, director
Evolving	**Nature of Knowledge**	Static, pre-determined

Figure 4.6: Comparison of discovery-based and guided learning approaches. *Adopted from Podolefsky et al. (2013)*

4.3 Multimodal features of pedagogical agent roles

Distinctiveness is defined as the quantitative or qualitative features that make agents communicate differently from one another Pelachaud (2009). The proposed dimensional framework for pedagogical agent roles in SSRL context is based on distinct social attitudes and regulation behaviours associated with each role. Social attitude is defined along the dimensions of dominance and friendliness while regulation scaffolding behaviour is represented by agent competency and feedback behaviour. Operationalization of agents roles along these dimensions involves verbal and non-verbal behaviours of the pedagogical agent Baylor and Kim (2005) such as smiling to promote warmth in interaction Biancardi et al. (2017) and mutual gazing that complement the interaction rapport Gratch et al. (2007). Various multi-modal elements of an agent-based interaction (Table 4.1) can be summarised as follows:

- **Speech**: Verbal interaction with agents through utterances or conversations involve various communicative factors such as dialogue acts, goals, emotions etc. According to Searle (1976), speech acts can be categorised as assertive, directive, commissive, declarational and expressive. Acoustic-prosodic features such as voice pitch, loudness, speaking rate, expressive style etc have correlations with dominance, rapport and entrainment (when dialogue partners become more similar to each other during the course of a conversation) in collaborative learning dialogues Lubold and Pon-Barry (2014) Ding et al. (2013).

- **Gesture**: Non-verbal behaviours of agent complement or even supplement the information provided in the speech Iverson and Goldin-Meadow (1998). Gestures can be of two kinds: (i) communicative gestures that convey information about the agent's attitude and goals, and (ii) adaptor gestures that are used to manage emotional states and responses (eg. self-touch). Communicative gestures can be further distinguished as deictic, iconic, metaphoric and beat gestures McNeill (2011). Deictic gestures are pointing movements indicating the location of items being referred to. Metaphoric gestures are used to represent an abstract idea while iconic gestures depict a physical aspect of the speech, such as the shape of an object. Beat gestures do not convey any semantic content, but reflect discourse structure by marking important words and phrases Theune and Brandhorst (2009). Appropriation of the agent's gestural features such as frequency, expressivity, intensity and amplitude is very relevant to convey the intended learning, social goals and role perceptions Baylor and Kim (2009) Ravenet et al. (2013).

- **Posture**: Body movements and positioning of agents can convey intentions and emotional states. Dominant traits include personal size postures such as upright pose, hands placed in hips, directly facing the listener etc. Postures that minimize size, such as bending, positioning bodies at an angle, bowing etc indicate submissiveness. A friendly attitude can be communicated through leaning forward, mirroring the movements, placing arms in open position etc. Castelfranchi (1999).

- **Gaze**: Gaze is considered as an important subset of embodied agent cues in non-verbal interaction that promotes immediacy ie the degree of perceived physical or psychological closeness between people Andrist et al. (2012). Mutual gaze is a sign of dominance and friendliness while gaze shift or aversion can be related to disengagement or submission Burgoon and Dunbar (2006). In a collaborative learning context, the agents can have mutual gaze between the learning partners as well as joint gaze at collaborative task elements gPejsa et al. (2015) Kolkmeier et al. (2016). Gaze direction is also used as a backchannel inviting cue in dialogue interactions Hjalmarsson and Oertel (2012).

- **Facial expression**: Facial cues such as facial expressions, gaze and head movements convey the emotional states of the agent and influence the perception of dominance and friendliness Youssef et al. (2015). Knutson (1996), observed that happy, angry and disgusted facial expressions are associated with high dominance perception than sad, fearful and neutral face. Interestingly, on studying the effect of pedagogical agent's smiling expression on learner's emotions and motivation,Liew and Tan (2016) observed negative motivational responses in learners as they perceived the social meaning of agent's smile to be polite or fake. Effective multimodal cues are thus important in establishing the right beliefs and perceptions in the learner. Ba et al. (2021) implemented a pedagogical agent with multimodal emotional cues using affective voice and gestures with facial expressions found positive outcomes on learner emotions, reduced cognitive load and improved knowledge transfer. The facial expression of emotions can also influence the learner's impressions, decision making and negotiations with the agent Yuasa and Mukawa (2007).

Agent attitudes and associated multi-modal features	
Attitude	Multi-modal features
Dominant	Authoritative and monotonous speech, formal task-oriented dialogue ; deictic, large and open gestures; touching others, leaning towards; mutual and directive gaze; joy, smile, anger, disgust expressions
Submissive	Emotional and complying speech, reduced expressive speech; self-touch, manipulation of objects, head nods and shake; leaning forward, bowed head; gaze avoidance or following; fear and sadness expressions
Friendly	Enthusiastic and emotional speech, informal and social talk; open and expressive gestures; touching others, leaning toward; head nod, tilt and shake; mutual gaze; smile, joy, surprise expressions
Hostile	Conflicting or distracting speech; disoriented postures; gaze aversion; angry and disgust expressions

Table 4.1: Agent attitudes and associated multi-modal features

4.3.1 Roles for External regulation

External regulation involves a more competent and capable entity delivering domain tutoring or regulation prompts and feedbacks to the learner. Thus the pedagogical roles providing external regulation support can be characterized with higher competence and explicit or direct feedback Panadero et al. (2013). External regulation is often characterised by an instructional discourse of strategies and information to the learner that promote performance-oriented learning goals Baylor and Kim (2004) Hadwin et al. (2011). The social attitude dimension of these roles can vary based on the degrees of dominance and friendliness levels. Dominance factor can vary between highly dominant, moderately dominant and less dominant levels. Similarly, the friendliness features of the agent can also vary between very friendly, moderately friendly and less friendly levels. In our dimensional framework of pedagogical agent roles in shared regulation context, the multi-modal features associated with each distinct role for external regulation (Table 4.2) are described as follows:

- **Expert**: The role of an expert agent in pedagogical context is associated with functions of domain-specific and contextualized knowledge, confident and stable performance etc Baylor and Kim (2004) Berliner (2004). An expert agent is characterised to be very dominant and less friendly through multi-modal behaviours such as authoritative and monotonous speech, formal and information-oriented dialogue exchanges, emotionally consistent behaviour etc. The expert agent would also display more deictic gestures, confident upright postures, mutual and directive gaze behaviours that establish control and dominance. Being a source for external regulation, the role of expert has qualities of higher competence and explicit feedback . An expert agent is thus limited to responsive domain-oriented feedback in the form of evaluations or knowledge delivery which is often invoked by learner request or actions.

- **Tutor / Mentor**: The role of a tutor (or mentor) features moderate levels of dominance and friendliness conveyed through behaviours such as expressive, informal and informative speech, social and task-oriented dialogues with emphasis on rapport and performance etc Baylor and Kim (2005) Hudson (2013). Unlike the expert role, the tutor (or mentor) does not simply give out information, but also provides guidance to the learner in bridging the gap in knowledge or skill levels to achieve the goals Driscoll (2000). Thus the tutor role is not very authoritative though it involves higher competence and explicit knowledge delivery traits. Other multi-modal behaviours associated with the role includes a combination of deictic and expressive gestures, mutual gaze behaviour, friendly and approachable attitude etc. A tutor agent facilitates external regulation through proactive feedbacks, suggestions and prompts for improving the performance and motivation of the learner.

- **Motivator**: A motivator agent is designed with the goal of supporting the self-efficacy belief and engagement of the learner Tien and Osman (2010). The role of a motivator agent is thus featured as less dominant and very friendly. The motivator role can be operationalized through emotional and motivating speech and gestures, mutual gaze, informal and personal dialogues, expressions of joy, surprise and smile etc. Unlike the roles of expert or tutor, the role of motivator provides motivational strategies and focuses less on knowledge-oriented interactions.

External regulation based pedagogical roles		
Agent role	Dominance level	Friendliness level
Expert	Very dominant	Less friendly
Tutor / Mentor	Moderately dominant	Moderately friendly
Motivator	Less dominant	Very friendly

Table 4.2: Dimensional features of external regulation roles

4.3.2 Roles for Co-regulation

Co-regulation(CoRL) involves learning partners of comparable knowledge levels supporting or influencing each other's learning. Thus the competency level of agent roles that facilitate co-regulation can be described as less or equivalent to the learner. These peer-like roles also exhibit implicit ways of knowledge exchanges through acts of thinking aloud, questioning, conflicts, help-seeking etc. Peer interactions can take various forms such as collaborative, cooperative or competitive learning that involves various distinct roles of peers based on their learning goals Boud et al. (1999). In general, the peer-based roles that facilitate co-regulation can be associated with varying levels of dominance and friendliness that shape their social attitudes (Table 4.3). Various roles of peer agents that can emerge in a shared learning interaction and their multi-modal operationalisation based on the dimensions of dominance and friendliness are described as follows:

- **Peer collaborator**: Collaboration can be termed as a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem Roschelle and Teasley (1995). In a collaborative learning interaction involving multiple peer learners, there can be different levels of dominance among the peers itself. A peer collaborator agent has learning goals that are aligned to the fellow human learner interacting with the agent and thus displays a moderately friendly attitude during the learning. Based on the variations in self-efficacy and leadership qualities, the peer collaborator role can be of two distinct types:

  Peer Leader: A peer leader agent role in collaborative context is characterised by moderately friendly and moderately dominant traits such as taking initiatives and decisions for the team, proactive behaviours of performance and motivation regulation etc Hurwitz (2018). The role of a collaborative peer leader can be realised through multi-modal behaviours such as enthusiastic and emotional speech, deictic and expressive gestures, confident postures, mutual gaze, expressions of joy, smile, surprise etc.

Peer Follower: The role of peer follower involves moderately friendly and submissive attitude often displayed through emotional and complying speech, responsive actions that tend to follow the fellow learning partners such as peer leaders etc Pareto et al. (2009). Peer followers exhibit limited collaborative agency and are restricted to behaviours such as mutual gaze and joint attentional gaze, expressive gestures, submissive postures such as leaning backward, bowing the head, head nods etc.

Co-regulation based pedagogical roles		
Agent role	Dominance level	Friendliness level
Collaborative Peer Leader	Moderately dominant	Moderately friendly
Collaborative Peer Follower	Submissive	Moderately friendly
Competitive Peer	Moderately dominant	Less friendly
Learning companion	Submissive	Very friendly
Disruptive peer	Very dominant	Hostile

Table 4.3: Dimensional features of co-regulation roles

- **Peer Competitor**: A peer competitor agent holds conflicting or incongruent learning goals or strategies as compared to the fellow learner Chan and Baskin (1990). These behaviours can be operationalised by traits of moderate dominance and less friendliness through multi-modal features such as confident and authoritative speech, limited social talk and motivational dialogues, interactions limited to task or performance goals, reduced mutual gaze and joint attention behaviours etc.

- **Co-learner**: Role of a co-learner is often attributed to the aspect of presence in the learning environment and are considered as passive actors in learning Baylor (2009) Yu (2015). The co-learner agent roles facilitate the orchestration of peer-based learning scenarios that can enable self-directed co-regulation behaviours in the learner. Based on the dominance and friendliness traits, the co-learner agent can be introduced in two forms:

  Learning companion: A learning companion agent complements the learning interaction through very friendly and submissive behaviours that focus on promoting engagement and discovery-based learning in the learner such as teachable agents Biswas et al. (2010) Greenwald et al. (2016). The role of learning companion would involve behaviours such as engaging and friendly speech, expressive gestures, expressions of joy, surprise, smile etc. Being passively involved in learning, the learning companion role focuses more on motivational aspects of learning and acts as a tool for the learner to engage in co-regulated learning behaviours.

  Disruptive peer: The negative social attitudes of the agent can also be elicited in learning scenarios to influence the learning goals and behavioursAimeur et al. (1997). A disruptive peer agent is characterised by highly dominant and hostile attitude that intend to cause interruptions or disturbances in the learning interaction. This is often done to study how learners cope with conflicts and undesirable behaviours in learning Ingram and Brooks (2018) Sebnem et al. (2019). The role of a disruptive peer can be realised through multi-modal behaviours of interrupting or distracting speech, disoriented postures that convey the loss of engagement, acts of gaze avoidance and lack of mutual gaze, expressions of anger and disgust etc.

4.4 Conclusion

A clear distinction of the roles and associated multi-modal behaviours is relevant in designing a multi-agent learning interaction. The proposed dimensional framework for pedagogical agent roles in SSRL context describes distinct behaviours of regulation based on agent competence and feedback factors and the associated social attitudes along the dimensions of dominance and feedback. This enables operationalization of these pedagogical agent roles through corresponding multi-modal behaviours of speech, gestures, posture, gaze and facial expressions. In our research on regulation scaffolding through pedagogical agent interaction, we have followed this dimensional framework to define the characteristics of the shared learning interaction involving multiple learning partners.

The key points of this Chapter:

- In a shared learning context, distinct social attitudes and regulation characteristics can be associated with each pedagogical role.
- The interpersonal circumplex (IPC) is the common representation of attitudes. IPC is composed of two orthogonal dimensions: friendliness (ranging from hostile to friendly) and dominance (ranging from submissive to dominant).
- Social attitude of agent roles can be defined across the dimensions of friendliness and dominance while regulation behaviours for each role can be defined by the competency and feedback characteristics.
- Roles of tutor, motivator and expert can constitute external regulation scaffolding and roles of peer collaborator, peer competitor and co-learner can provide co-regulation support in a socially shared learning context.

Chapter 5

CardBot: An affordable humanoid robot peer platform for Human Robot Interaction studies

Contents

In this chapter we present the motivation behind designing a new humanoid platform for representing the role of a peer learner in learning interactions. The design and implementation of the robot and the associated Wizard of Oz tools are described along with perspectives on extending the platform as an affordable alternative for popular robots used in HRI studies.

5.1 Social robots in education

Virtual agents and social robots have been used widely to design pedagogical interactions with children as well as adult learners (Kulik and Fletcher (2016); Krämer and Bente (2010)). Virtual agents are often implemented in intelligent tutoring systems (ITS) or computer-based learning environments (CBLEs) and facilitate social interaction with the learners using multi-modal features such as gestures, gaze, facial expressions and speech. Such systems are often deployed on computer screens, tablets or phones, that the learner can manipulate using speech-based or action-based interfaces. The factor of the physical presence of an agent in the learning environment has been observed to have a significant impact on the engagement of the learner and related learning gain (Bainbridge et al. (2008); Leyzberg et al. (2012)). As compared to virtual agents, it has been observed that physically embodied agents in pedagogical roles facilitate better engagement in learning involving physical manipulations as well as increased social learning behaviours promoting learning gains (Belpaeme et al. (2018); Kennedy et al. (2015)). Hence, we aimed to explore the aspect of using a social robot to deliver pedagogical and regulation strategies in our learning interaction. Social robots in educational contexts were usually introduced

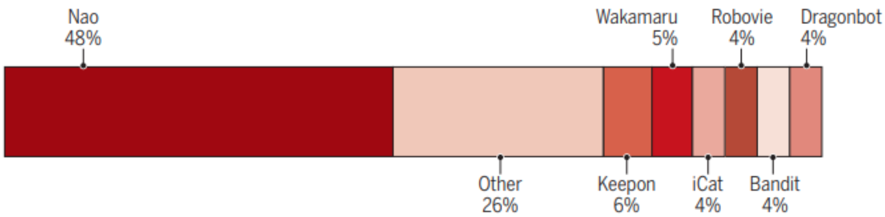

Figure 5.1: Types of robots used in HRI studies for education. *Adopted from Belpaeme et al. (2018)*

in the roles such as tutor, peer, novice, etc. Various studies have explored the scenario of robot as a tutor in learning tasks based on teaching handwriting skills Chandra et al. (2020), language skills Gordon et al. (2016), mathematical skills Brown and Howard (2014), STEM education Karim et al. (2015) etc. Similarly, introducing the robot as a peer learner has also been adopted in various studies aiming to promote peer to peer learning interactions. For instance, Kory-Westlund and Breazeal (2019b) explored the aspect of rapport building and social emulation in young children interacting with a robot playmate on storytelling game using an expressive robot called DragonBot Setapen (2012). The results suggested that interacting with a learning companion benefited in improving the rapport which was identified as a modulating factor for learning gain. Robots were also used to act as novices or teachable agents in learning interaction based on learning by teaching, also referred to as protege effect Chase et al. (2009). The CoWriter project Hood et al. (2015b) used a teachable humanoid robot which the children taught in a handwriting skills task. The learning interaction suggested that in the process of teaching, children reflected on their own skills and improved their motor skills. Regarding metacognitive aspects of learner, Vrochidou et al. (2018) used a NAO robot as a self-regulating mediator to co-teach a learning activity with elementary school students and observed that the learners were motivated by the presence of robot and displayed a better understanding of the learning topic and awareness of their own performance in the task during the interaction.

5.2 Wizard of Oz interactions in HRI

Regarding the design of robots used in learning interactions, it is often observed that the robot's presence and appearance greatly influence the expectations of the learners about the qualities and perceived role of the agent Reich-Stiebert and Eyssel (2015). A physically embodied agent is expected to perceive the actions and behaviours emerging in the learning environment, associate it with the task or social goals according to the context and act responsively enough to engage the learner without causing a distraction to the learning process. However, even though the reliability and quality of social signal processing and manipulation have greatly improved in recent times, a fully autonomous social teaching behaviour in unconstrained environments still remains challenging.

A recent survey of social robots in educational context Belpaeme et al. (2018) observed that the research using robots in pedagogical roles is greatly dominated by few popular robots in the market. The most popular robot used for HRI studies is the Nao robot (48%) (Figure 5.1) which is a 54-cm-tall humanoid capable of having 14, 21, or 25 degrees of freedom which allow the robot to walk, gesture and pan/tilt the head. The dominance of such a Nao can be attributed to the technical robustness and ease of programming but the robot is not often suitable for wider deployment and in-the-wild studies because of constraints in cost, accessibility and adaptability.

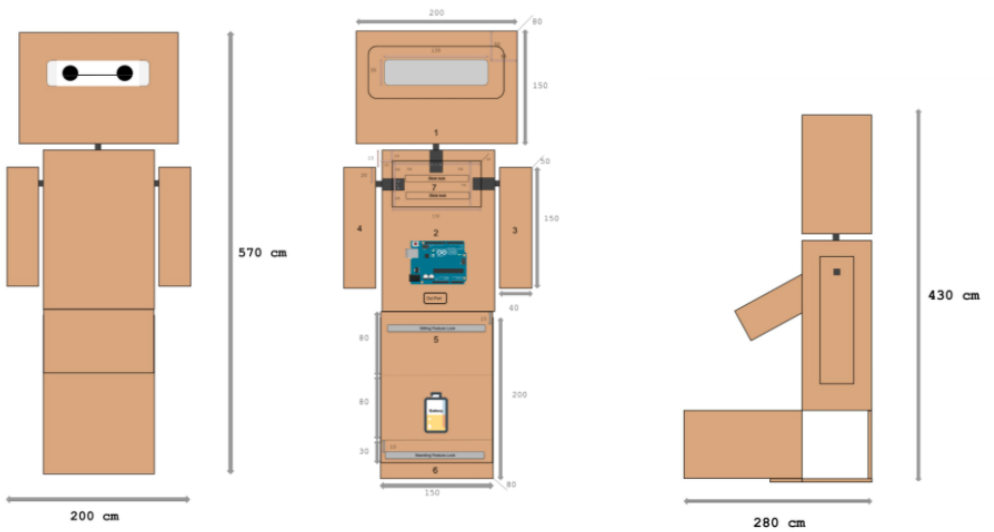

Figure 5.2: Various configurations and components of CardBot. (i) Standing posture - front view (Left), (ii) Internal components of CardBot (Middle) and (iii) Sitting posture - side view (Right)

The "Wizard of Oz" approach in human-robot interaction (HRI) allows a human operator (referred to as the "wizard") to monitor and control necessary aspects of the robot behaviour, to simulate autonomy in perspective of the user Thellman et al. (2017). A great deal of Wizard of Oz interactions in HRI often involves the use of robots that are sophisticated and expensive, yet restricted to their minimal verbal and non-verbal behaviours and perceptual abilities for making the wizard manipulation feasible Riek (2012). The field of HRI, being inherently multidisciplinary and dynamic, thus calls for robust, affordable and scalable solutions for rapid prototyping of human-robot interactions involving minimal engineering efforts. CardBot is designed to serve this purpose and aims to evolve as a platform for rapid prototyping in HRI.

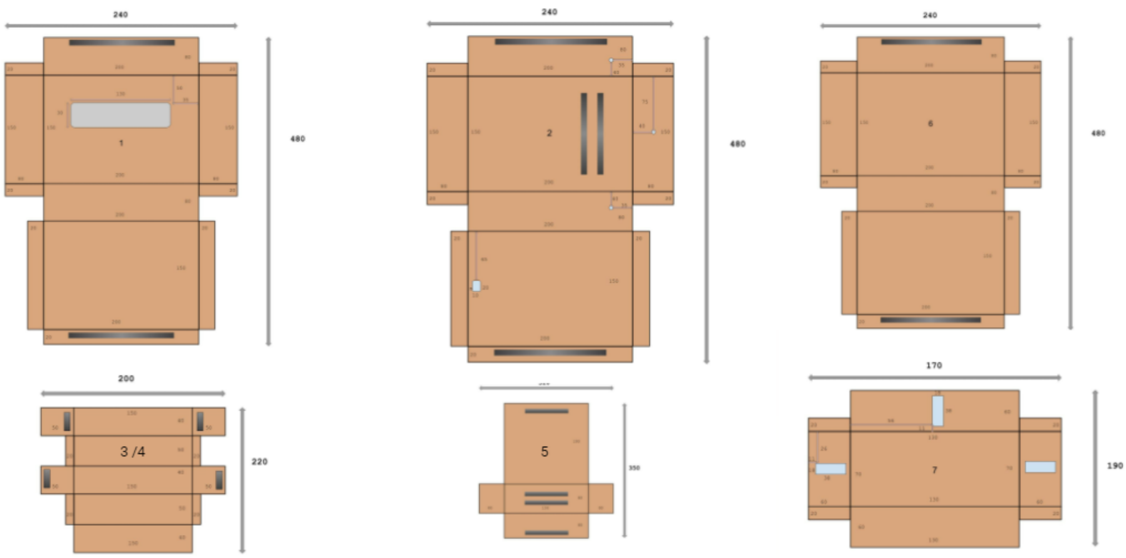

Figure 5.3: Cardboard templates for various modules of CardBot

5.3 Design and Architecture

The design of CardBot robot is intended to address the aspects of affordability, scalability and adaptability which can facilitate designing more human-robot interaction experiences and experiments. CardBot uses cardboard as its skeleton material to make the fabrication affordable, scalable and accessible. The Cardbot can be assembled by putting together the foldable cardboard templates of three contained modules and two coupling modules for the arms (Figure 5.3). The contained modules, which are the head, torso and limb, houses the smartphone, actuators and controller respectively. The robot has two possible posture configurations of standing and sitting which can be adjusted as per the need for interaction (Figure 5.2). In the standing configuration, the robot is 57-cm tall and is capable of panning the head and moving the arms. CardBot platform also enables researchers to make improvisation to the robot by design character templates which can be printed on the cardboard sheets to create a new CardBot character.

Cardbot software architecture consists of an Arduino responsible for actuation of head and arm movements, which can be composed and controlled by the wizard through a serial communication established between Arduino and Unity3D Teyssier (2018) (Figure 5.4). This equips the robot to display basic non-verbal behaviours such as eye gaze, head movements, arm pointing gestures etc. The speech-based interaction is powered by IBM Watson that enables speech synthesis and analysis. An android app running on the smart-

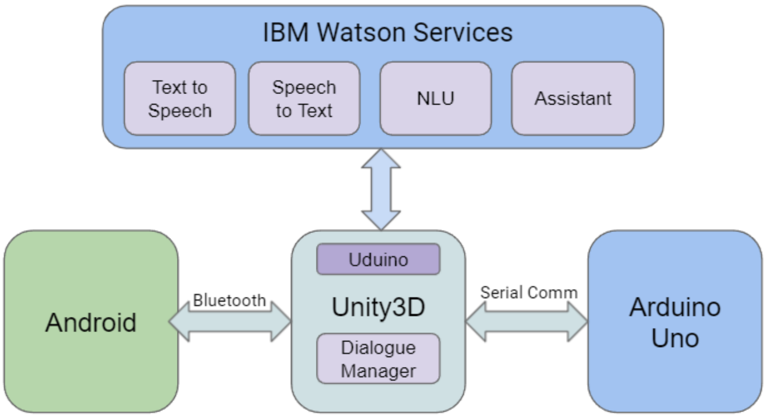

Figure 5.4: CardBot software architecture elements

phone mounted on the head module of the CardBot displays animated virtual eyes and performs eye gaze to add expressions for the robot. The Wizard console for the robot facilitates the human wizard to input the text for speech and initiate the gesture and head movements of the robot instantly from the control interface provided with a live-camera feed of robot's view (Figure 5.5).

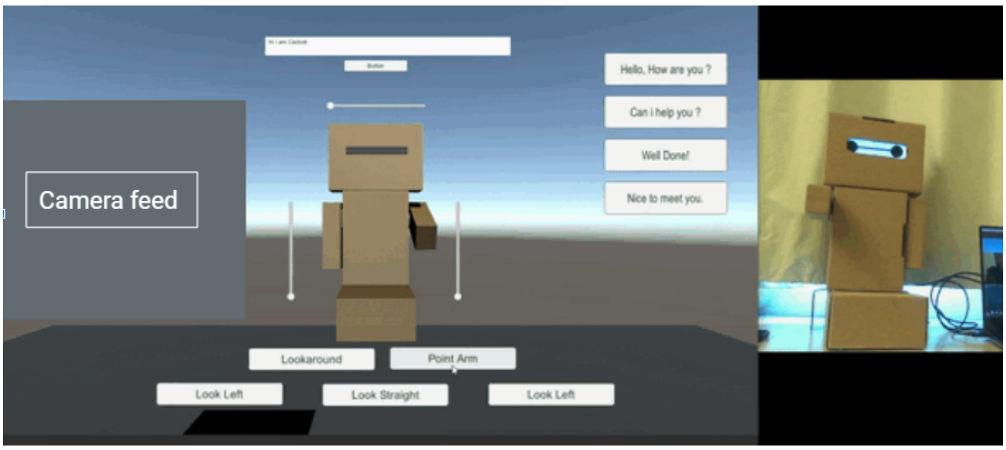

Figure 5.5: Wizard console for controlling the CardBot

5.4 Conclusion and future perspectives

This chapter described the motivation behind proposing a new robot platform for human-robot interaction studies along with the design and architecture of the system. The CardBot robot was presented as an accessible and affordable alternative for popular robots in current HRI research, which are often difficult to adapt, maintain and procure. The design and implementation of the robot ensured minimum effort and expertise in building and configuring a humanoid robot which is equipped with speech, basic gestures and expressive acts to engage socially with users. The Cardbot robot can be used effectively in WoZ contexts which should involve minimal efforts in configuring and controlling the interaction elements. The platform can also be extended in future to be integrated with other existing research tools in HRI and also made capable for more autonomous behaviours such as navigation.

In the initial phases of our research on designing a multi-agent learning interaction involving agents in various pedagogical roles, we intended to have a configuration with a virtual tutor and a peer robot to drive the learning activity. The CardBot robot was used in one of the pilot interaction studies conducted with children engaging in a learning interaction with a virtual tutor and the robot in the role of a peer, which gathered positive feedbacks on the design and perceived usefulness of the robot. However, the constraints in conducting user studies with participants interacting with a physically embodied agent during the pandemic period has limited us in using the Cardbot robot in our research further, as we shifted to conducting studies online using virtual characters only. We intend to enhance the CardBot robot by adding more autonomous capabilities and enhancements in the Wizard control interface based on feedback from the HRI research community.

The key points of this Chapter:

- Research for using robots in pedagogical contexts is greatly dominated by few popular robots in the market.
- A great deal of Wizard of Oz interactions in HRI often involves the use of robots that are sophisticated and expensive, yet restricted to their minimal verbal and non-verbal behaviours and perceptual abilities.
- CardBot is intended to address the aspects of affordability, scalability and adaptability which can facilitate designing more human-robot interaction experiences and experiments.
- The design of CardBot ensures minimum effort and expertise in building and configuring a humanoid robot which is equipped with speech, basic gestures and expressive acts to engage socially with users.

Chapter 6

FRACTOS - Learning to be a Better Learner by Building Fractions

Contents

6.1 Introduction

Collaborative learning involves learners at various performance levels working together towards a common learning goal where the learner's are responsible for one another's learning as well as their own Laal and Ghodsi (2012). In computer-based collaborative learning scenarios, the learning environment comprises of a problem space (joint learning activity, simulations, serious games etc.) and a social interaction space (chat, argumentation tools, conversations etc.) Dillenbourg and Betrancourt (2006). The notion of socially shared regulation involves processes by which multiple learning partners regulate their collective activity, co-constructing perspective, goals and standards and the desired product is socially shared cognition Hadwin et al. (2011). The central tenet of these collaborative learning interactions involving multiple learning and regulating partners is the presence of a learning task that can enable effective shared goals for learning and reflection.

According to Bellotti et al. (2010), learning tasks are activities that embody units of knowledge embedded in a learning environment, through which the learners can explore a learning topic/domain to construct meaning, build lasting memories and deepen the understanding of the featured item(s). Constructionist theories of learning consider the learner as an active builder of knowledge, engaged in constructing internal concept representations and interacting with external artifacts through social interactions with others to share representations of their understandings and thoughts Han and Bhattacharya (2001).

Learning by Design (LBD) emerges from constructionist theory and involves learners creating physical/digital artifacts representing a learning outcome that is relatable to their knowledge and skill potentials. Learning by Design constitutes tasks that are based on a real-world context that allow opportunities for multiple strategies for the problem-solving process. A constructionist learning task should thus provide a balance of constrained, scaffolded challenges in an open-ended learning environment that considers the learner preferences, knowledge and skills. Also the collaborative work involved in the task should allow the learners to obtain feedback and reflect on their actions and performance Kalantzis and Cope (2005). In this work, we have designed and implemented a constructionist learning task called FRACTOS, which is structured to emphasize the learner on different phases of self-regulation such as planning, performance and reflection while engaging in a constructionist task of building, identifying and comparing fractions using virtual LEGO blocks in a multi-agent learning interaction.

6.2 Learning topic: Fractions

Fractions are among the most complex mathematical concepts that children need to learn in their early years of education Lamon (2012). Several studies have reported the instructional difficulties and learner misconceptions Sarwadi and Shahrill (2014) that challenge both researchers and scholars in teaching and learning fractions. Fractions are considered as a multifaceted concept Charalambous and Pitta-Pantazi (2007) that involves the following interrelated sub-constructs of part-whole, ratio, operator, quotient and measure (Figure 6.1). These sub-constructs has been identified to be relevant for various understanding on fraction such as fraction operations (addition/multiplication etc), fraction equivalence and problem-solving.

The part and whole construct is defined as a case in which a continuous quantity or a set of discrete objects are partitioned into parts of equal size and is considered as the foundational construct for the other subconstructs. The ratio subconstruct conveys the notion of a comparison between two quantities and is foundational to the understanding of fraction equivalence Sophian (2000).In the operator interpretation of fractions Marshall (1993), they are treated as functions applied to a number, object, or a set. For a

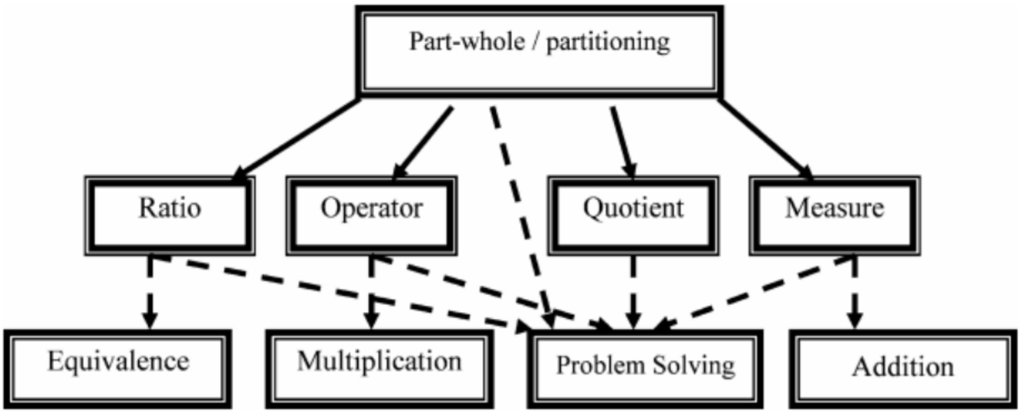

Figure 6.1: Mathematical sub-constructs related to fractions. *Adopted from Charalambous and Pitta-Pantazi (2007)*

quotient subconstruct Kieren (1993), a fraction is treated as a result of a division operation. The measure subconstruct Smith III (2002) conveys the quantitative aspect of the fractions. The proposed learning task will be focusing on the foundational construct of part and whole and would move on to ratio subconstruct for teaching the understanding of fractional equivalence in further levels.

A central aspect of the understanding of ratios and fractional equivalence is proportional reasoning which involves thinking about part and wholes, or in general, about fractional quantities. It is considered as a form of reasoning that is necessary for understanding relationships in science and mathematics as well as in everyday life Piaget and Inhelder (2014). According to Lamon (1993), there exists four semantically distinct types of problems based on ratios and proportions which are:

- Part-Part-Whole : where the 'whole' is described in terms of two or more 'parts' of which the whole is composed.
- Associated sets: where the relationship between two elements is explored within the problem situation.
- Well-chunked measures: where two measures are compared to give a third inclusive measure.
- Stretchers and Shrinkers: where equivalence of ratios between two measures is preserved.

The proposed learning task will be exploring the first two categories of Part-Part-Whole and Associated sets in the design of learning interventions and evaluation of learning outcomes.

Various studies that explored the development of proportional reasoning have reported mixed results. Some earlier studies Case (1985) identified proportional thinking as a late-emerging thinking process after the age of 11. Möhring et al. (2015) reported that children of ages 3 years and 10 months to 4 years and 10 months were capable of distributing a set of objects equally among a small number of people, although they did not have a deep understanding of fractions. Furthermore, Pitta-Pantazi and Christou (2011) found that by the age of 5, children can share a single object among more number of people. In addition, young children can have an understanding of proportional relations such as equivalence Fazio and Siegler (2011). Recent research on the topic suggests that proportional thinking is rooted in learning experiences and can be strengthened through appropriate learning activities Jitendra et al. (2013).

Resnick et al. (1988) presented a LEGO/Logo learning environment to experiment with situated learning activities using digital artifacts and tools. A digital game for instruction of fractions was developed by Lee and Shanks (2009), that involved comparison of fractions of different sizes. The game included instructional strategies, conceptual analysis of fractions and visual representations based on a story of forming staircases to go up to a tower. Gould (2011) experimented on using LEGO bricks as manipulatives in mathematical classrooms to help students learn about fractions with an emphasis on equivalent fractions. A digital LEGO-based learning environment for fraction ordering was presented by Agbonifo and Ogunmoroti (2015) and provided the learner with feedback and rewards on countering misconceptions and conflicts during the game. On exploring the effectiveness of didactical games using LEGO blocks involving a sequence of activities to achieve learning goals on fractions, Rejeki et al. (2017) observed that LEGO representations of fractions supported conceptual understanding for both high-ability and low-ability students. The intervention also promoted computational skills in low-ability students and improved the student's motivation and engagement. These explorations thus expand the scope for using LEGO representations for fractions in providing clear pedagogical instructions and interventions in a digital learning environment.

6.3 Task Framework

FRACTOS learning task is designed in the context of a triadic learning interaction involving a human learner and two pedagogical agents in the roles of a tutor and peer. The virtual agent assumes the role of a more knowledged entity capable of external regulation support such as mentor, motivator or expert, while the peer agent facilitates co-regulation scaffolding. This configuration is also analogous to the real-world learning interactions happening in classrooms, which often involve the learners interacting simultaneously with instructors and peer learners. The learning task is based on the mathematical concepts of fractions and proportional reasoning, focusing on the foundational constructs of part and whole and ratios for teaching the understanding of fractional equivalence.

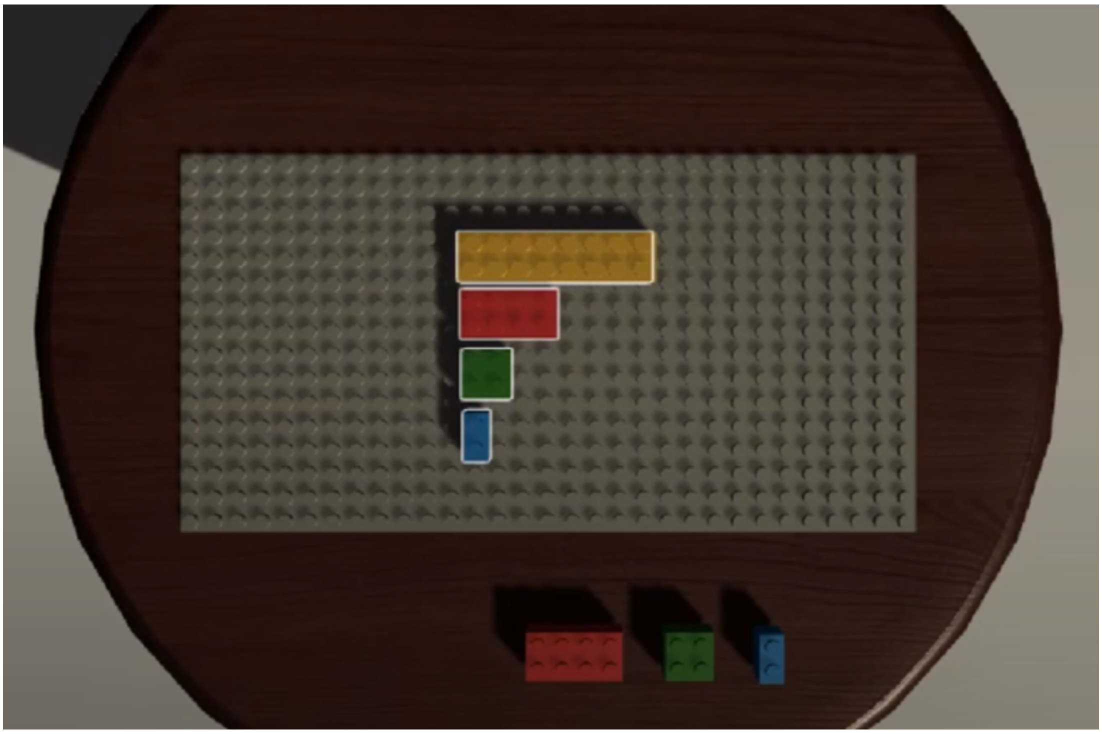

Figure 6.2: Virtual LEGO blocks representing fractions

The FRACTOS task is designed and implemented as a desktop/tablet-based 3D game developed in Unity3D. The task activity represents the concept of fractions through representations based on virtual LEGO blocks of various sizes and colours. The fundamental building blocks involved in the activity are the ones representing the fractions 1/2, 1/4 and 1/8, which can be used to build new fractions (Figure 6.2). The virtual LEGO blocks provide the interaction affordances to be manipulated through user interface (UI) actions of select and drag for moving, drag and drop for combining, hold for 2 seconds and release for duplication etc. For instance, to build the fraction 5/8 during the activity, the learner can combine five blocks of 1/8 fraction to represent the value 5/8. The learning task is structured into various levels that introduce distinct constructs related to fractions and different phases during each exercise to allow the learner to engage in self-regulating processes.

6.3.1 Agent implementations

The entire learning interaction in FRACTOS activity is intended to have multiple roles of learning partners engaging with the learner. The FRACTOS framework allows the representation of pedagogical agents in virtual and physical forms for the roles of more knowledged entities such as mentor, tutor, expert etc as well as peer-like roles such as peer-collaborator, co-learner etc. Two distinct types of regulation are realised through the agents in various roles and associated behaviours in the FRACTOS learning task environment which are

- External regulation : through instructional discourse of strategies through roles of more-knowledged entities aimed at motivating performance-oriented learning interactions and providing domain-scaffolding for the learner.
- Co-Regulation : through peer behaviour-based agent representations exhibiting demonstration of regulation strategies that can promote adaption of self-regulation behaviours in the learner.

The current implementation of FRACTOS learning task involves a virtual human character in the role of a tutor and a virtual robot character as a peer learner (Figure 6.3). The virtual agent is modelled on GRETA Pelachaud (2015), which is an Embodied Conversational Agent Platform equipped with socio-emotional and communicative behaviours such as gaze and gesture that enables designing various social attitudes for each role. GRETA based virtual agent implementation allows the real-time generation and animation of agent's verbal and non-verbal behaviours. Based on the verbal intentions of the pedagogical agent communicated to the GRETA platform, the 'intent planner module' in GRETA generates the communicative intentions of the agent such as speech and emotion which are represented in the Functional Markup Language (FML). The 'behaviour planner module' translates these communicative intentions into a set of multi-modal signals such as gestures and facial expressions. Finally, these multi-modal behaviours sets represented in Behaviour Markup Language (BML) format are transformed into animations of the embodied agent through the 'behaviour realizer module' and the respective animation parameters are sent to Unity3d, that renders the animation of the pedagogical agent character in FRACTOS learning task accordingly.

The peer agent in FRACTOS task is represented as a virtual robot character with basic gestural and expressive features such as head and arm movements for acts pointing, greeting, calling and attention etc. The speech and associated emotions of the peer agent character is realised through the Text-to-Speech (TTS) and Natural Language Understanding (NLU) modules in IBM Watson services High (2012) which are later translated into associated gestural animations through animator controller components in Unity3d. The speech of the robot generated using the IBM Watson service and is modified later in Unity3D to sound like a child's voice as it suits the role of a peer learner better.

6.3.2 Task Levels

The FRACTOS learning task comprises of three distinct activity levels based on the constructs of fractions. The learning task is initiated with an introduction to the fundamental blocks of fractions involved in the game and the rationale behind the available LEGO blocks demonstrated through a sample task of constructing a new fraction using the basic

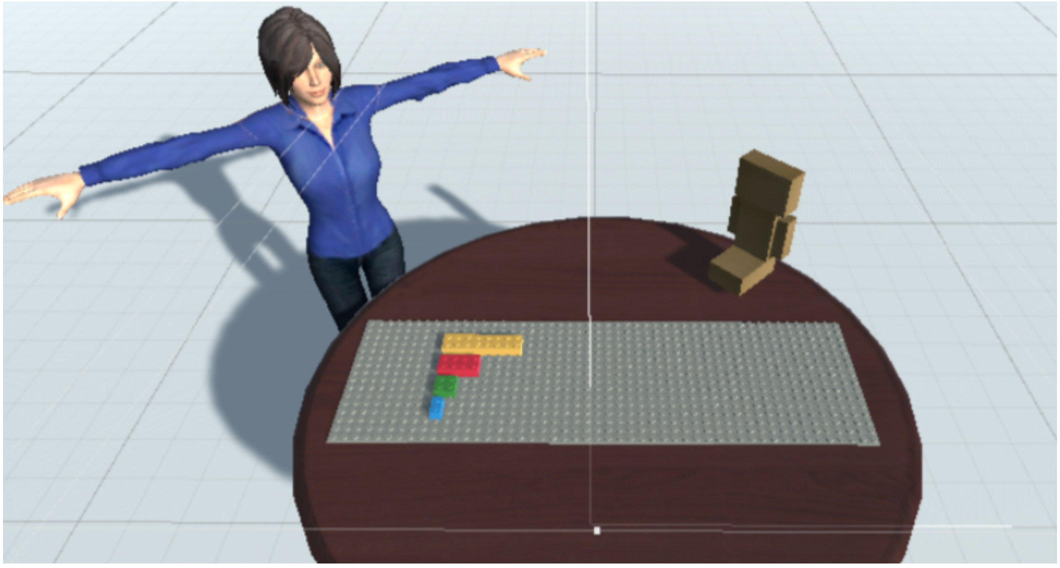

Figure 6.3: Virtual tutor agent and virtual robot peer in FRACTOS game environment

blocks. The FRACTOS task framework allows to perform three kinds of exercises related to fractions:

- Building fractions: that involves identifying parts from the whole and combining parts to build bigger parts or whole itself (Figure 6.4). eg: 1/4 + 1/4 +1/4 = 3/4
- Identifying fractions: when the learner should identify the value of fraction represented by a given combination of parts
- Comparing fractions: which involves comparing parts or combination of parts to each other to understand the greater or smaller amongst the given fraction representations. eg: 3/2 < 5/2

The learner can advance progressively from the introductory part to the highest level or choose to perform the activity suitable for the moment. The system would generate new exercises in each level as the learner completes the task and the associated reflective interactions with the fellow agent partners.

6.3.3 Phases

The FRACTOS learning task is structured in context of promoting self-regulation in the learner through shared task and learning goals with the learning partners. The tutor agent promotes external regulation through explicit domain knowledge support and instruction along with behaviours of feedback and monitoring. The peer agent facilitates co-regulation through behaviours such as thinking aloud, expressing doubts, raising questions, asking for suggestions etc and promotes encouragement for the learner in perform-

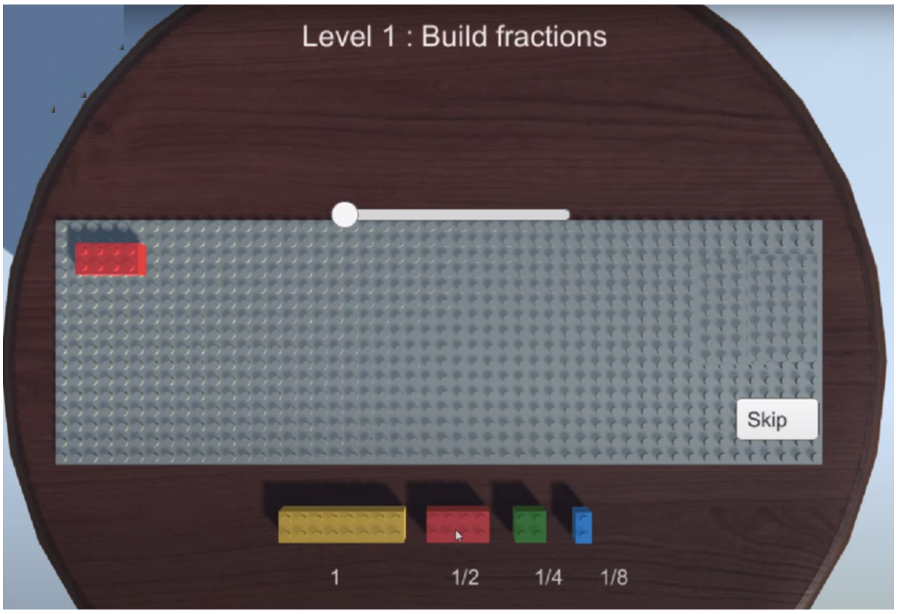

Figure 6.4: FRACTOS game interface for building fractions

ing the activity. Based on the models of self regulation, the activity has been broken down into three recursive phases, describes as follows:

- Planning Phase: Verbalization or behaviour related to the selection of procedures necessary for performing the task which is done before starting to build the fraction.
  Tutor agent: You can use the red blocks to build this fraction.
  Peer agent: Which block shall we use for building 5/2 ? Red or green?

- Performance Phase: Verbalization or behaviour related to the ongoing on-task assessment and the degree to which performance is progressing towards a desired goal.
  Tutor agent: Try using the 1/2 blocks instead.
  Peer agent: Do you think 1/2 block is the right one, my friend ?

- Reflection Phase: Verbalization or behaviour related to reviewing task performance and evaluating the quality of performance which is done after building the required fraction.
  Tutor agent: Now tell me, how many red blocks did you use for building this fraction?
  Peer agent: I think we took three 1/2 blocks to build 3/2. Am i correct, my friend ?

6.4 Task instance

Introduction session: The FRACTOS task-based interaction starts with an introduction session when both agents introduce themselves to the learner by engaging in a small talk. After the gentle introduction, the tutor agent gives an overview of the game elements and the potential actions that the learner can perform. This is followed by a sample task of fraction building using the basic virtual LEGO fraction blocks that conveys the value representations and foundational construct of part and whole to the learner.

Tutor agent: Hello, My name is Alice, Nice to meet you. Today we will learn about fractions by playing an interesting game called FRACTOS.
Peer: Hello, I am Bot and we will be playing this game together.
Tutor: Perfect. In this game, we will use LEGO blocks to build fractions. Let me teach you both, the basics of this game.
Peer: Tell us about the game. I am really curious to play the game now.

Activity session: The Activity session presents the exercises for the learner based on the chosen activity level among building, identifying and comparing fractions. Each exercise is divided into planning, performance and reflection phases where both tutor and peer agents initiate respective regulation scaffolding behaviours. For instance, in the fraction building task, the tutor agent would present the value of fraction to be built asking the learner and peer agent to find the right combination of basic LEGO blocks. Before starting to construct the fraction, the agents would initiate a conversation on the planning by proposing to try with a block or asking for alternatives.

Tutor: You can use 1/2 blocks to make this fraction.
Peer: Hmm. Let me have a look at the fraction.

In the performance phase, the learner starts building the required fraction using the virtual LEGO blocks and the agents would provide feedback and suggestions depending whether the learner's choice was right or wrong. The tutor agent provides explicit and direct delivery of information while the peer agent, being less knowledged, resorts to making implicit suggestions and acknowledgement.

Tutor: Let me help you here. Three blocks of red makes the three by two fraction.
Peer: Exactly what i thought. Let's build the fraction now.

Finally, after building the fraction, the tutor agent informs the learner and the peer agent if it was correct or not and gives feedback on their performance. During the reflection phase, the peer agent would actively engage in reviewing the mistakes or seeking more information about the fraction to motivate the learner to engage in reflective regulation behaviours. The tutor agent would promote reflection by asking questions or providing the overview of performance in the overall activity.

Wrap-up session: The learning activity is concluded by a wrap-up session where the tutor agent presents an overview of the learner performance and score in the completed activity as the peer agent express encouragement and gratitude to the learner for the collaborative engagement during the game. The agents bid goodbye to the learner and reminds the learner to continue learning about fractions.

Tutor: Let me ask you one question, how many red blocks are used to build the three by two fraction?
Peer: I think we used three blocks of 1/2 to make this fraction. Am i right, my friend?

6.5 Wizard of Oz (Woz) Implementation

The FRACTOS-WoZ framework is developed in Unity3d as tablet-based game which is played along with a virtual tutor and a robot peer both of which are partly controlled by a human wizard to make sure the interaction stays within the learning topic. The virtual tutor is modelled on GRETA Pelachaud (2005), which is an Embodied Conversational Agent Platform equipped with socio-emotional and communicative behaviours such as gaze and gesture that enable designing various social attitudes for each role. The role of peer learner is played by an arduino-based humanoid robot called CardBot (discussed in Chapter 5) which was designed and developed for the activity as a scalable and affordable alternative for Wizard of Oz based Human-Robot interaction orchestrations Krishna and Pelachaud (2020). The actions of the robot are animated and controlled from Unity3d by establishing a serial communication with Arduino using Uduino Unity plugin Teyssier (2018). The tutor agent and peer agent are positioned on either side of the activity space facing the learner at equal angles. The system enables collecting the regulation behaviours of the child from the gaze behaviours and performance trace measures from the tablet such as error rate, response time, time for task completion etc during the activity and enables the wizard to trigger appropriate agent behaviours to promote regulation.

The FRACTOS game enables the wizard operator to advance through the interaction step by step and also return back to any specific instance in the interaction script if needed, for example when the learner is distracted from the activity (Figure 6.5). The wizard interface is split into 3 parts:

- Activity monitor: Real-time monitoring of the tactile interactions which the child is performing on the tablet screen. This section also indicates error notification, accumulated error count and the current score of the learner in the task.
- Camera monitor: Real-time video feed from the camera facing the learner, along with the information on the gaze direction of the learner.
- Agent Controls: Includes triggers for pre-scripted or custom text inputs instantiated to multimodal behaviours for both agents, which can be triggered whenever needed by the wizard.

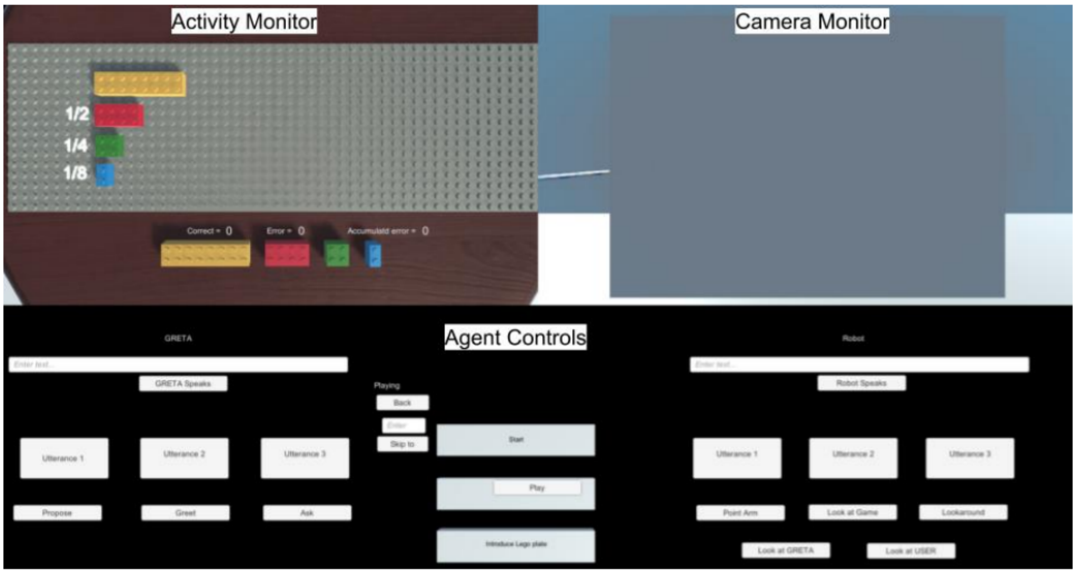

Figure 6.5: Wizard console for FRACTOS game

The FRACTOS learning task using the WoZ framework was showcased to public for a pilot interaction with 25 children between age 5 to 13 at a science festival, which gathered positive feedback on agent perception and task engagement from children through questionnaires and also receiving appreciation from parents and teachers alike.

6.6 Conclusion

The unique context of combining socially shared regulation in learning and triadic multi-agent interaction involving various roles of pedagogical agents demanded a learning task that provided scope for an engaging interaction and regulation scaffolding. The definition of FRACTOS task structure was motivated by the models of self-regulation and the associated processes of regulation. The FRACTOS learning task framework also allows virtual characters or physical agents such as robots to be integrated to the Unity3D based architecture easily, thus extending the potential of use with other agent platforms. In general, the FRACTOS learning task presents a scenario for bringing together various roles of pedagogical agents to co-construct shared goals, make decisions and deploy various regulation strategies through structured and recursive phases of regulation relevant for our research.

The key points of this Chapter:

- FRACTOS learning task is designed in the context of a triadic learning interaction involving a human learner and two pedagogical agents in the roles of a tutor and peer based on the mathematical concept of fractions.
- The learning activity involves recursive phases of planning, performance and reflection aiming at promoting self-regulation in the learner.
- The tutor agent promotes external regulation through explicit domain knowledge support and instruction along with behaviours of feedback and monitoring.
- The peer agent facilitates co-regulation through behaviours such as thinking aloud, expressing doubts, asking for suggestions etc and promotes encouragement for the learner in performing the activity.

Chapter 7

Multi-agent triadic learning interaction design in socially shared regulation context

Contents

7.1 GRETA VIB

GRETA-VIB is a platform for visualising embodied conversational agents (ECAs) and their real-time generation and animation of verbal and nonverbal behaviours Pecune et al. (2014). The GRETA platform is based on SAIBA framework, which is a common framework for the creation of multimodal communicative behaviours and emotional states in ECAs. The GRETA architecture allows to specify the communicative function and the associated communicative behaviour at two levels of abstraction. The functional level denotes the agent's intent and the behavioural level determines how the agent will communicate by instantiating the intent through multi-modal realization of gestures, speech, facial expressions etc.

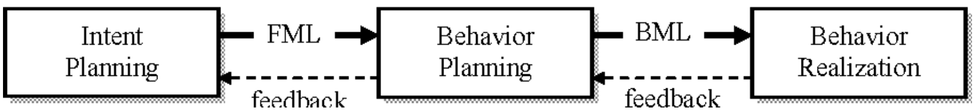

Figure 7.1: SAIBA framework for embodied conversational agents

The GRETA architecture (Figure 7.1) involves different levels of behaviour generation, implemented through three main modules which are:

- Intent Planner: This is a high-level module that handles the communicative intentions of the agent such as goals, beliefs, emotional states etc. The intents of the agent are encoded in Functional Markup Language(FML) files and can contain a sequence of dialogue acts such as asking a question, giving feedback etc. For instance, an FML file (Figure 7.2) that containing the dialogue: "Hello, My name is Camille. What is your name ?" associates the communicative intentions of emphasis(*pitch accent*), question marker(boundary tone), greeting and asking a question(performative), to generate the agent behaviour.

```
<?xml version="1.0" encoding="ISO-8859-1"?>
- <fml-apml>
  - <bml>
    - <speech language="english" text="" type="SAPI4" voice="marytts" start="0.0" id="s1">
      - <description type="gretabml" level="1">
          <reference>tmp/from-fml-apml.pho</reference>
        </description>
        <tm id="tm1"/>
        Hello,
        <tm id="tm2"/>
        My name is Camille.
        <tm id="tm3"/>
        I am one of the virtual character
        <tm id="tm4"/>
        of the Greta platform.
        <tm id="tm5"/>
        <pitchaccent type="HStar" start="s1:tm3" id="pa2" level="medium" importance="1" end="s1:tm4"/>
        <boundary type="LL" start="s1:tm5" id="b1" end="s1:tm5+0.5"/>
      </speech>
    </bml>
  - <fml>
      <performative type="greet" start="s1:tm1" id="p1" importance="1.0" end="s1:tm2"/>
      <performative type="ask" start="s1:tm4" id="p2" importance="1.0" end="s1:tm5"/>
        <!--<rest id="rp1" type="restpose" start="0" end="s1:tm5" importance="1.0"/>-->
    </fml>
</fml-apml>
```

Figure 7.2: Example of a FML file

- Behaviour Planner: This module translates the communicative intentions received from the intent planner module into multimodal features such as facial expressions, gestures, poses etc and are encoded in Behaviour Markup Language(BML) files. For instance, the communicative intention of *'greet'* can be expressed through a face expression of smile with raised eyebrows, direct gaze, a greeting gesture defined in a set of non-verbal behaviours called *'behaviour set'* (Figure 7.3). The behaviour planner module selects the multimodal signals relevant for each BML tag based on the agent intentions.

- Behaviour Realizer: This module produces the animations for the agent's face, lips, body that is aligned with the generated speech audio from the BML descriptions given by the behaviour planner module. The gestures involve a combination of var-

```xml
<?xml version="1.0"?>
- <behaviorset name="performative-greet">
  - <signals>
      <signal name="faceexp=raise_eyebrows" modality="face" id="1"/>
      <signal name="performative=GreetNew_Ges_R" modality="gesture" id="2"/>
      <signal name="NOD" modality="head" id="3"/>
      <signal name="gaze=look_at" modality="gaze" id="4"/>
    </signals>
</behaviorset>
```

Figure 7.3: Example of a "Behaviour set" for a performative gesture

ious hand movement trajectories with variable expressive parameters such as spatiality, temporality, openness etc. Facial expressions are realised through animations of facial features such as eye and mouth movements, based on Facial Animation Parameters(FAPs) Pandzic and Forchheimer (2003) that describe facial action units related to various emotional states of the agent.

Figure 7.4: Embodied conversational agent character 'Alice' in GRETA-VIB platform

7.2 Generation of communicative gestures

The automatic generation of communicative gestures from the dialogue is realised through *Meaning Miner module* in GRETA Ravenet et al. (2018), which is based on the concept of image schemas and ideational units (Figure 7.4). Image schemas are mental representations of what is being conveyed by the agent and ideational units are the units of rhythm and meaning in a discourse Calbris (2011). The *Meaning Miner module* reads the communicative intentions and the related prosodic and ideational unit markers to identify related image schemas for generating the corresponding coherent gesture.

The GRETA platform also allows integration with the Unity3D engine through Apache Thrift interface that transfers the FAP and BAP parameters to the *Character animator* in Unity3d. This would enable using the GRETA architecture in interactive applications developed in Unity. Figure 7.5. presents the configuration of GRETA that we have used for integration with a Unity3d based interactive learning task that features a virtual agent character in a 3d game environment whose communicative behaviours are generated within GRETA platform.

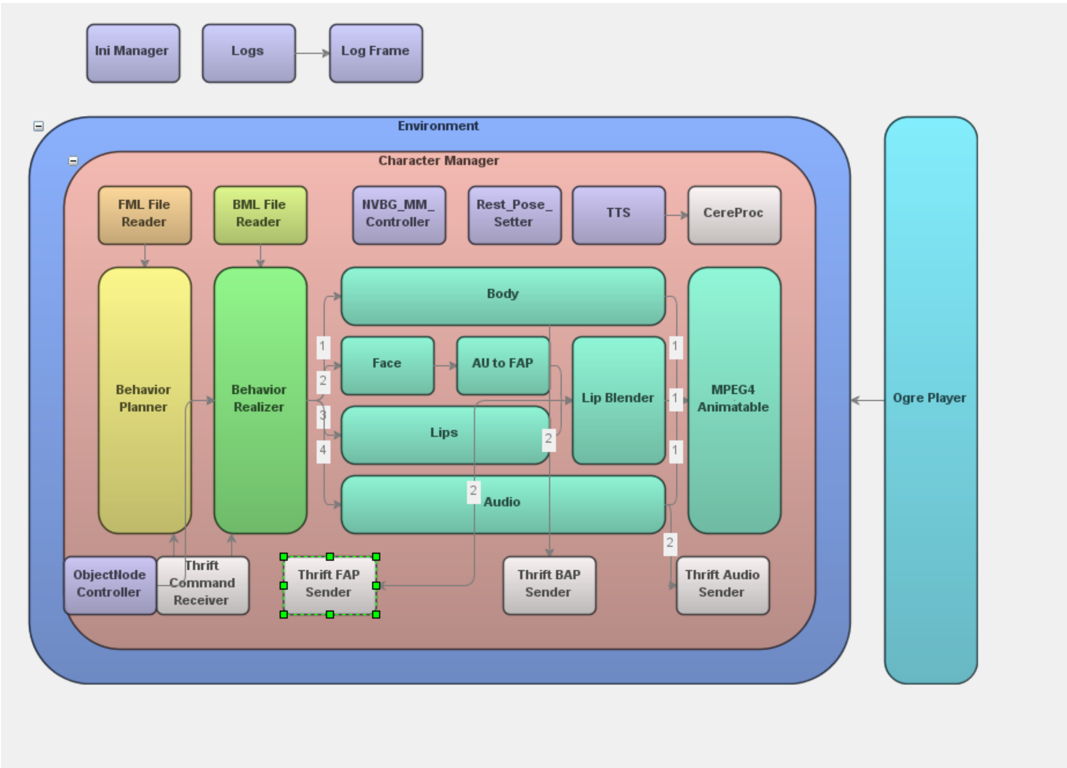

Figure 7.5: GRETA-VIB configuration for integration with Unity3D

7.3 Triadic learning interaction for SSRL

Socially shared regulation of learning occurs when a group of learners regulate together as a collective by constructing shared task perceptions, goals and take decisions through collaborative interactions. This shared regulation of learning may involve various distinct types of regulation scaffolding such as: (i) External regulation: facilitated by more capable or knowledgeable learning partners such as an expert or tutor providing instructions, feedbacks or prompting strategies that can enhance regulation of the learner or (ii) Co-regulation: when a peer learner influence the regulation behaviours in the learner through jointly constructed goals and decisions. Artificial pedagogical agents have great potential to be used for learning interactions with specific regulation goals and behaviours. According to the proposed dimensional framework for pedagogical agent roles in Chapter 3, the agents in a shared learning context can have various distinct social roles and attitudes that influence the self-regulation of a learner in different ways. To date, multi-agent learning interactions involving different role of pedagogical agents in SSRL context remains largely unexplored Panadero (2017), and in this research, we aim to address this opportunity for orchestrating shared regulation interactions with agents of various roles and related regulation scaffolding strategies.

In general, a learning interaction with pedagogical agent(s) in socially shared regulation context can be broken down into three elements which are (i) a human learner, (ii) pedagogical agent learning partner(s) and (iii) a collaborative learning activity. For our research, we design the shared learning interaction with two pedagogical agents, where one agent assumes the role of a more knowledged other(MKO) providing external regulation support and the other is presented in the role of a peer learner facilitating co-regulation functions. Based on the dimensional framework for pedagogical roles in SSRL context, we have operationalized the roles of tutor and peer collaborator to represent sources of external regulation and co-regulation respectively. Hence the proposed learning interaction would involve a human learner, and two agents with distinct regulation behaviours engaging in a collaborative learning task as represented in Figure 7.6.

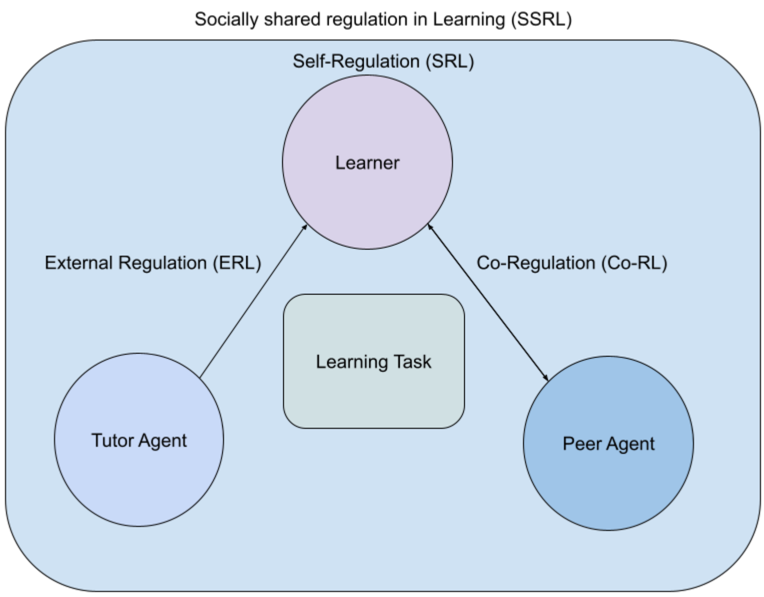

Figure 7.6: Triadic learning interaction elements constituting SSRL

Tutor agent: Tutor role is operationalized through behaviours such as instruction of regulation strategies, explicit delivery of knowledge through hints, suggestions etc and displays moderate levels of dominance and friendliness towards the learning partners. The tutor agent is also characterised by expressive, informal and informative speech, deictic and open gestures, social as well as task-oriented dialogues aimed at improving the learner performance. Being more competent and knowledged, the tutor agent is thus considered as a source for external regulation scaffolding and will take control of the learning activity in terms of providing direct guidance, proactive feedbacks and performance evaluations.

Peer agent: The peer agent is presented as a friendly and inquisitive collaborative learning partner who displays self-regulation behaviours such as thinking aloud, asking for help and suggestions etc. The peer agent will actively engage in demonstration of regulation strategies that the learner can adopt or learn from. In terms of multimodal behaviours, the peer agent features enthusiastic and engaging speech through acts of acknowledgement and encouragement, informal and friendly dialogues as well as behaviours of taking the lead or following the learner during the activity depending on the task states.

Learning task: The features of a collaborative learning task involves a relevant learning topic on which the activity is structured. It is important for the learner to develop interest in the activity and identify some value with the task, so that the interaction remains engaging. The learning task should also provide a scenario for shared conceptions of goals, beliefs and actions between the learners. Another important aspect of a good collaborative learning task in terms of SSRL is the opportunity for activating regulation processes in recursive manner.

In particular, the proposed triadic learning interaction setup with multiple pedagogical agent roles aims to address the following research questions:

- **RQ1**: Does engaging in a learning interaction with self-regulated learning partners improve the self-regulation behaviours of the learner?
- **RQ2**: Do various roles of agents (tutor and peer collaborator) influence the learner's regulation in different ways?

7.4 Conclusion

Multi-agent collaborative learning interactions prove to be a great setting for studying socially shared regulation processes and its effect on self-regulation of the learner. Distinct social attitudes and regulation strategies associated with different pedagogical agent roles allows us to manipulate the learning interaction towards performance-oriented or regulation-oriented learning pathways depending on the task levels and learner behaviours. This learning configuration becomes relevant as it is analogous to the real-world learning interactions like classrooms, online courses etc where the learning happens in presence of multiple entities having different levels of knowledge and competency as well as social and learning goals. The further chapters of this thesis will look into the development of a collaborative learning task, specific for our research on self-regulation in SSRL context and the studies conducted based on the proposed triadic learning interaction with multiple pedagogical agent roles.

The key points of this Chapter:

- Socially shared regulation of learning occurs when a group of learners regulate together as a collective by constructing shared task perceptions, goals and take decisions through collaborative interactions.
- The proposed learning interaction would involve a human learner, and two agents with distinct regulation behaviours engaging in a collaborative learning task aimed at promoting self-regulation.
- Tutor role is operationalised through behaviours such as instruction of regulation strategies, explicit delivery of knowledge through hints, suggestions etc and displays moderate levels of dominance and friendliness towards the learning partners.
- The peer agent is presented as a friendly and inquisitive collaborative learning partner who displays self-regulation behaviours such as thinking aloud, asking for help and suggestions etc.

Part V

User Studies

Chapter 8

User Study 1: Understanding user's perception of agent roles, behaviours and the learning activity

Contents

This chapter presents our first perceptive study with the proposed multi-agent learning interaction based on the FRACTOS learning task involving the tutor and peer agent roles. We were interested in understanding the perception of users on the agent roles, associated qualities such as likeability and perceived intelligence as well as the learning activity in general. In this study, we also looked at the regulation behaviours and learning gains during the interaction to understand the effectiveness of newly designed FRACTOS learning task in promoting a self-regulation oriented learning interaction with the agents.

8.1 Introduction

Collaborative interactions with pedagogical agents have proved to impact the cognitive, motivational and emotional aspects of learning. The principles of embodiment and presence suggest that embodied pedagogical agent can influence the learning behaviours through the features such as gestures, gaze, facial expressions, social attitudes etc Mayer (2014). The social-cognitive perspective of learning considers the social interactions with pedagogical agents as a significant factor in improving the self-efficacy Bandura (2001) and self-regulation of the user Zimmerman (2000). Thus the perception of agent attitudes, behaviours and the associated roles by the user becomes relevant in deciding the effectiveness of a learning interaction. The development of a social relationship with the pedagogical agent and the correct perception of agent persona would help the user to better understand the agent intentions and capabilities as well as to predict its actions and behaviours Baylor and Kim (2005). For our research, we have proposed a collaborative learning interaction involving two pedagogical agents in the roles of a tutor and peer, focusing on the aspect of improving self-regulation behaviours in the user in a shared regulation context. Each agent role is defined by the social attitude expressed through distinct levels of dominance and friendliness characteristics along with associated traits of regulation behaviours relevant for that role. This study aims to understand the perception of agent attitudes, behaviours and roles as well as the effectiveness of the developed FRACTOS learning task in creating an engaging learning interaction.

8.2 Related work

8.2.1 Multi-agent learning interactions

The proposed learning interaction for our research on scaffolding the regulation behaviours of a user in a socially shared regulation context, involves the operationalisation of a multi-agent learning interaction based on a collaborative learning task. The split-persona effect suggests that figuratively defining the agent persona features by functionality into two or more separate agents can enhance learning Baylor (2003b). Empirical evidence from studies that explores the presence of multiple roles of pedagogical agents provides mixed results in terms of learning outcomes and is often attributed to the differences in definition and implementation of agent behaviours and strategies. For instance, considering the cognitive load, a clear definition and consistent behaviours are required for each agent role, which allows the user to attribute specific kinds of feedback and actions to an agent, thus reducing their effort in engaging with multiple agents Dinçer and Doğanay (2017).

On studying the effects of agent feedback, Baylor and Chang (2002) found that the presence of two agents was preferred to one agent when the system provided non-adaptive and timely feedback to the users. Interestingly, in another similar study with two agents having instructivist and constructivist approaches, there was no evidence for improvement in learning but it was observed that the presence of two agents promoted metacognitive awareness Baylor (2002). Various multi-agent systems like MASCARET Buche et al. (2004), VCAT Johnson et al. (2011) etc have explored the potential of having pedagogical agents of different roles and goals together in a learning interaction. Kim et al. (2006) observes that having different roles can enable the user to have multiple perspectives on the same learning situation, thus enhancing the interaction possibilities. Interacting with multiple agents can also improve self-efficacy and agency of the user to control and direct the learning according to their preferences towards the agent and related learning goals Baylor and Kim (2005). In general, multi-agent learning interactions can enable distinct affordances of interaction, control and choice for the users.

8.2.2 Self-regulated learning interactions

Self-regulated learning (SRL) includes the cognitive, metacognitive, behavioural, motivational, and affective aspects of learning. Pedagogical agent-based open learning environments such as Betty's brain Biswas et al. (2010) and Metatutor Azevedo et al. (2009) have explored the scaffolding of regulation skills and understanding the metacognitive processes in the user. Leelawong and Biswas (2008) used the teachable agents with self-regulated learning feedback features to promote deeper learning and understanding in science learning scenario. The users were also able to query the agent to monitor their learning and problem-solving skills, which indirectly engaged the users in regulating themselves and organizing the knowledge acquired.

Various studies on Metatutor platform Bouchet et al. (2016) focusing on self-regulation and socially shared regulation in learning have presented and tested the regulation strategies of planning and monitoring to understand user's self-efficacy, feeling of knowing, judgement of learning, agency etc. iDRIVE platform Graesser et al. (2008) had dyads of animated agents that train users to engage in inquiry-based science learning by modelling deep reasoning questions during dialogue with the agents which successfully resulted in better comprehension and transfer skills in users who asked more questions. In a longer-term study with a robotic tutor providing adaptive SRL scaffolding, Jones and Castellano (2018) observed increased motivation and regulation behaviours in users as compared to regular domain tutoring. These findings suggest the use of pedagogical agents as a tool for designing learning environments with increased emphasis on the self-regulation, which can complement the cognitive, metacognitive and motivational aspects of the learning.

8.3 Research objectives

The proposed triadic learning interaction involving multiple pedagogical agents facilitates regulation in SSRL context through external regulation strategies such as instruction, monitoring, feedback etc from the tutor agent and co-regulation behaviours like thinking aloud, asking doubts, etc demonstrated by the peer agent. The pedagogical roles of peer and tutor are operationalised through multimodal behaviours described along the dimensions of social attitude (based on dominance and friendliness) and regulation (based on competence and feedback). Also, the interaction is based on the FRACTOS learning task which has been developed specifically to let the users engage in the processes of planning, monitoring and reflection while completing the exercises in the learning activity.

The main objective of this study is to understand how the user perceives the attitudes, behaviours and roles associated with both agents. The study also aims to understand the effectiveness of the proposed multi-agent interaction setup and the FRACTOS learning task in facilitating an engaging interaction and improving self-regulation of the user.

The objectives of this study can be described as follows:

- To understand the user's perception and attitudes towards the roles and associated behaviours of the tutor and peer agents.
- To understand how users perceive the learning task.
- To understand the self-regulation behaviours of the user during the interaction.

8.4 Methodology

In order to understand the perception of the proposed triadic learning interaction and agent behaviours involved, we have conceived a perceptive study in which the participants were asked to watch videos of tutor and peer agents presenting, performing and regulating themselves or each other during the FRACTOS learning task and to answer questionnaires about their perception of both agents, learning activity and their regulation behaviours.

8.4.1 System design

The triadic learning interaction based on the FRACTOS learning task focuses on the aspect of promoting the self-regulation in the user through external regulation (ERL) from the tutor agent and co-regulation emerging from the peer agent (Co-RL), which altogether constitutes a context for socially shared regulation in learning. The agent roles and associated behaviours are defined according to the proposed dimensional framework based on agent's social attitude and regulation behaviour. The system design thus consists of three elements which are implemented as follows:

- FRACTOS learning task: For this study, we have used the FRACTOS learning task framework to design a learning interaction based on the task of building new fractions (Task level 1) using virtual LEGO blocks. This task level involved familiarising with the fundamentals of the game and the learning topic as well as identifying correct game blocks to build a required fraction.

- Tutor agent (named Alice): The Tutor agent is characterised by behaviours of moderate dominance and friendliness that defines the social attitude and external regulation strategies that present the agent as a more knowledgeable entity. The tutor agent is presented as a virtual agent modelled in GRETA platform Pelachaud (2015) and animated in Unity3D environment. The multimodal behaviours of the tutor agent involve expressive, informal and informative speech, deictic and expressive gestures, social and task-oriented dialogues with the user with emphasis on performance, mutual gaze behaviour etc. The tutor agent facilitates external regulation through direct instructional strategies such as explicitly delivery of knowledge through hints or suggestions, pro-active feedback and prompts for improving the performance and motivation of the user.

  Alice : You can use the red blocks to build this fraction.
  Bot: okay. Let me try with the red blocks then.

- Peer agent (named Bot): The peer agent is implemented in FRACTOS learning environment as a virtual robot peer character expressing moderate levels of dominance and friendliness through multimodal behaviours such as informal, emotional and inquisitive speech, expressive gestures, mutual and joint gaze behaviours. Unlike the tutor agent, the peer agent has limited facial expressions and gestural capabilities, though it has anthropomorphic features. The animations and speech of the virtual peer agent were driven by IBM Watson services platform which associated relevant gestures and animations based on sentiment and semantic analysis of the agent's intended dialogues. The peer agent provided co-regulation support through the demonstration of regulation behaviours such as asking questions, thinking aloud, seeking help, encouraging the user etc.

  Bot : I think we can use 1/4 blocks to build this fraction. Is that correct?
  Tutor: Exactly. You are correct. You can go ahead to build the fraction now.

The human user thus engages in the learning interaction based on the FRACTOS task of building fractions where the tutor agent facilitates external regulation and peer agent constitutes co-regulation support to enhance the self-regulation of the user. The design of the learning interaction constitutes a Unity3d game environment in which the multimodal behaviours of tutor agent is generated by GRETA-VIB and the virtual peer agent is animated in Unity3D. The game environment presents the user with tutor and peer agents in a classroom environment, along with visual representations of the fractions using virtual LEGO blocks. For the user's reference, the basic blocks of 1/2, 1/4 and 1/8 are displayed in the right side of the interface which disappears once the problem is presented by the tutor (Figure 8.1).

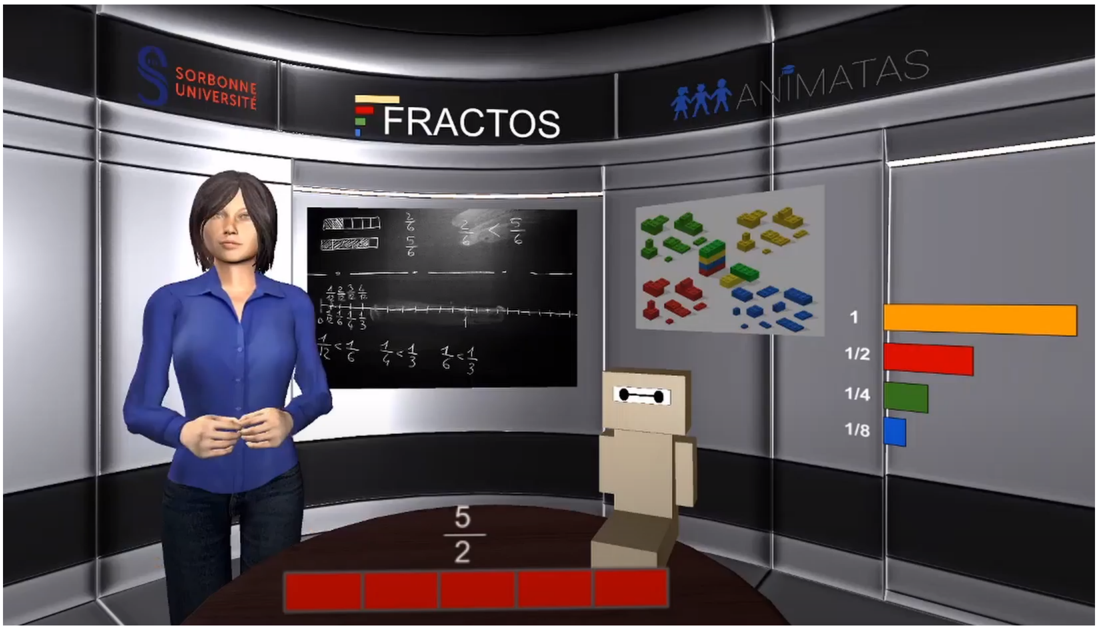

Figure 8.1: Tutor agent and virtual robot peer engaging in the FRACTOS learning task

8.4.2 Questionnaires

- **NARS**: We used an adapted version of Negative Attitudes towards Robots Scale Nomura et al. (2006) to measure participant's a-priori negative attitudes towards situations and interactions with agents and their social influence. Since we had a virtual human and a virtual robot in our interaction we had used the term 'robot or virtual agent' for referring to the agents in the questionnaire items. The participants gave their ratings for 6 items on a 5-points Likert scale, from 1 = " I completely disagree" to 5 = "I completely agree". The items of the questionnaire are listed in Table 8.1.

- **Godspeed**: To measure the perception of agents by the participants, we used an adapted version of Godspeed questionnaireBartneck et al. (2009b) which looked at the aspect of perceived intelligence (3 items) and likeability (3 items) of the

Negative Attitudes towards Robots Scale
The words 'robot' or 'virtual agent' means nothing to me.
I would feel uneasy if I had to do my work with help of a robot or a virtual agent.
I would feel nervous using a robot or a virtual agent in front of other people.
I don't like a robot or a virtual agent making judgments about things.
I would not feel comfortable talking with a robot or a virtual agent.
I would feel very nervous just standing in front of a robot or a virtual agent.

Table 8.1: NARS questionnaire items

tutor and peer agents separately. Thus the questionnaire had 12 items (6 each for both agents) which the participants rated on a 5-point Likert scale (Table 8.2). The Godspeed questionnaire was administered to the participants before as well as after the activity session so as to understand how the perceptions evolved as a result of engaging with the agents.

Godspeed questionnaire
Alice is competent/Bot is competent.
Alice is knowledgeable/Bot is knowledgeable.
Alice is intelligent/Bot is intelligent.
Alice is pleasant/Bot is pleasant.
Alice is friendly/Bot is friendly.
I like Alice/I like Bot.

Table 8.2: Agent perception questionnaire items

- **IMI**: The Intrinsic Motivation Inventory (IMI) scale is used to assess participant's subjective experience and perception related to the learning activity. An adapted version of the activity perception questionnaire of IMI with selected items on activity interest and value were used for this study and the participants rated them on a 5-point Likert scale. The items of the activity perception questionnaire are described in Table 8.3.

Intrinsic Motivation Inventory (IMI) scale
I thought this was a very interesting game.
I felt like I was enjoying the game while I was doing it.
I think this game is important for my improvement.
I am willing to do this game again because I think it is somewhat useful.
I think this was a very boring game.
It is possible that this game could improve my studying habits.

Table 8.3: Activity perception questionnaire items

- **SRQ-A**: The participant's self-regulation skills were measured using the Academic self-regulation Questionnaire (SRQ-A) (Ryan and Connell (1989); Deci et al. (1992)) which consists of four subscales: external regulation, introjected regulation, identified regulation and intrinsic motivation. According to Deci et al. (1991), identified regulation refers to a condition in which the regulation originates from self when the associates it to his/her values and goals. Intrinsic motivation can be related to the behaviours that the engage in for their own interest and enjoyment. Introjected regulation accounts for behaviours which are internalized but not really originating from the self (for example: "*I would feel guilty if i don't learn*"). Finally, external regulation refers to behaviours that are controlled through rewards, constraints or support involving others. The scores of these subscales can be combined to give the Relative Autonomy Index score (RAI) using the formula given below:

  RAI = 2 x Intrinsic + Identified - Introjected - 2 x External

  The RAI score indicates how well self-regulated the participant is and can act as a measure for comparing participants based on their regulation behaviours. The participants were asked to rate 12 questionnaire items on a 4-point Likert scale, from 1 = "Never" to 4 = "Always". The items in the adapted SRQ-A questionnaire used in the study are described in table 8.4 below.

Academic self-regulation Questionnaire (SRQ-A)
I play the game because I want to learn new things.
I try to answer hard questions to find out if I'm right or wrong.
I do the game because it's fun.
I enjoy playing the game.
I try to do well in the game because I like doing a good job in the game.
I try to answer hard questions because it's fun to answer hard questions.
I try to do well in the game because I'll feel bad about myself if I don't do well.
I try to answer hard questions because I'll feel bad about myself if I don't try.
I try to answer hard questions because I want others to think I'm smart.
I try to do well in the game because that's what I am supposed to do.
I play the game because that's the rule.
I try to do well in the game because I will get in trouble if I don't.

Table 8.4: Self-regulation questionnaire items

- **Role perception**: We have added two questions which asks the participants about the role that they can associate with each agent. These questions were added in the pre-activity and post-activity questionnaires to understand how the role perceptions varied during the activity (Table 8.5).

- **Knowledge test**: A 3 item domain knowledge test on the topic of fractions were also included in the pre and post-activity questionnaires to see if there is any learning gain from the activity.

Agent role perception
Which role do you think would describe the behaviour of Bot accurately? Which role do you think would describe the behaviour of Alice accurately?

Table 8.5: Role perception questionnaire items

8.4.3 Procedure

The objectives of the study were to understand how participants perceive the agent roles, behaviours and the learning activity as well to see how they engage in self-regulated learning behaviours. The study was initially conceived to be conducted in a laboratory setting with participants interacting with the agents and performing the learning task in real-time. However, as an impact of the new health and safety regulations concerning the pandemic situation, we had to modify the study to be conducted online. The study thus involved the participants watching the videos of both agents introducing themselves and explaining about the game activity in the beginning and later observing the virtual peer agent performing in the game, while being instructed by the tutor agent. In this way, the participants were assigned the role of a peer who actively observes the learning interaction rather than performing in the learning task. The participant and the peer agent are often addressed together as a team during the interaction by the tutor agent to emphasize the peer learning scenario. The entire study interaction can be divided into the following sessions:

Study overview and test on attitude towards agents: Before the agents were introduced, the participants were introduced to the context of the study and the details regarding the privacy of the information collected. The participants were instructed to watch the videos involved in the study fully and were also asked to answer an adapted NARS questionnaire on user's attitudes and prejudices towards virtual characters.

S1 Introduction: After they have submitted the information, the participants were introduced to a video of the tutor and peer agents introducing themselves and engaging in a social talk. Later, the tutor agent explains the fundamentals of the concept of fraction and introduces the game elements to the participant and the peer agent. This is followed by an example video of building a fraction using the virtual LEGO blocks present in the game.

Alice : Hello, my name is Alice and I am your tutor for this game on fractions.
Bot: Hello, my friend. I am Bot and we will play this game together.
Alice: Excellent. Now let me ask you this. Bot, do you already know what fractions are?
Bot: I think when something is divided into parts, you get a fraction. Am i right?
Alice: Exactly. Now let us start the game and learn more about fractions.

Pre-activity questionnaire: Once the activity and agents are introduced, the participants are asked to answer a questionnaire on the perception of agent roles, qualities based on the Godspeed questionnaire and a test on knowledge of fractions .

S2 Activity: During this session, the participants watch the video of the tutor agent presenting the three distinct fractions and asking the peer agent to build them using the virtual LEGO blocks of values 1/2, 1/4 and 1/8. The tutor agent provides instruction and knowledge support during the planning, performance and reflection phases of the activity while the peer agent attempts to build the fraction. The peer agent demonstrates think-aloud behaviours and often shares his suggestions and doubts with the before answering the problem. The participant is instructed to observe the learning task and attend carefully to the questions and the interaction driven by both agents.

In FRACTOS activity framework, the task of building each fraction constitutes three phases of regulation which are planning, performance and reflection. In the planning phase, the tutor presents a fraction and asks the peer and to come up with their solution using the virtual LEGO blocks. During this phase, the tutor may give direct hints and suggestions to find the correct game blocks. The peer agent actively thinks aloud, asks questions and seeks help for building the fraction. Whenever a question is directed at the participant by one of the agents, a reflection period of 5 seconds is given to the participant to let him/her reflect upon it, even though they does not have to submit an answer. During the performance phase, the peer completes building the given fraction and asks the tutor for feedback.

Alice : You can try with the green blocks to build this one.
Bot: Hmm. Let me see.[pause].Yes, I think we can use the green blocks for this.
Alice: Okay, you can go ahead then.
[Bot builds the fraction]
Bot: Is this correct?
Alice: Absolutely. You have built the 5/4 fraction.

Once, the fraction is completed, the tutor initiates the reflection phase by asking questions related to the given solution. The peer agent then engages in acts of self-evaluation and reflection demonstrating co-regulation behaviours to influence the self-regulation of the observing participant.

Alice : Let me ask you this. How many 1/4 blocks did you use to make 5/4 fraction?
Bot: Let me check.[pause]. There are five blocks of 1/4 here.
Alice: Excellent. Now let me give you another fraction to try.

This cycle of planning, performance and reflection phases repeats for three exercises of building fractions which together constitutes an interaction time duration of around 6 minutes. Notably, the peer agent builds all three given fractions correctly following the instructions from the tutor and sharing the suggestions and doubts with the participant.

S3 Wrap-up: After completing the tasks of building three fractions, both agents concludes the activity thanking the participant for the attention and engagement. The tutor and peer agent bids farewell reminding the participant to continue learning about fractions.

Post-activity questionnaire: On completing the activity and wrap-up sessions, the participants are asked to provide basic demographic information and were given a questionnaire on perceptions of agent roles, features, learning task and self-regulation based on the Godspeed, IMI and SRQ-A scales along with a knowledge test on fractions. After answering the questionnaire the participants, if interested, they could also submit their general feedback on the activity experience in a separate text field.

8.5 Hypotheses

The study employs a within-subjects design based on the variables of agent perception (perceived intelligence and likeability) along with the factors of attitude towards agents (NARS score), activity perception (interest and value) and self-regulation skill (RAI score). We hypothesised that:

- **H1**: Engaging in the learning interaction with the tutor and peer agents would improve the ’s perception of agent qualities.
- **H2**: Positive perceptions of agent qualities and learning activity would encourage better self-regulation in s.

8.6 Analysis and Results

8.6.1 Participants

The study involved 30 adult participants (20 Female, 9 Male, 1 not disclosed) recruited online using a survey hosting platform named Prolific. Since the interaction happens in English language, we recruited participants who had English as their first language. Analysis of demographic information collected from the participants shows that the most number of participants belonged to the age group of 31-40 years (46.7%) and 21-30 years (43.3%). Regarding the education level, the majority of the participants had an undergraduate degree (46.7%).

8.6.2 Attitudes toward agents

The test for reliability of NARS scale on attitudes toward situations and interactions with the agents gave a Cronbach's alpha value of 0.8, indicating good reliability. We computed the means of the item scores to obtain the overall mean NARS score for each participant. We then divided the participants into two groups, "Positive" and "Negative", according to the overall mean (*M = 2.47, SD = 0.80*). On dividing into groups, the "Positive" attitude group had 16 participants and the "Negative" attitude group had 14 participants. Performing an independent t-test between these two groups found *Pre-activity likeability of peer agent* to be significantly different ($p = 0.03$). The likeability of peer agent before the activity was higher for "Positive" attitude group (*M = 4.18, SD = 0.59*) as compared to the "Negative" attitude group (*M = 3.64, SD = 0.73*). This suggests that positive attitudes towards the agents can promote better perception of agent qualities.

8.6.3 Activity perception

The IMI scale on activity perception was found to have good reliability only for the *activity interest* factor ($\alpha = 0.87$) and hence the *activity value* factor was not considered for further analysis. In general, among all the participants in the study, the FRACTOS learning task-based interaction reports high activity interest score (*M = 3.86, SD = 0.64*). This indicates that the proposed learning interaction was successful in engaging the users.

8.6.4 Role perception

The analysis of questions on role perception of both agents before and after the learning interaction shows that three participants gained correct perception of the intended roles of both agents after the activity while two participants maintained the wrong perception even after the activity. All the remaining 25 participants were able to associate the role of tutor to the virtual agent and the role of peer to the virtual robot correctly at the beginning of interaction as well as after the activity session. Every participant who had the wrong perception of agent roles were observed to have misunderstood the virtual peer agent as a tutor. This suggests that the agent behaviours and strategies effectively convey the associated pedagogical role to the majority of participants though some users remain confused about the roles, especially in the case of the peer agent.

8.6.5 Agent perception

The Godspeed questionnaires on agent perception was found to have good reliability for pre-activity (*Tutor = 0.85, Peer = 0.89*) and post-activity (*Tutor = 0.9, Peer = 0.92*) for both factors of **perceived intelligence** (*Tutor = 0.86, Peer = 0.89*) and **likeability** (*Tutor = 0.85, Peer = 0.87*). On conducting a paired samples t-test on the agent perception variables of both agents, the perceived intelligence of both agents were found to have improved significantly (Figure 8.2). Post-activity perceived intelligence of Tutor agent was higher (*M = 3.74, SD = 0.71*) than before the activity (*M = 3.47, SD = 0.74*). Similarly, the perceived intelligence of peer agent also improved (*M = 3.77, SD = 0.82*) than before the activity session (*M = 3.42, S D= 0.74*). This can be attributed to the learning and regulation strategies exhibited by both agents during the learning interaction. However, there were no significant improvement in the likeability factor of both agents after the activity. Thus the hypothesis **H1** which states that the learning interaction can improve the user's perception of agent qualities, remain partly supported.

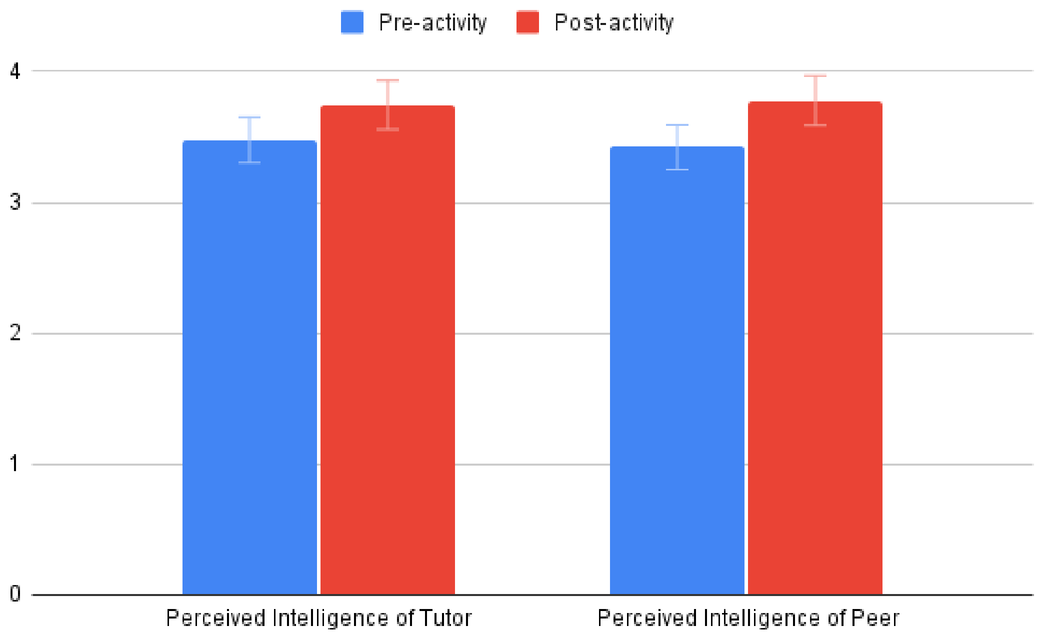

Figure 8.2: Perceived intelligence factor means of tutor and peer agents along the interaction

8.6.6 Self-regulation behaviour

The reliability test for the subscales of SRQ-A showed a good reliability for **identified regulation** (α = *0.77*), **intrinsic motivation** (α = *0.84*), **introjected regulation** (α = *0.79*) and **external regulation** (α = *0.67*). The Relative autonomy index (RAI) score was calculated from these subscales for each participant and majority of the participants (*N = 18*) were observed to have higher RAI scores, indicating that they are well self-regulated (Figure 8.3).

Based on the RAI scores, the participants were divided into two groups,"High" (*N = 18*) and "Low" (*N = 12*), which indicated their self-regulation potential. We then conducted an independent t-test between these two groups which concluded that the differences in the variables of *pre-activity perceived intelligence (p = 0.02) and likeability (p = 0.03)*

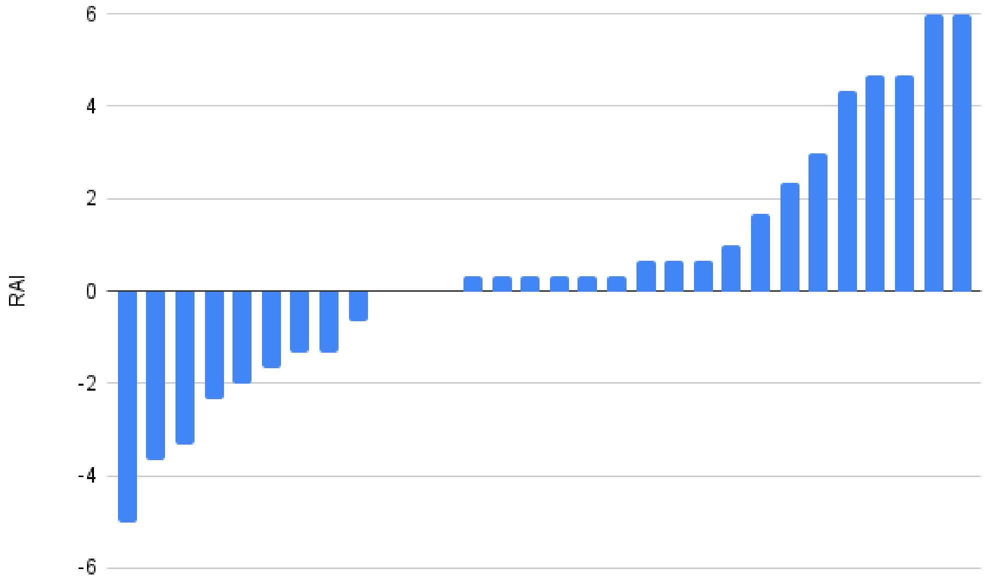

Figure 8.3: Distribution of RAI scores of participants in the study

of the tutor agent, intrinsic motivation (p = 0.002) and external regulation (p = 0.02) were statistically significant (Figure 8.4). **Perceived intelligence** (*M = 3.72, SD = 0.81*) and **likeability** (*M = 3.87, SD = 0.7*) of the tutor agent was observed to be higher in the group of "Highly" self-regulated users. Also, the well self-regulated users exhibited higher **intrinsic motivation** (*M = 3.05, SD = 0.83*) and lower **external regulation** (*M = 2.31, SD = 0.71*) as compared to the group with lower RAI scores. This suggests that the tutor agent had more impact on influencing the self-regulation behaviours in the participant users. Higher intrinsic motivation and lower external regulation also suggests higher interest and enjoyment of learning activity and self-directed learning behaviours.

Pearson correlations for RAI score		
	RAI score	Pre-activity Likeability of Tutor
Pre-activity Likeability of Tutor	0.507	
Activity Interest	0.557	0.480

A Pearson correlation analysis showed a strong correlation of **pre-activity likeability of Tutor** and **activity interest** with the RAI score of the participants (table). A multiple linear regression analysis was run with *RAI score* of the participants as the outcome and *pre-activity likeability of Tutor* along with *activity interest* as predictors. The multiple regression model statistically significantly predicted the RAI score (*F(2,27) = 8.456, p =.001, adj.* R^2 *= 0.34*) where both variables added significantly to the prediction, $p < .05$.

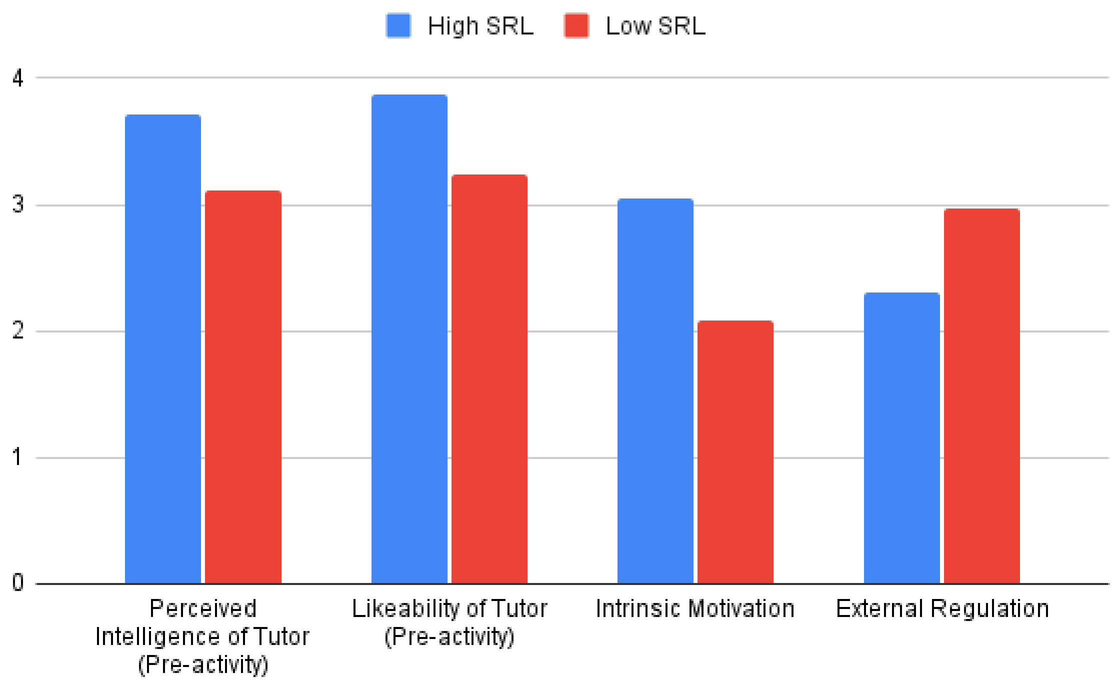

Figure 8.4: Significant differences between the Higher and Lower Self-regulation groups of users

Hence, the analysis supports the hypothesis **H2** that better agent and activity perceptions can promote self-regulation in users.

8.6.7 Learning gain

The learning gain for the activity was calculated from the pre-activity and post-activity knowledge test scores of the participants. The majority of the participants answered all questions correctly in both tests while five participants improved their scores after the learning interaction. Only two participants had lesser score in the knowledge test after the activity.

8.7 Discussion

The results from this perceptive study on agent role, behaviours and the proposed FRACTOS learning activity shows the influence of a-priori attitudes towards virtual agents in promoting a better perception of agent qualities, especially regarding the likeability factor. The results indicate the positive influence of a-priori attitudes towards virtual agents in promoting better likeability for the peer agent. The learning activity was observed to be engaging and interesting for participants in general though few users provided the feedback that the task of building fractions were too simple for them. Since the objective of our research is to enhance the self-regulation skills of the user through external regulation and co-regulation strategies emerging from the tutor and peer agent, the learning task was made easier intentionally as we emphasize less on achieving learning gain. According to Zimmerman and Kitsantas (2005), it is necessary to have some cognitive, motivational and emotional processes that have become an automatic response pattern so that the users can actively employ regulation strategies with less cognitive load. A simpler learning activity is thus beneficial to reduce the cognitive load of the user that can aid better activation of self-regulation behaviours in the participants.

Concerning the changes to the perception of agent qualities, the factor of perceived intelligence of both agents were observed to have improved significantly after the learning interaction, thus partly supporting the hypothesis **H1**. This can be accounted to the regulation strategies and knowledge presented by both agents during the activity. However, there was no significant improvement in the likeability factor of both agents after the activity which can be attributed to the fact that the interaction was mainly task-oriented, involving less time for social talk. Regarding the perception of pedagogical roles assigned to the agents, the majority of the participants were able to associate the tutor and peer roles to the agents correctly, while few participants were confused over the role assigned to the virtual robot peer agent. This suggests a better design of peer agent behaviours to clearly convey the intended pedagogical role.

Regarding the self-regulation behaviours in the study, most number of participants were observed to have good self-regulation behaviour. The users who exhibited high self-regulation capability were observed to be influenced by likeability and perceived intelligence of the tutor agent along with display of higher intrinsic motivation. In general, the RAI score, which is an indicator of self-regulation potential of the user, was observed to have a relationship with the interest in the learning activity and pre-activity likeability of the tutor agent. This suggests that the self-regulation of the user can be influenced through the manipulation of agent behaviours as well as the learning activity. Hence, it can be concluded that the hypothesis **H2** which expected the self-regulation of the user to be improved by positive perception of agent qualities and learning activity, is supported by the study results.

The study produced interesting insights into the relationship between the self-regulation, agent perceptions, learning activity and user attitudes. The qualitative and quantitative data collected from the study suggests the effectiveness of the proposed multi-agent triadic learning interaction involving the role of tutor and peer and the developed FRACTOS learning task which together constitutes a socially shared regulation context for learning.

8.8 Conclusion

This chapter describes the methodology and results of a perceptual study on agent behaviours, associated roles and the learning task for interaction. The objective of the study was to understand how attitudes of users towards the agent and their perception of agent qualities and pedagogical roles would influence the self-regulation behaviours. The study also aimed to understand how the users perceive and engage with the newly developed FRACTOS learning task. The results shows that the proposed multi-agent triadic interaction setup consisting of a tutor agent providing external regulation support and a peer agent exhibiting co-regulated learning behaviours proves to be effective in engaging the participants as well as influencing their self-regulation behaviours. The tutor agent was observed to have a significant influence on the user's self-regulation and the learning activity was successful in engaging the participants, evident from high intrinsic motivation reported by the users. However, regarding the role perception of agents, the role of peer was not clearly understood by some users which call for better implementation of peer behaviours and actions.

The key points of this Chapter:

- The proposed multi-agent learning interaction involving the roles of tutor and peer user providing external regulation and co-regulation strategies turns out engaging for the users and effective in promoting self-regulated learning.
- Positive a-priori attitude towards agents promoted better likeability of peer agent among the users.
- Perceived intelligence of tutor and peer agents was observed to have improved after the learning interaction.
- The majority of the participants were able to associate the tutor and peer roles to the agents correctly, while few participants were confused over the role assigned to the virtual robot peer agent.
- The users who exhibited high self-regulation capability were observed to be influenced by likeability and perceived intelligence of the tutor agent along with the display of higher intrinsic motivation.

Chapter 9

User Study 2: Understanding the impact of error making peer agent behaviours on user perceptions and self-regulation

Contents

In this chapter, we describe the perceptive study where we introduced error making behaviours in the peer agent to improve the agent role perceptions. We looked at the agent perceptions, self-regulation behaviours, activity perception and attitudes toward agents related to the error behaviours to compare it with the first perceptive study conducted.

9.1 Introduction

Socially shared regulation in learning (SSRL) Järvelä et al. (2013) constitutes multiple learning partners regulating themselves as a collective unit, through negotiations, decision making and knowledge sharing. Such a shared learning environment would involve entities of different social attitudes and competencies which makes the learning interaction interesting in terms of the types of regulation behaviours emerging from each learning partner. In our research, we have presented the pedagogical roles of tutor and peer providing external regulation and co-regulation scaffolding to the user in a multi-agent learning interaction based on the FRACTOS learning task. Accurate perception of the pedagogical roles associated with each agent in the learning interaction is essential to ensure that the user receives and processes the regulation strategies as intended by the design of learning interaction (Baylor and Kim (2005); Lester et al. (1997a)). The results from the first user study on understanding the user perceptions of agent roles, associated behaviours and the proposed learning task suggested the potential of a multi-agent learning interaction in promoting self-regulation. However, some participants in the latter study, who were observed to have held a wrong perception about the agent roles were reported to be confused over the correct judgement of the peer agent's role. This calls for modifying the peer behaviours in the interaction to enable a correct perception of the role that can facilitate the regulation scaffolding as intended. Hence, the objective of this study is to introduce error-making behaviours in the peer agent during the learning activity and to understand how it influences the agent role perception and self-regulation in the user.

9.2 Related work

9.2.1 Error making peer agents

In the self-regulation context, the role of peer is considered as the source for co-regulation strategies which involves supporting and influencing each other's regulation of learning, typically in an independent and reciprocal manner through behaviours such as thinking aloud, seeking help, suggesting alternatives etc. Prior research on pedagogical agents has shown that the users apply social judgements to agent behaviours and respond to their social cues in accordance to the attributed roles (Kory-Westlund and Breazeal (2019a); Breazeal et al. (2016); Kim et al. (2006)). For instance, Weiss et al. (2010) found a significant drop in the credibility of the peer agent when it provided an incorrect hint to the user during the game. Yadollahi et al. (2018) designed an interaction with a robot peer reading to the child and sometimes making mistakes which the user is supposed to correct. The mistakes committed by the peer in the task were either contextual, representational or concerning the pronunciation or syntax of the reading material. The study results suggested that the use of pointing gestures by the agent helped the users to identify and respond to the peer's mistakes. In another study, Ogan et al. (2012) regarding the interaction with teachable agents where the users were instructed to narrate their experiences in teaching the virtual agent Stacy, it was found that the agent's task errors were a significant predictor for user engagement. The authors also suggested making the error more realistic and making the agents acknowledge their errors socially to correctly convey the agent competency level. Concerning the trust factor of the agents, Geiskkovitch et al. (2019) explored the effect of informational error by the peer in a learning task which observed that the error behaviours do impact the user's trust on the agent although the effect was limited to the task phase involving the mistake.

Regarding the effect of error behaviours of agents on the regulation of the user, Coppola and Pontrello (2014) observed that learning from error can be an explicit strategy for teaching and can promote self-monitoring and reflection. Okita (2014) examined self-training and self-other training in a computer-supported learning environment, designed to assist the users in assessing and correcting their own learning. The self-training practice involved the users solving problems on their own while self-other training involved working with a virtual character, taking turns to solve problems and monitoring each other's mistakes. The results suggested that self-other training involving a peer agent which made task errors helped the users in engaging in metacognitive activities of self-monitoring and correction. Thus error making behaviours by a peer agent can complement the regulation aspects as well signify the associated competency level of the peer.

9.3 Research questions

The proposed multi-agent learning interaction in SSRL context involves a virtual tutor agent responsible for external regulation and a virtual robot peer exhibiting co-regulation behaviours. The results from the first user study observed that peer agent was perceived wrongly as a tutor and associated with high competence by some participants. According to the design of the learning interaction, it is necessary for the user to associate the role of tutor and peer to the intended agents in order to avoid misinterpretation of the regulation strategies and behaviours. Thus, in this study we introduce error making behaviours in the peer agent, aiming to improve the role perception as well as regulation behaviours in the user.

9.3.1 Hypotheses

- **H1**: Error making behaviour of the peer agent would promote the correct perception of agent roles and associated qualities.
- **H1a**: The peer agent will be perceived to be less intelligent than the tutor agent after the activity.
- **H1b**: The user's role perception of peer agent will improve after the activity.
- **H2**: Error making behaviours of the peer agent would promote better regulation in users.

9.4 Methodology

We have conceived a perceptive study that employs within-subjects design to understand the effect of introducing error making behaviours in the peer agent on the perception of agent roles, associated qualities and the regulation of the user. The participants were asked to watch videos of tutor and peer agents presenting, performing and regulating themselves or each other during the FRACTOS learning task and to answer questionnaires about their perception of both agents, learning activity and their regulation behaviours.

9.4.1 System design

The learning interaction for the study was based in the FRACTOS learning task in which the virtual agent (named Alice) is presented as the tutor and the virtual robot (named Bot) is introduced in the role of a peer user. The Tutor agent is modelled in GRETA platform Pelachaud (2015) and animated in Unity3D environment and is characterised by behaviours of moderate dominance and friendliness that defines the social attitude and external regulation strategies that present the agent as a more knowledgeable entity. The peer agent is characterised with moderate levels of dominance and friendliness through multimodal behaviours such as informal, emotional and inquisitive speech, expressive gestures, mutual and joint gaze behaviours. The speech of the virtual peer agent were driven by IBM Watson services platform which associated relevant gestures and animations based on sentiment and semantic analysis of the agent's intended dialogues were realised in Unity3d game environment. For this study also, we have used the Level 1 of the FRACTOS learning task which involves building fractions using virtual LEGO blocks.

9.4.2 Questionnaires

Before the agents were introduced, the participants were introduced to the context of the study and were asked to answer a NARS(Negative Attitudes towards Robots Scale)Nomura et al. (2006) questionnaire on user's attitudes and prejudices towards virtual characters.

The participants gave their ratings for 6 items on a 5-points Likert scale, from 1 = "I completely disagree" to 5 = "I completely agree".

9.4.2.1 Pre-activity questionnaire

The pre-activity questionnaire consisted of 17 items in total and was composed of selected items from Godspeed questionnaire Bartneck et al. (2009b) on agent perception (12 items), questions on agent role perception (2 items) and a knowledge test on fractions (3 items). The items of Godspeed scale looked at the aspect of perceived intelligence (3 items) and likeability (3 items) of the tutor and peer agents separately and the participants rated the items on a 5-point Likert scale.

9.4.2.2 Post-activity questionnaire

After the activity, the participants were instructed to provide their basic demographic information(gender, age group, education level, first language and ethnic identity) and a were given a 35 item questionnaire, which measure the agent perception, activity perception, user's self-regulation, role perception and knowledge on learning topic. The questionnaire contained selected items from Godspeed questionnaire on agent perception (12 items on perceived intelligence and likeability of both agents), Intrinsic Motivation Inventory (IMI) scale (6 items on activity interest and value), Academic Self-Regulation Questionnaire (SRQ-A) (12 items of identified regulation, intrinsic motivation, introjected regulation and external regulation), role perception (2 items) and knowledge test (3 items). After answering the questionnaire the participants could also provide general feedback on the activity experience in a separate text field, if interested.

9.4.3 Procedure

The study aimed at improving the role perception of the agents in the learning interaction and the regulation of the user by introducing an episode of error making by the peer agent during the learning task (Figure 9.1). We hypothesized that the mistakes by the peer agent would make the user to perceive the peer agent as less competent than the tutor as well as encourage the user to involve in better regulation behaviours during the learning. The study was conducted online and involved the participants watching the videos of both agents introducing themselves and explaining about the game activity in the beginning and later observing the virtual peer agent performing in the game, while being instructed by the tutor agent. The participants were instructed to actively observe the interaction and attend to the questions and tasks emerging in the game. The participant and the peer agent were often addressed together as a team during the interaction by the tutor agent to emphasize the peer learning scenario. The learning interaction could be broken down into three stages of introduction, activity and wrap-up sessions.

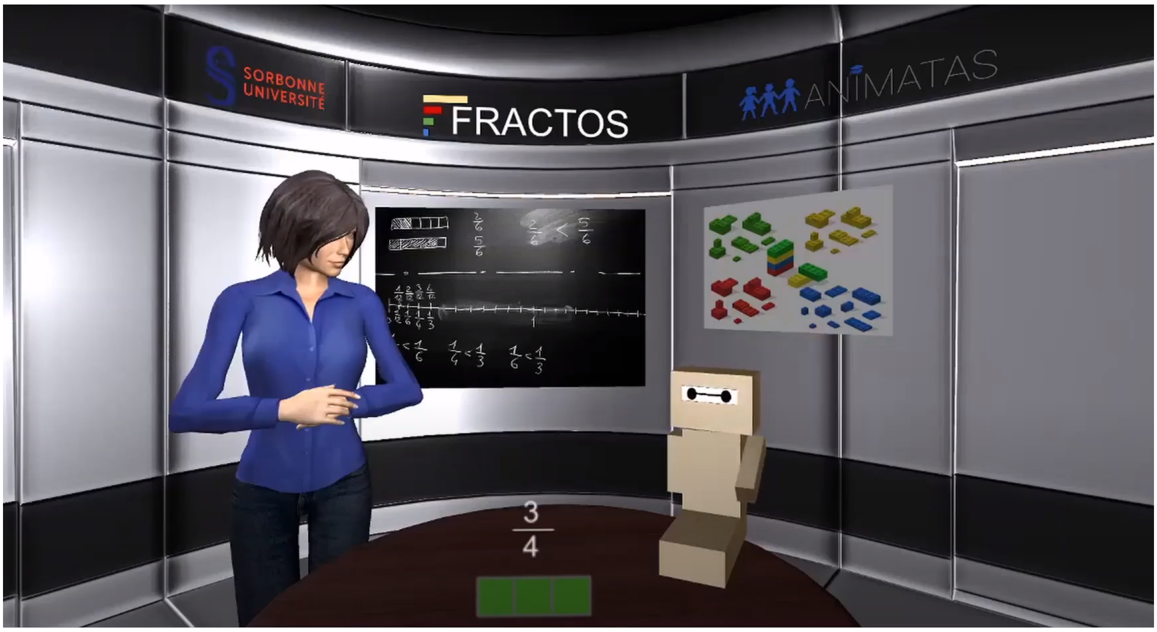

Figure 9.1: Peer agent making error in the FRACTOS learning task

S1 Introduction: The participants were introduced to a video of the tutor and peer agents introducing themselves and engaging in a social talk. Later, the tutor agent explains the fundamentals of the concept of fraction and introduces the game elements to the participant and the peer agent. This is followed by an example video of building a fraction using the virtual LEGO blocks present in the game. At, the end of the introduction session, the participants are asked to answer the pre-activity questionnaire.

S2 Activity: The activity session involves the participants watching a video of the tutor agent presenting the three distinct fractions and asking the peer agent to build them using the virtual LEGO blocks of values 1/2, 1/4 and 1/8. The peer agent attends to the tutor's instructions and suggestions during the activity and demonstrates traits of co-regulation such as thinking aloud, seeking help etc. Unlike in the previous study, the peer agent doesn't completely follow all the suggestions and hints given by the tutor and thus acts more self-directed in the actions and choices. The activity involves the task of building three distinct fractions and the error making episode occurs in the turn of building the second fraction value of 3/4.

Error making episode: The tutor agent presents the task of building the fraction 3/4 and asks the peer agent to try it. In the planning phase, the peer agent makes the wrong choice of using 1/2 blocks for building the fraction and goes ahead building the fraction though the tutor suggests using the 1/4 blocks for the solution. After building the fraction, the tutor gives feedback to the peer agent and the user that the solution was wrong and shows the correct solution to both. Later the tutor agent asks the peer agent and the user to observe the number of 1/4 blocks required to build the solution and thus reflect on the mistake that occurred.

Alice: Do you know how to build this fraction?
Bot: I think we can use the 1/2 blocks for this. I mean the red ones.
Alice: Are you sure? Why don't you try using the 1/4 blocks instead?
Bot: I think three blocks of red should make this fraction. Let me try it.
Alice: Okay. Let's see if it is the correct solution
[Correct solution appears]
Alice: That was not correct. Three blocks of 1/4 make the 3/4 fraction. I hope you understood the mistake.
Bot: Yes, I understand now.

S3 Wrap-up: The learning interaction is concluded by both agents thanking the participants and bidding farewell reminding them to continue learning about fractions. After the wrap-up session, the participant is given the post-activity questionnaire on perceptions of agent roles, features, learning task and self-regulation along with a knowledge test on fractions.

9.5 Analysis and Results

9.5.1 Participants

The study involved 30 adult participants (19 Female, 10 Male, 1 not disclosed) recruited online using a survey hosting platform named Prolific. Since the interaction happens in English language, we recruited participants who had English as their first language. Analysis of demographic information collected from the participants shows that the most number of participants belonged to the age group of 21-30 years (43.3%) and 31-40 years (36.7%). Regarding the education level, majority of the participants had an undergraduate degree (43.3%).

9.5.2 Attitude towards agents

The NARS scale on attitudes toward situations and interactions with the agents gave a Cronbach's alpha value of 0.82 on the test for reliability, indicating the good reliability of the measure. We computed the means of the item scores to obtain the overall mean NARS score for each participant and divided them into two groups, "Positive" and "Negative", according to the overall mean *(M = 2.31, SD= 0.80)*. The "Positive" attitude group had 20 participants and the "Negative" attitude group had 10 participants. On performing an independent t-test between these two groups, we found significantly higher scores for the factors of **perceived intelligence** (*p(Tutor) = 0.01, p(Peer) = 0.029)* and **likeability** *(p(Tutor) = 0.032, p(Peer) = 0.001)* of both agents prior to the activity. Also the **activity interest** was higher for the "Positive" attitude group *(M = 3.72, SD = 0.59)* as compared to the "Negative" attitude group *(M = 3.2, SD = 0.34)*. The results suggest that the positive a-priori attitude towards the agents can promote a better perception of the agent qualities as well as the interest in the learning activity (Figure 9.2).

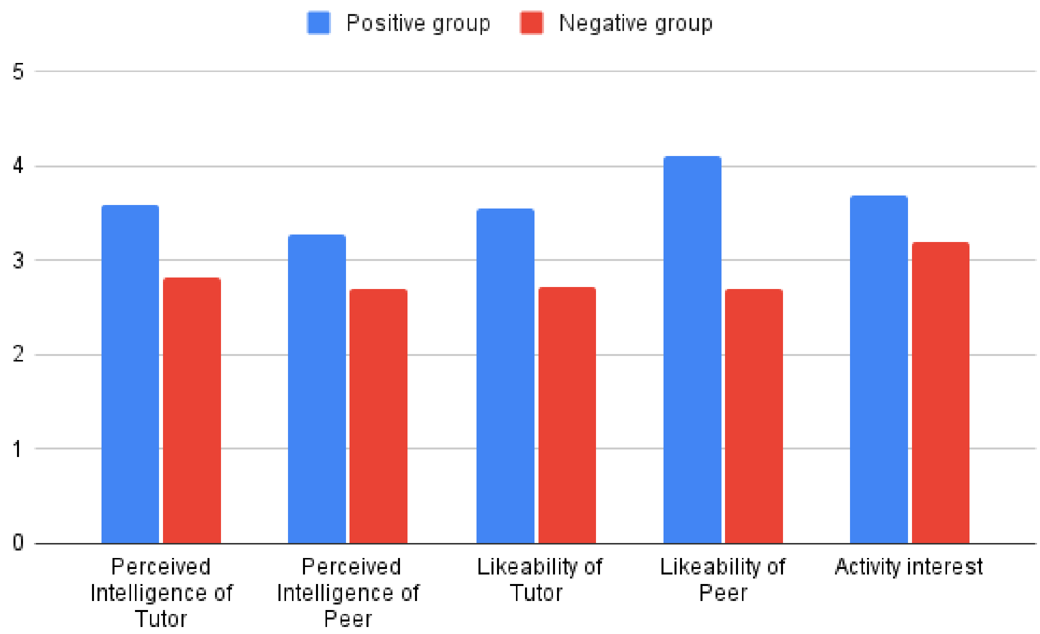

Figure 9.2: Comparing the groups of positive and negative attitudes towards agents

9.5.3 Activity perception

The IMI scale on activity perception was found to have good reliability only for the activity interest factor (α = 0.874) and hence the activity value factor was not considered for further analysis. In general, among all the participants in the study, the FRACTOS learning task based interaction reported high activity interest score (M = 3.55, SD = 0.57). This indicates that the proposed learning interaction was engaging for the users, in general.

9.5.4 Agent perception

The Godspeed questionnaires on agent perception was found to have good reliability for pre-activity (*Tutor = 0.92, Peer = 0.87*) and post-activity (*Tutor = 0.94, Peer = 0.92*) for both factors of **perceived intelligence** (*Tutor = 0.87, Peer = 0.75*) and **likeability** (*Tutor = 0.91, Peer = 0.91*). On conducting a paired samples t-test on the agent perception variables of both agents, only the perceived intelligence of the tutor agent was found to have improved significantly (*p = 0.003*) while the perceived intelligence of the peer agent remained relatively the same (Figure 9.3). Post-activity perceived intelligence of Tutor agent was higher (*M =3.76, SD = 0.9*) than before the activity (*M = 3.34, SD = 0.80*). The difference in the perception of intelligence associated with both agents can be attributed to the introduction of error making behaviours by the peer since the perceived intelligence of the peer agent is observed to have not improved after the activity. Thus our hypothesis **H1a** that the peer agent with error making behaviour will be perceived to be less intelligent than the tutor agent, as intended in the design of their roles, is supported by the study results.

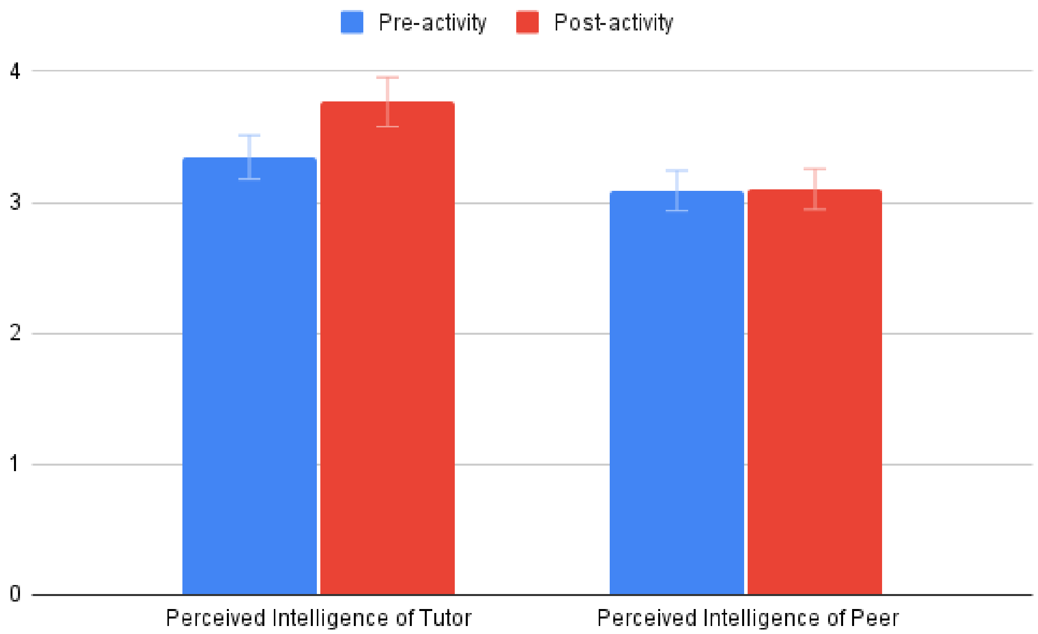

Figure 9.3: Perceived intelligence factor means of tutor and peer agents along the interaction

9.5.5 Role perception

The analysis of the role perception questions for the tutor and peer agent roles given before the learning activity shows that only one participant wrongly perceived the virtual tutor agent in the role of a peer while five participants wrongly perceived the virtual robot agent as a tutor and three participants remained undecided on their role perception. All other 21 participants reported the roles of the tutor and peer agents as intended by the design of the learning interaction. However, after the learning activity, all participants who had the initial wrong perception of the agent roles except one improved by assigning the role of peer correctly to the virtual robot agent. The only participant who maintained the wrong perception of peer agent after the activity still considered the virtual robot agent as a tutor. Since 88% percentage of the participants improved to gain the correct perception of agent roles and behaviours, we can conclude that the hypothesis **H1b**, which expects the error making behaviours of the peer agent to improve the agent role perception of the user, is sufficiently supported by the results.

9.5.6 Self-regulation behaviour

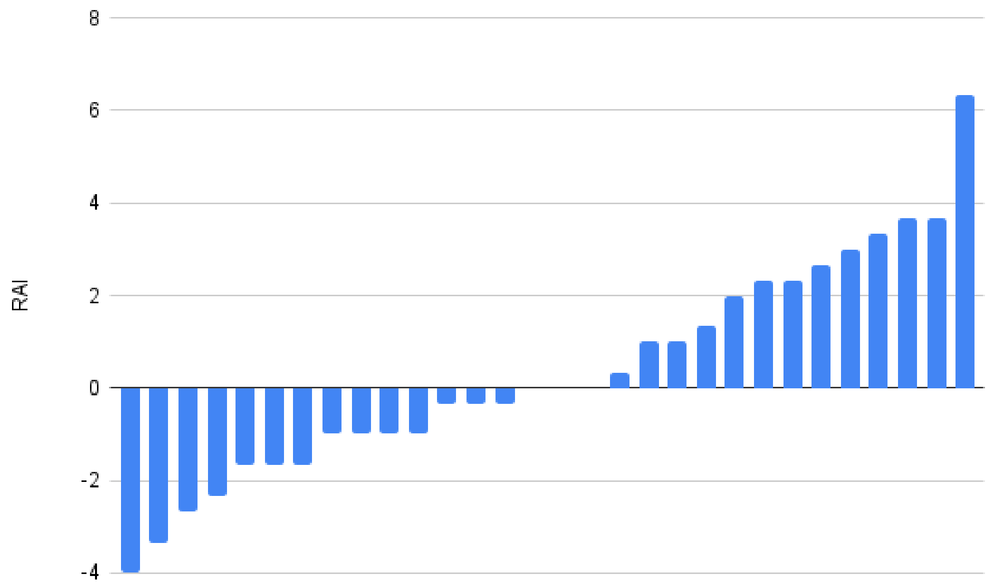

Figure 9.4: Distribution of RAI scores of participants in the study

The subscales of SRQ-A showed good reliability scores for **identified regulation** (α = *0.80*), **intrinsic motivation** (α = *0.74*), **introjected regulation** (α = *0.70*) and **external regulation** (α = *0.67*). The Relative autonomy index(RAI) score was calculated from these subscales for each participant and based on the RAI scores, the participants were divided into two groups, "High" (*N* = *13*) and "Low" (*N* = *17*), which indicated their self-regulation potential (Figure 9.4). We then conducted an independent t-test between these two groups which concluded that the differences in the factors of *pre-activity likeability (p = 0.049) of the peer agent, intrinsic motivation (p = 0.003), external regulation (p = 0.048) and activity interestp* = *0.045* were statistically significant. The **perceived likeability** (*M* = *4.10, SD* = *0.47*) of the peer agent was higher for in the group of "High" self-regulated user. The "High" self-regulation group also were associated with higher **intrinsic motivation** (*M* = *2.89, SD* = *0.51*), higher **activity interest** (*M* = *4.46, SD* = *0.90*) and lower **external regulation** (*M* = *2.10, SD* = *0.67*) as compared to the "Low" self-regulation group of participants (Figure **??**). This suggests that the peer agent influenced the regulation better and facilitated higher engagement and motivation for the learning activity.

A multiple linear regression analysis was performed with RAI score as the outcome and *pre-activity likeability of Peer* along with *activity interest* as predictors. The multiple

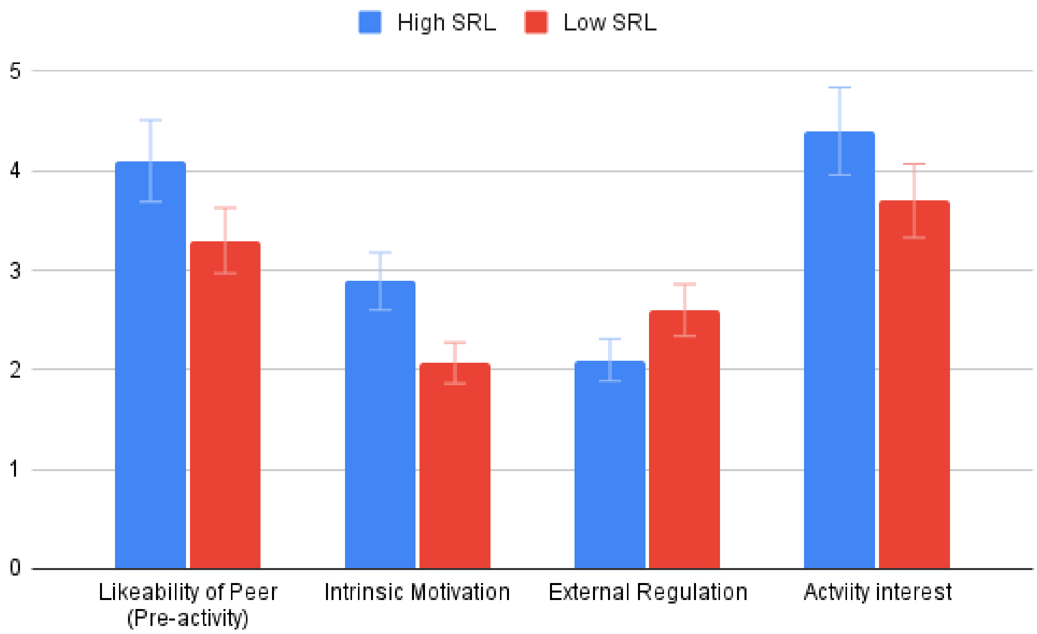

Figure 9.5: Significant differences between the Higher and Lower Self-regulation groups of users

regression model statistically significantly predicted the RAI score (*F(2,27)* = *8.456, p* = *.019, adj.*R^2 = *0.253*) where both variables added significantly to the prediction, p < .05. Thus the results from the study support the hypothesis **H2** which states that the error making behaviours by the peer agent can promote better regulation in users.

9.5.7 Learning gain

On calculating the learning gain from the knowledge test conducted before and after the activity, it was observed that five participants improved their scores and two participants got lesser scores after the learning interaction while all the remaining 23 participants were able to answer all questions correctly both in the pre-activity and post-activity tests.

9.5.8 Comparison with Study 1

The first user study looked at the user's perception's of the agent roles, qualities, learning task and the associated self-regulation behaviours emerging from the learning interaction. The results from the first user study indicated that some participants wrongly associated the role of tutor to the virtual robot agent which was originally introduced as a peer user. The second study differs from the previous one in the aspect of error making behaviours of the peer agent, which was introduced to convey the role of peer and the associated competency level more clearly.

A comparison of the results from both studies reveals some interesting observations on the aspects of regulation, agent perception and activity interest. We conducted a paired samples t-test on the perceived intelligence and likeability of both agents, activity interest and regulation factors between the participant groups of both studies to find that differences in **perceived intelligence of peer agent** (p = *0.013*) and **activity interest** (p = *0.039*) were significant. The perceived intelligence of the peer agent was significantly lower*(M = 3.1, SD = 0.88)* for the participants who interacted with the peer agent that made mistakes. Similarly, the activity interest also dropped significantly*(M = 3.55, SD = 0.57)* in the group from second study as compared to the study without the error making episode. It can be concluded from the results that the error making behaviour by the peer agent has helped in conveying the role of virtual robot correctly by making the user to perceive it as less competent compared to the tutor, but the activity interest seems to have dropped in the case of having mistakes in the learning interaction. Regarding the agent likeability factor, we did not observe significant difference between both studies as the users expressed good likeability for both agents consistently.

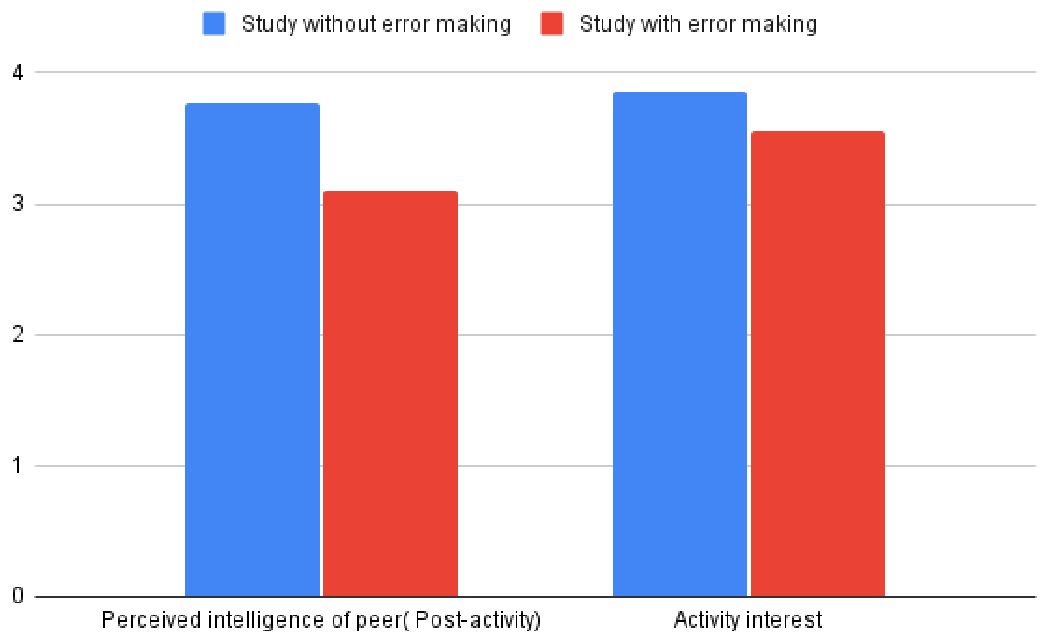

Figure 9.6: Significant differences on comparing both perceptive studies conducted.

9.6 Discussion

The objective of this study was to understand how error making behaviours by the peer agent would help the user to perceive the pedagogical roles in the interaction as intended. Regarding the impact of a-priori attitudes of the users on the agent perceptions, the factors of perceived intelligence and likeability of both agents as well as the interest in the learning activity were observed to be higher in the group of users with positive a-priori attitudes for virtual agents in general. Thus familiarising the users with virtual agents can help in ensuring that the learning interaction turns out to be effective and engaging. The learning activity was perceived to be interesting by the majority of the participants.

Regarding hypothesis **H1**, we observed that the error making behaviour by the peer agent had significant effects on the perception of agent qualities as well as the associated pedagogical roles. The perceived intelligence of the tutor agent improved after the activity while that of the peer remained almost the same. This shows that the users perceived the peer agent to be less intelligent than the tutor after seeing the error making instances during the learning activity. Hence, it can be concluded that the hypothesis **H1a** is supported by the study results. Concerning the perception of agent roles, the study started with 8 participants having the wrong role perceptions but after the learning interaction, 7 among those participants gained the correct association of tutor role to the virtual agent and peer role to the virtual robot agent. This supports our hypothesis **H1b** that the error making behaviour of peer agent would help in improving the role perception. It can be concluded that the difference in perceived intelligence of both agents has complimented the role perception by the users, since peer agent behaviours were designed to convey lesser competence level as compared to the tutor. Thus the study results support the hypothesis that error making behaviour of the peer agent would promote correct perception of agent roles and associated qualities.

Regarding the self-regulation behaviour of the participants, the user who had higher self-regulation scores were seen to have higher likeability of the peer agent before the activity as well as higher intrinsic motivation and interest in the learning activity. The hypothesis **H2** expected the error making episode by the peer to promote better regulation behaviours in the user. The results suggest that the RAI score, which an indicator for the self-regulation potential of the user, is influenced by the agent perceptions as well as the activity interest. The factors of likeability of the peer agent and activity interest prove to be significant predictors for the regulation of the user and hence the hypothesis **H2** is supported by the study findings.

On comparing the finding from the study with the data from the previous study, which did not feature the peer agent with error making behaviours, we were able to find some interesting observations. The introduction of error making episode seems to have influenced the perceived intelligence factor in such a way that for the study without error making, the perceived intelligence of both agents improved after the activity while for the latter study only the tutor agent's intelligence factor improved. This clearly conveys the impact of error making episode on the perception of peer agent. Specifically, on comparing the perceived intelligence factor of peer agent between the participants of both studies, it was found that the participants who interacted with the error making peer gave lower perceived intelligence scores for the peer agent. However, the activity interest scores were lesser in the second study with error making and can be attributed to the fact that mistakes would have let down the user's motivation or engagement during the course of the activity. In general, the results from the study suggests significant improvement in role perception by the user after making the peer agent to commit mistakes during the game.

9.7 Conclusion

This chapter presented the perceptual study conducted in the context of introducing error making behaviours in the peer agent for promoting better perception of agent roles and overall self-regulation of the user. The study hypothesised that the error making peer would be perceived less competent compared to the tutor agent, thus conveying its pedagogical role clearly to the user. The results confirmed the hypotheses and suggest that the error making behaviours by the peer agent as an effective way of manipulating the user perceptions and thus the regulation. In this study the peer agent was observed to have influenced the user more than the tutor. The study provided good understanding about the influence of agent perceptions, activity perception and self-regulation factors with each other. The findings from the results and comparisons across both user studies shows the effectiveness of the proposed learning task and the multi-agent interaction in promoting self-regulation in the user.

The key points of this Chapter:

- The error making behaviour by the peer agent had significant effects on improving the perception of agent roles as well as regulation of the users.
- The users perceived the peer agent to be less intelligent than the tutor after seeing the error making instances during the learning activity.
- The factors of likeability for the peer agent and activity interest prove to be significant predictors for the self-regulation of the user.
- Error making behaviours for the peer agent lowered the perceived intelligence of the peer and and also resulted in lower activity interest.

Chapter 10

User Study 3: Exploring distinct modes of regulation scaffolding in SSRL context

Contents

The perceptive studies conducted on the proposed multi-agent learning interaction in socially shared regulation context showed the effectiveness of having the tutor and peer agents together supporting the regulation of the user. This chapter describes the user study conducted to understand the influence of distinct modes of regulation ie external regulation strategies from the tutor agent and co-regulation strategies demonstrated by the peer agent in self-regulation and performance of the user. We also observed how the user perceptions of agent roles and associated qualities evolved during the interaction.

10.1 Related work

10.1.1 Modes of regulation

Self-regulation of a user can be supported by distinct kinds of regulation behaviours exhibited by the agents. "Students can be described as self-regulated to the degree that they are metacognitively, motivationally, and behaviourally active participants in their own learning process" Zimmerman (1989). The interpersonal regulation can happen in pairs or groups that engage in intentional, goal-directed meta-cognitive processes and establish strategic influences over the behaviours, decisions and actions of the learning partners Järvelä et al. (2016). Based on the roles and behaviours of the agents delivering regulation strategies, the perception of the user about the goals and related motivation in the activity may differ greatly.

External regulation: External regulation involves a more competent and capable entity delivering domain tutoring or regulation prompts and feedbacks to the user is often characterised by an instructional discourse of strategies and information to the user that promotes performance-oriented learning goals Panadero et al. (2015). The study of Azevedo and Cromley (2004), examined the effectiveness of self-regulated learning(SRL) training using computer supported collaborative learning environments and hypermedia. The results suggested that the user who received SRL scaffolding gained deeper understanding on the learning topic evident from the shift in their mental models of concept understanding. In a subsequent study Azevedo and Cromley (2004), used a tutor agent to provide adaptive instructional support and external regulation scaffolding and observed great variability in the self-regulating behaviours of the users during different phases of the activity. On comparing the groups that received specific scaffolding through self-regulated (SRL) and externally regulated (ERL) learning strategies respectively, Azevedo et al. (2007) found that the groups show significant differences in performance. The declarative knowledge gain was reported higher for the ERL group while the SRL group reported increased levels of motivation. The ERL participants engaged in more activation of prior knowledge, utilization of feeling of knowing and judgment of learning, monitoring their progress toward goals, hypothesizing, and expressing task difficulty. In a recent study on identifying and analyzing the aspect of self-regulation and motivation in a foreign language learning process involving an online tutor, Fandiño and Velandia (2020) concluded that high motivation and regulation in learning is associated with immediacy of the strategies and facilitation of autonomous behaviours of intrinsic motivation.

Co-regulation: Co-regulation refers to a transitional process in a user's acquisition of self-regulated learning, within which users and peers share a common problem-solving plane, and SRL is gradually appropriated by the individual user through interactions Hadwin et al. (2011)Volet et al. (2009a). Co-regulation thus relies on the processes of scaffolding and inter-subjectivity. Scaffolding involves the facilitation of SRL of the users as their competence level improves along the learning activity. Inter-subjectivity involves facilitation of sharing rationales, goals and plans in a common regulatory space. Hadwin et al. (2010) explored the social influences emerging in co-regulated learning interactions using a computer supported learning environment called gStudy. The learning environment included an open chat feature that allowed the users to converse with the peers during a collaborative task which was observed to help the user in the planning, monitoring and reflection phases of their self-regulation. On examining the effect of socially shared regulation involving peer users collaborating as a group in a CSCL setting, Zheng et al. (2017) reported improved user performance, group achievement as well as self-regulation frequency. Allal (2020) conceptualised co-regulation as emerging from joint influence of user self-regulation and sources of regulation in the environment and observed that the research on co-regulation and student learning is currently oriented in assessment of group of users interacting or collaborating and calls for implementations and studies in programmatic way.

The research concerning self-regulation and specifically socially shared regulation involving remains constrained to methods and tools for orchestrating and analysing the learning interactions that either assumes agency for one user or distributes attention over a group of users. To date, multi-agent learning interactions involving different roles of pedagogical agents in SSRL context remains largely unexplored Panadero (2017) and hence we are motivated to look at the distinct aspects of regulation scaffolding provided by multiple pedagogical agent roles in a shared learning context.

10.2 Research questions

The objective of this study is to understand how the distinct modes of external regulation and co-regulation influence the user differently while engaging in the proposed multi-agent learning interaction. These two distinct types of regulation support are realised through the agent roles of tutor and peer and associated behaviours in the FRACTOS learning task environment which are:

- External regulation by Tutor agent: through instructional discourse of strategies aimed at motivating performance-oriented learning interactions and providing domain-scaffolding for the user.
- Co-Regulation by Peer agent: through demonstration of regulation strategies that can promote adaption of self-regulation behaviours in the user.

The research questions for the study can be described as follows:

- Does different roles of pedagogical agents providing distinct modes of regulation influence the self-regulation differently?
- Does differences in regulation scaffolding influence user perception of the activity and agent qualities?

10.3 Methodology

The study involves the participants watching videos of tutor and peer agents presenting the learning task, performing the task and supporting the regulation of the user through their distinct regulation strategies. The peer and user, who are treated as a team by the tutor agent during the interaction, take turns in solving the problems emerging during the game. The participants for the study were recruited online using a survey hosting platform named Prolific and the interaction happens in English language, we only recruited participants who had English as their first language.

10.3.1 Study design

The multi-agent interaction with tutor and peer agent in a shared regulation context was designed based on the Task level 2 of the FRACTOS learning which involved comparing two given fractions. The task of comparing fraction was adopted for the study based on the participant feedback from the previous studies mentioning that the task of building fractions seemed too simple and less challenging (Figure 10.1). On the beginning of the study, the participants were presented with the objective of the study and the context of multi-agent learning interaction involving virtual agents. Later the participants watched a video in which both agents introduced themselves and explained about the elements of learning task. The agent roles and associated behaviours were defined according to the proposed dimensional framework based on agent's social attitude and regulation behaviour. The tutor agent featured moderate dominance and friendliness that defines the social attitude and external regulation strategies that present the agent as a more knowledgeable entity. The peer agent showed less dominance and moderate friendliness in the EXT-REG group interaction while featuring moderate dominance and friendliness in the CO-REG condition. In this way, the peer agent acted as a collaborative peer follower in the condition with active external regulation(EXT-REG condition) while taking the role of an actively regulating peer leader in the CO-REG condition.

The study adopted a between-subject design with two groups of participants namely, (i) Pro External regulation group(EXT-REG) and (ii) Pro Co-regulation group(CO-REG), differed by the kind of regulation support prominent in the interaction. The **Pro external regulation group(EXT-REG)** was characterised by the tutor agent actively directing the

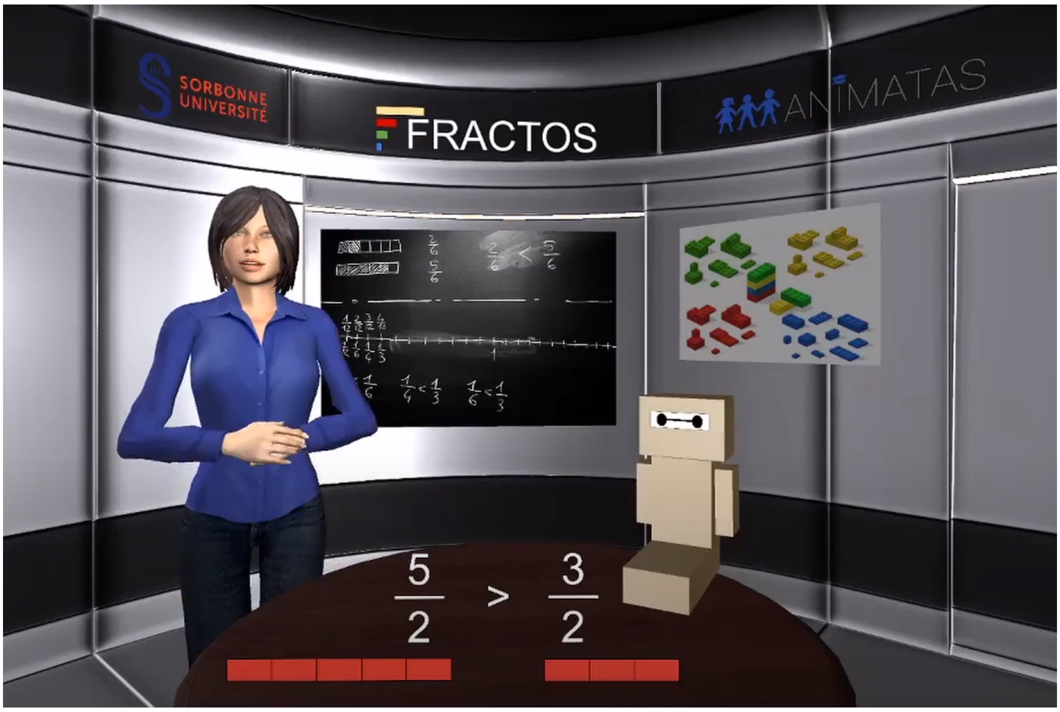

Figure 10.1: Tutor and peer agents engaged in task of comparing fractions during the learning interaction.

learning interaction through instructional delivery of regulation strategies such as providing direct hints, suggestions and information to the user during various phases of the activity while the peer agent was limited to acts of agreement, encouragement and acknowledgement to the actions and suggestions emerging in the activity. The tutor agent proactively provided hints and revealed the visual representation of the fractions to help the user find the solution.

[set of fractions appear for the user]
[Planning phase]
Alice : You should find the bigger fraction among these two.
Bot: Hmm. This looks interesting.
Alice: Which one do you think is bigger? Five by two or three by two? [5 sec pause]
Alice: I will give you a hint. Both fractions are built by the one by two blocks.
Bot: Ohh. That is correct.
[Performance phase]
Alice: Now tell me, which fraction is the bigger one?
[time for user to submit answer]
Bot: Let's see if this is correct.
Alice: Well done, you are correct.
Bot: Perfect. You are doing well in this game.

[Reflection phase]
[Correct solution appears]
Alice: As you see, five by two is bigger than three by two. Three blocks of red make three by two but to make five by two, you need five red blocks.
Bot: Yes, I understand.
Tutor: Let me ask you one question, how many red blocks are used to build the three by two fraction?

The **Pro Co-regulation group(CO-REG)** involved the tutor agent presenting the problem to the user and the peer agent, providing instructions and feedback for different phases of the task. The tutor agent was thus restricted to acts of instruction and feedback while the peer agent actively demonstrated co-regulation behaviours of thinking aloud, seeking help, asking questions, reflecting over the solution etc. For this group, the peer agent actively asked the tutor agent questions and made observations on the given fractions sometimes requesting to reveal the fraction representations to find the solution.

[set of fractions appear for user]
[Planning phase]
Alice : You should find the bigger fraction among these two.
Bot: Hmm. This looks interesting. Which one do you think is bigger? Five by two or three by two? [5 sec pause]
Bot: I think both fractions are built by the one by two blocks.
[Performance phase]
Alice: Now tell me, which fraction is the bigger one ?
[time for user to submit answer]
Bot: Good job. Now we have to see if it is correct.
Alice: Well done, you are correct.
Bot: Perfect. You are doing well in this game.
[Reflection phase]
[Correct solution appears]
Bot: Oh yes, five by two is bigger than three by two. Three blocks of red makes three by two but to make five by two, you need five red blocks.
Tutor: I hope you understand clearly now.
Tutor: Now let me ask one question, my friend. how many red blocks do we need to build the three by two fraction?

The learning interaction involved the peer and the user taking turns to complete the task of comparing fractions presented by the tutor agent. Both the user and the peer agent are given two fraction comparison exercises in which the peer agent answers the first one correctly while making mistake on the second exercise. Each exercise started with a planning phase consisting of suggestions or hints given by the respective agent for each regulation group and was followed by submitting the answer to the tutor. After the feedback on whether the given answer was correct or not, the agents initiated reflection phases by asking questions or discussing the solution. After completing the activity session, the agents thanked the participant for their attention and wrapped up the interaction. The participants were given a post-activity questionnaire and were also asked to provide basic demographic information.

10.3.2 Questionnaires

10.3.2.1 Pre-activity questionnaire

The pre-activity questionnaire was given to the participants after the introduction video and consisted of 26 items in total and were composed of selected items from Godspeed questionnaire Bartneck et al. (2009a) on agent perception(12 items), Academic self-Regulation Questionnaire(SRQ-A)(12 items) and questions on agent role perception(2 items). The items of Godspeed scale looked at the aspect of perceived intelligence(3 items) and likeability(3 items) of the tutor and peer agents separately and the participants rated the items in a 5-point Likert scale.

10.3.2.2 Post-activity questionnaire

After the activity, the participants were instructed to provide their basic demographic information(gender, age group, education level, first language and ethnic identity) and a were given a 32 item questionnaire, which measure the agent perception, activity perception, user's self-regulation, role perception and knowledge on learning topic. The questionnaire contained selected items from Godspeed questionnaire on agent perception(12 items on perceived intelligence and likeability of both agents), Intrinsic Motivation Inventory(IMI) scale(6 items on activity interest and value), Academic self-Regulation Questionnaire(SRQ-A)(12 items of identified regulation, intrinsic motivation, introjected regulation and external regulation) and role perception(2 items). After answering the questionnaire the participants could also provide general feedback on the activity experience in a separate text field, if interested.

10.4 Hypotheses

- **H1**: Instructional discourse of external regulation strategies by the tutor agent would motivate performance-oriented learning behaviour in the user

- **H2**: Demonstration of co-regulation strategies by the peer agent would motivate better regulation-oriented learning behaviour in the user

10.5 Analysis and Results

10.5.1 Participants

The study had 40 participants in total recruited online from the survey platform, Prolific, who were randomly assigned to two groups of Pro External regulation(EXT-REG)(11 Female, 9 Male and 1 Other) and Pro Co-Regulation(CO-REG)(10 Female, 10 Male) respectively. The majority of participants for the study belonged to the age group of 21-30 years(50%) followed by 32-40 years group(30%). Regarding the education level, majority of the participants had either a graduate(35%) or undergraduate degree(25%).

10.5.2 Agent Perception

The Godspeed questionnaires on agent perception was found to have good reliability for pre-activity (*EXT-REG = 0.74, CO-REG = 0.92*) and post-activity (*EXT-REG = 0.88, CO-REG = 0.87*) for both groups as well as for both factors of perceived intelligence (*EXT-REG = 0.82, CO-REG = 0.87*) and likeability (*EXT-REG = 0.86, CO-REG = 0.90*). We conducted the paired samples t-test on the agent perception factors within both groups of participants and found that the factor of perceived intelligence of the peer agent had significant decreased after the interaction in both EXT-REG and CO-REG groups. In EXT-REG group that received more active and explicit regulation support from the tutor agent where the peer agent was limited to acts of encouragement and acknowledgement, the **perceived intelligence of peer agent** dropped significantly ($p = 0.035, M = 3.23, SD = 0.87$) after the learning activity. For the CO-REG group also, the perceived intelligence of the peer agent was significantly lower ($p = 0.04, M = 3.31, SD = 0.9$) compared to the beginning of the interaction (Figure 10.2). The lower perception of peer agent's intelligence after the activity for both groups can be attributed to the error making behaviour exhibited by the peer on the second exercise performed as well as the intended design of the peer agent role as a less competent learning partner.

On conducting the paired samples t-test between the groups of EXT-REG and CO-REG on agent perception factors, significant difference were found in the **perceived intelligence of tutor agent** and **likeability of the peer agent** after the activity between both groups (Figure 10.3). In case of perceived intelligence of the tutor agent, the EXT-REG group that received active external regulation strategies from the tutor through pro-active instructions and suggestions associated significantly higher perceived intelligence score to the tutor ($p = 0.03$, *M(EXT-REG) = 4.08, M(CO-REG) = 3.65*) as compared to the CO-REG group. Regarding the likeability factor, the participants in the CO-REG group that received co-regulation focused learning interaction reported lower likeability for the peer agent ($p = 0.02$, *M(EXT-REG) = 3.96, M(CO-REG) = 3.45*) which was not expected. This suggests that the peer agent who acted submissively to the tutor in the EXT-REG condition earner more likeability than the more active and dominant peer agent in the CO-REG condition.

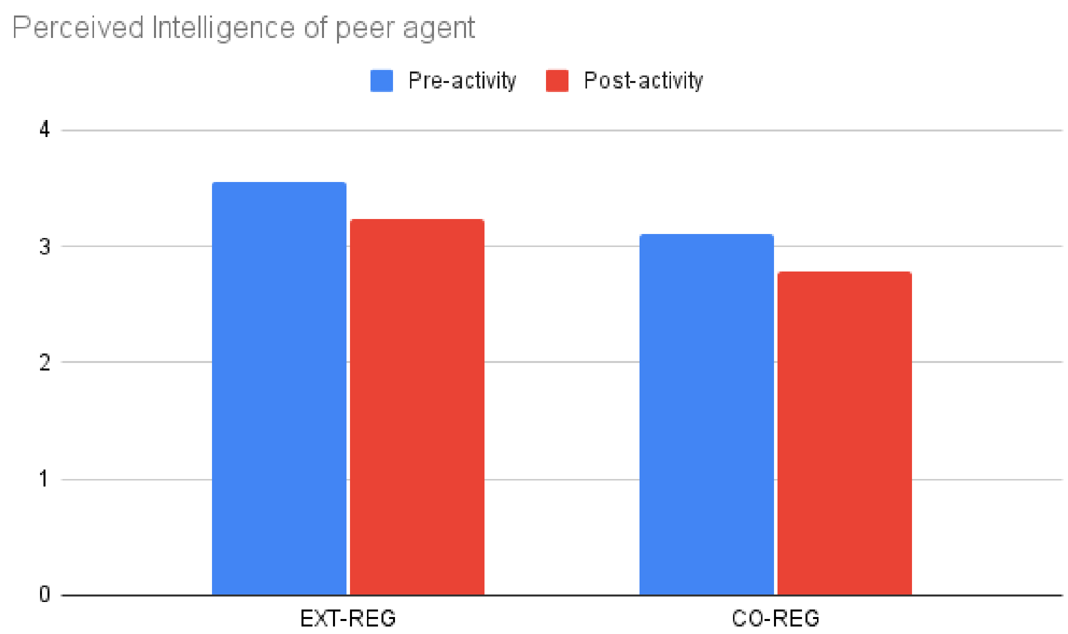

Figure 10.2: Comparison of perceived intelligence factor among the EXT-REG and CO-REG groups along the learning interaction.

10.5.3 Activity Perception

The IMI scale on activity perception was found to have good reliability for the activity interest (*EXT-REG = 0.77, CO-REG = 0.85*) and activity value (*EXT-REG = 0.76, CO-REG = 0.65*). However, comparing the means of these factors between the groups of EXT-REG and CO-REG did not find any significant difference. Although not statistically significant, the activity interest was observed to be good and almost similar across both groups while the CO-REG group showed observed higher activity value compared to the other (*M(EXT-REG) = 4.37, M(CO-REG) = 4.02*). We relate this to the active demonstration of self-regulation strategies by the peer agent which would have motivated the user to engage deeply in the learning topic.

10.5.4 Role perception

Regarding the perception of agent roles by the participants of both groups, the role of tutor agent was associated correctly to the virtual agent character by all participants. However, in the beginning of activity, 3 participants in the EXT-REG group and 2 participants from CO-REG group misunderstood the peer agent as another tutor in the activity while 3 participants from both groups remained were undecided about the role of peer. After the learning interaction, all participants of the EXT-REG group who were mistaken about the peer role gained the correct role perception by the end of activity while for the CO-REG

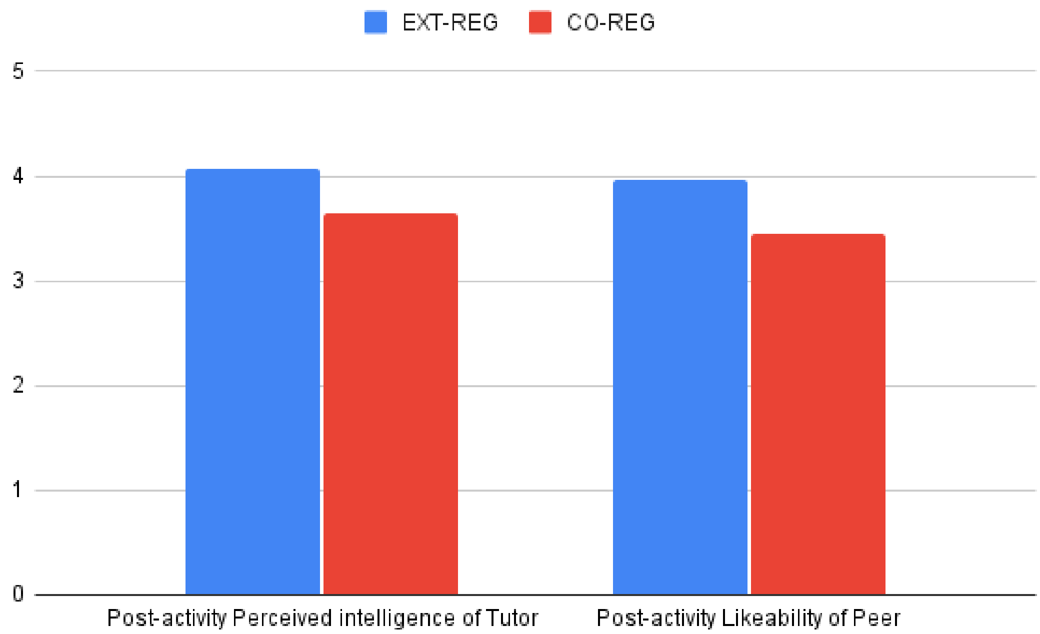

Figure 10.3: Significant differences in agent perception between the groups of EXT-REG and CO-REG after the activity.

group only one participant maintained a wrong understanding of the peer role after the activity. In general, from the data from the perceptive studies and the current study, we observe that the peer agent is often misunderstood as a tutor before the activity while the perception gets corrected once the participants see the peer agent making mistakes in the task and exhibiting co-regulation behaviours.

10.5.5 Task performance

The performance of the users in the learning activity was evaluated from the answers given to the two exercises presented to the user. Each exercise contained one question on comparing two given fractions to find the greater or smaller one as instructed and one question during the reflection phase regarding the related fractions. The *activity score* for each participant was calculated based on these questions and a paired samples t-test was conducted to compare the performance between EXT-REG and CO-REG groups. The analysis found a significant difference in the performance levels of both groups. The EXT-REG group that received prominent external regulation support from tutor reported **higher activity score** (*p = 0.016, M(EXT-REG) = 3.85, M(CO-REG) = 3.4*) compared to the CO-REG group where the peer dominated the regulation strategies(fig). This supports the hypothesis **H1** suggesting that the instructional discourse of external regulation strategies by the tutor agent would promote performance-oriented learning behaviour in the user.

10.5.6 Self-regulation behaviours

The subscales of SRQ-A showed good reliability scores for identified regulation (α*(EXT-REG) = 0.81,* α*(CO-REG) = 0.78*), intrinsic motivation (α*(EXT-REG) = 0.88,* α*(CO-REG) = 0.65*), introjected regulation (α*(EXT-REG) = 0.92,* α*(CO-REG) = 0.77*) and external regulation (α*(EXT-REG) = 0.79,* α*(CO-REG) = 0.76*) for both conditions. The Relative autonomy index (RAI) scores were calculated for all participants from the subscale scores. A paired samples t-test comparing the regulation behaviours of the participants before and after the activity, within the groups, found no significant increase in the self-regulation of both participants in either condition. The mean difference in the RAI scores for the CO-REG group was observed to be higher than that of the EXT-REG group (*M(EXT-REG) = 0.26, M(CO-REG) = 1.31*), though there was no statistical significance. This suggests that the participants in the CO-REG group that received active demonstration of self-regulation behaviours by the peer agent performed better in improving their self-regulation skills during the interaction. Then we compared the RAI scores of the participants between both conditions to find that the CO-REG group had significantly **higher post-activity RAI score** (*p = 0.045, M(EXT-REG) = 0.91, M(CO-REG) = 2.44*) that indicated higher self-regulation potential as compared to the EXT-REG group (Figure 10.4). Hence, the study results support the hypothesis **H2** which stated that the demonstration of co-regulation strategies by the peer agent would motivate better regulation oriented learning behaviour in the user.

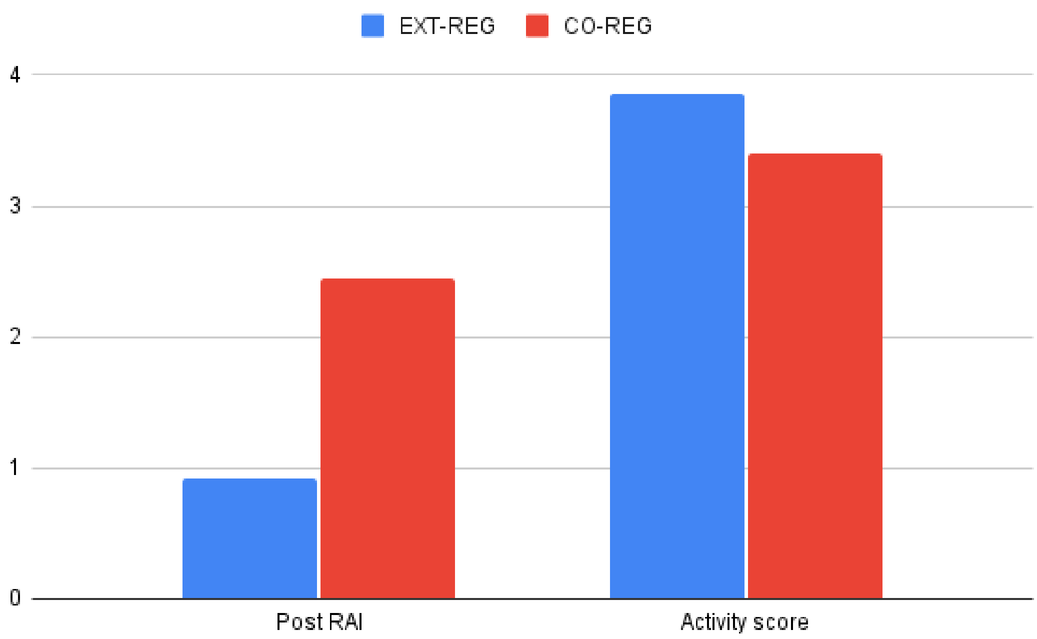

Figure 10.4: Comparing EXT-REG and CO-REG groups in terms of their regulation and activity scores

10.6 Discussion

The study aimed at understanding the differences between distinct modes of regulation support emerging from tutor and peer agents in a multi-agent shared learning interaction. The study compared two groups EXT-REG and CO-REG characterised by external regulation and co-regulation oriented regulation strategies respectively. In the EXT-REG group, the tutor agent directed the learning focusing on the performance of the user by providing direct hints, pro-active suggestions etc while the peer agent acted submissively following the instructions and encouraging the user. The CO-REG group had the peer agent actively exercising co-regulation behaviours of thinking aloud, seeking help, asking questions and expressing doubts while the tutor agent was limited to the acts of presenting the task and providing feedback on request.

Regarding hypothesis **H1**, it was observed that the activity score which indicated the performance level of the user was significantly higher for the EXT-REG group , thus validating the hypothesis. This can be attributed to the direct hints and instructions proactively given by the tutor which might have helped the user to arrive at the right solution easily. However, in the CO-REG group the peer agent always provide information only implicitly in the form of doubts or suggestions which the peer itself-were not sure about. This suggests that external regulation strategies are effective in promoting performance oriented learning interactions.

Hypothesis **H2** considered CO-REG group, which received co-regulation strategies from an actively self-regulating peer agent who asked questions and gave suggestions proactively to the learning partners, to show better self-regulation skills than the group with prominent external regulation based interactions. The active demonstration of regulation behaviours by the peer was expected to help the user adopt good regulation traits for themselves. The results from the study indicated that the RAI score, which is an indicator of the self-regulation potential of the user, to be significantly higher for the CO-REG group than the EXT-REG group after the learning interaction. Hence, the second hypothesis is also supported by the study results. The increased levels of self-regulation the CO-REG group can be associated with the implicit delivery of strategies and knowledge to the user which required the user to analyze the information for themselves to arrive at a decision, hence motivating deeper self-regulation. In general, the users in the EXT-REG group exhibited better performance in the task being assisted with explicit delivery of knowledge and strategies prominently from the tutor agent while showing less improvement in regulation skills. However, the CO-REG group had higher levels of self-regulation during the activity, motivated by the demonstration and indirect delivery of strategies by the peer agent, while compromising on the task performance.

10.7 Conclusion

This chapter on the user study conducted to understand distinct modes of regulation scaffolding and the related impact on self-regulation and performance of the user produced promising results on the proposed learning interaction in SSRL context. The study hypothesised external regulation to promote better performance oriented learning interaction and co-regulation to promoted better self-regulation in the users. The results indicated higher task performance score for the group receiving external regulation strategies from the tutor agent and better regulation scores for the group involving co-regulation oriented learning. The proposed multi-agent learning interaction intended to support the user through distinct modes of regulation using agents in related pedagogical role. The observations and participant feedback from the study suggest a need for blending the different kinds of regulation strategies using agents to promote better performance along with ensuring deeper self-regulation activation in the user.

The key points of this Chapter:

- The study compared two groups EXT-REG and CO-REG characterised by external regulation and co-regulation oriented regulation strategies respectively.
- The users in the EXT-REG group exhibited better performance in the task being assisted with explicit delivery of knowledge and strategies prominently from the tutor agent while showing less improvement in regulation skills.
- The CO-REG group had higher levels of self-regulation during the activity, motivated by the demonstration and indirect delivery of strategies by the peer agent, while having lower task performance.

Chapter 11

User Study 4: User-driven approach for regulation scaffolding in a shared learning interaction

Contents

In this chapter, we describe a user-driven approach for providing regulation strategies in a multi-agent learning interaction. We observe how user preferences towards both agents evolve during various phases of the task and over the entire learning interaction. The study aims at finding a balance of external regulation and co-regulation strategies which can promote self-regulation as well as task performance in the user.

11.1 Introduction

The proposed multi-agent learning interaction based on FRACTOS learning task involving tutor and peer agents providing external regulation and co-regulation oriented scaffolding respectively has proven to be influencing the self-regulation of the user. The previous studies conducted on understanding the user perceptions on agent role, related behaviours, learning activity and the distinct regulation modes have found the shared learning configuration be engaging and effective for promoting self-regulation oriented learning interactions using pedagogical agents. The first user study on user perceptions observed the influence of positive a-priori attitudes towards agents in ensuring interest in learning activity and promoting positive perception of agent qualities. The study also found improvement in the perceived intelligence of tutor and peer agent after the learning interaction along with significant influence of activity interest and likeability for agents in promoting self-regulation in users. From the second user study, aimed at understanding the effect of introducing error making behaviours in the peer agent, it was observed that the error making act made the peer agent to be perceived less competence compared to the tutor, which promoted better role perception in users. The self-regulation of the user was also seen to be influenced more by the error making peer behaviours. However, the activity interest was found to have dropped while the peer was making mistakes.

The third user study was conducted to understand the aspects of external regulation and co-regulation exclusively in the given shared learning context. The study involved two groups of users, where one group received active external regulation by the tutor agent while the peer was limited to follow along while the other group involved more active peer agent demonstrating self-regulation through think aloud behaviours, proactive suggestions etc. The results found that external regulation by the tutor is beneficial for improving the performance while co-regulated behaviours of the peer better promote the self-regulation in the user. However, the groups the gain on performance or regulation aspect for each group came at the cost of compromising either on the less emphasized aspect respectively. This calls for a learning interaction setup where both external regulation and co-regulation can be provided by the agents together to achieve a balance between the task performance and self-regulation. This chapter addresses this aspect of designing a learning interaction where external regulation and co-regulation oriented strategies can co-exist based on the preferences of the user. Hence, in this study we let the user choose the agent for regulation scaffolding in the planning and reflection phases of the learning activity to understand whether the combination of multiple regulation modes can benefit the regulation and performance of user effectively.

11.2 Research questions

The study aimed at understanding the combination of external and co-regulation modes of regulation based on the user preferences during the activity. In this way, we hope the user-driven regulation support through tutor and peer agents would help in attaining more adaptive and balanced scaffolding in the learning interaction. This configuration is also close to the learning interactions happening in real-world scenarios such as classrooms and online learning platforms where the user interacts with more knowledged entities such as tutors as well as peer users simultaneously. In such scenarios, the user often choose to seek help from the entity which one expects to provide knowledge or regulation support suitable for the situation. We designed this study on this context where the user can seek help from the preferred agent at various instances during the learning activity.

11.2.1 Hypotheses

- **H1**: Adaptive regulation scaffolding driven by the user preferences of agents during the activity will improve both the performance as well as self-regulation scores of the users.

- **H2**: users would prefer to seek external regulation support from the tutor during the planning phases of the task.

- **H3**: users would prefer to seek co-regulation support from the peer during the reflection phases of the task.

11.3 Methodology

This study used a within-subjects design where the participants watched videos of tutor and peer agents presenting the learning task, performing the task and supporting the regulation of the user through distinct regulation strategies driven by their choices during the activity. The learning activity consisted of planning, performance and reflection phases for each exercise presented and the user was asked to select the preferred agent before starting the planning and reflection phases. The participants for the study were recruited online using a survey hosting platform named Prolific and the interaction happens in English language, we only recruited participants who had English as their first language.

11.3.1 Questionnaires

The pre-activity and post-activity questionnaires used for the study were the same as that mentioned in the previous chapter on the third user study on Chapter 10. The questionnaires consisted of items from GODSPEED, IMI and SRQ-A along with questions on role perception of both agents.

11.3.2 System design

Similar to the previous study, this study was also based on the Level 2 of the FRACTOS game framework, which involved the exercises of comparing two given fraction values to identify the greater or smaller value among the two (Figure 11.1). The peer and user, who are treated as team by the tutor agent during the interaction, took turns in solving the problems emerging during the game. As in the previous study, the tutor agent provides active external regulation to the user exhibiting moderate dominance and friendliness through behaviours such as providing direct hints, suggestion and information to the user. The peer agent also features moderate dominance and friendliness for social attitude and is presented as a less competent learning partner compared to the tutor. The peer agent actively demonstrates co-regulation strategies of thinking aloud, seeking help, asking questions, reflecting over the solution etc during the interaction. However during the planning and reflection phases where the user choose between the agents, the chosen agent's regulation strategies become prominent while the other resorts to compliance and agreement. For instance, when the user choose the tutor agent for planning phase, the tutor starts providing direct hints and suggestions to help the user find the solution while the peer agent gets limited to encouraging the user and agreeing with the tutor.

On the beginning of the study, the participants were presented with the objective of the study and the context of multi agent learning interaction involving virtual agents. The learning interaction in the study consisted of the following sessions:

S1 Introduction: The participants were shown the video where both agents introduced themselves and engage in a social talk with the users. The tutor agent and the peer also introduce the learning topic of fractions during this talk and is followed by presenting the learning task elements such as virtual LEGO blocks and the task exercise of comparing fractions. At the end of this session, we provide the participants with the pre-activity questionnaire that measures their perception of agent qualities, activity and self-regulation potential.

S2 Activity: In this session, the tutor presents the exercises of comparing two fractions to the users and asks to identify the greater or smaller among the two. The activity starts with the peer agent attempting the first exercise and successfully identifying the greater fraction in the task. The tutor agent provides active external regulation and the peer agent shows active co-regulation during this stage. Once the peer agent's turn is over, the tutor presents the next exercise for the user to initiate the planning phase for the

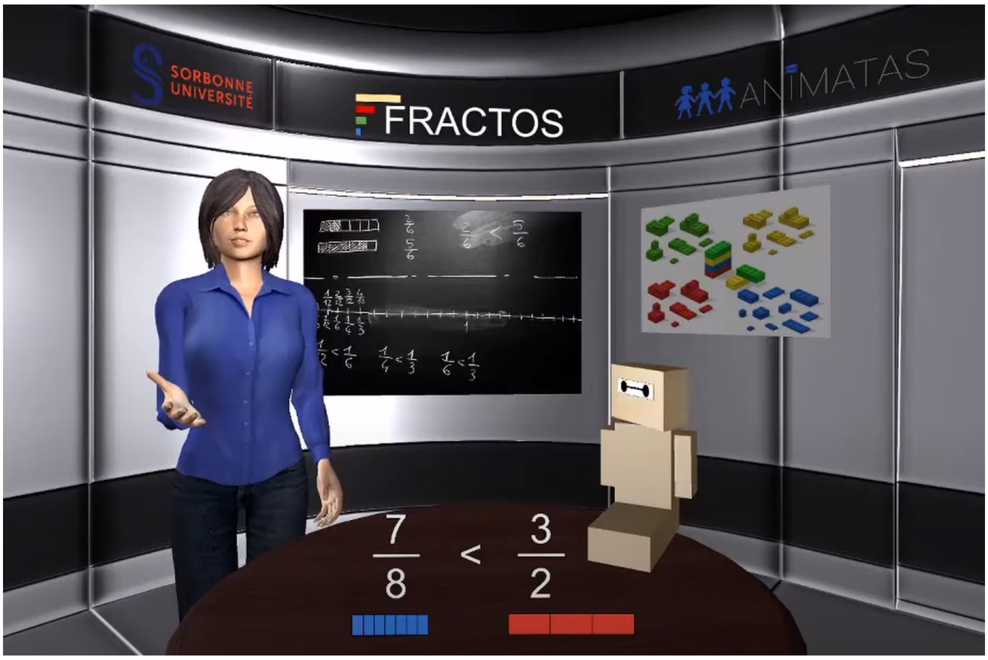

Figure 11.1: Tutor and peer agents providing regulation support based on user preferences

task. The user will be given three exercises during the interaction and the planning and reflection phases are referred to as P1/P2/P2 and R1/R2/R3 denoting the exercise number respectively. In each exercise, the user submits one answer at the end of planning phase for the comparison task and one answer during the reflection phase based on the solution.

Planning phase (P1/P2/P3): In this phase, the agents present the user with suggestions and information that help the user in finding the solution or to understand the given fractions better. Before the planning phase, the user is asked to choose the agent among the tutor and peer agents, which would be most suitable to assist them further. Once the user makes the choice, the respective agent presents the related regulation strategies actively while the other agent is limited to compliance and encouragement acts. The following is an excerpt from the interaction script in case of selecting the tutor agent for planning.

[user chooses Tutor for Planning phase]
Alice: Let me show you how the fractions would look like.
[Hints appear]
Bot: Ohh. This makes the comparison easy.
Alice: Let me explain.Three blocks of red makes the three by two fraction. To make the three by four fraction, you will need three green blocks.
[2 sec pause]
Alice: Okay. You can give your answer now.
Bot: Let's try that.

Similarly, if the peer agent is chosen for the planning phase by the user, the interaction involves active co-regulation by the peer which progress as follows:

[user chooses Peer for Planning phase]
Bot: Alice,can you show us how the fractions would look like?
[Hints appear]
Alice: Sure. Have a look at the fractions now.
Bot: Perfect, I think three blocks of red makes the three by two fraction. To make the three by four fraction, we need three green blocks. Am i right?
[2 sec pause]
Alice: Okay. You can give your answer now.

After the planning phase, the user submits the answer, which is termed as the performance phase and the tutor agent provides feedback to inform whether the user was correct or not.
Reflection phase (R1/R2/R3): Once the user's answer is evaluated, the user is presented again with a choice to choose among the agent preferred for the reflection phase. Once the user has chosen an agent, the respective agent initiates reflection on the solution by asking a question to the user related to the fractions involved. After the user submits the answer to this reflection question, the same agent makes an observation on the user's answer, providing related information. For instance, the interaction in the case when the user choose tutor agent for reflection phase progress as follows:

[user chooses Tutor for Reflection phase]
Alice : Let me ask you this, which blocks did we use to make the three by two fraction.
[user submits the answer]
Alice: That is correct. Three blocks of red makes the three by two fraction
Bot: Good job, my friend.

In the other case, when the user choose to receive regulation support from the peer agent, the interaction for the same instance unfolds as follows:

[user chooses Peer for Reflection phase]
Bot : Let me ask you this, my friend. Which blocks did we use to make the three by two fraction.
[user submits the answer]
Alice: That is correct.
Bot: Exactly what i thought. Three blocks of red makes the three by two fraction.

S3 Wrap-up: After the user and peer agent have completed the task of answering two exercises given to them, both agents conclude the session by thanking the user and the post-activity questionnaire is given to the participant.

11.4 Analysis and Results

11.4.1 Participants

The study had 31 participants in total (20 Female, 10 Male and 1 Other) recruited online from the survey platform, Prolific. The majority of participants for the study belonged to the age group of 31-40 years (48.4%) followed by 21-30 years group (41.9%).

11.4.2 Agent Perception

The Godspeed questionnaires on agent perception was found to have good reliability for pre-activity (*Tutor = 0.93, Peer = 0.91*) and post-activity (*Tutor = 0.94, Peer = 0.93*) for both factors of perceived intelligence (*Tutor = 0.96, Peer = 0.97*) and likeability (*Tutor = 0.92, Peer = 0.85*). In general, the participants expressed positive perceptions about the perceived intelligence and likeability towards the tutor and peer agents but no significant difference were observed in the agent perceptions of the users after the activity, on running a paired samples t-test on comparing the means.

11.4.3 Role perception

Regarding the role perception of both agents by the users, all the participants were observed to have associated the role of tutor to the virtual agent as intended by the system design whereas three students initially perceived the virtual robot also as tutor and one participant was undecided about the virtual robot's role in the beginning. However after the activity, all these participants were observed to have gained the correct perception of virtual robot character as the peer user while engaging in the learning interaction. This suggests that the users interacted with the participants associating the correct roles to each agent as planned.

11.4.4 Activity Perception

Concerning the activity perception of the users, the IMI scale on activity perception was found to have good reliability only for the activity interest (α = 0.746) and hence the activity value factor was not considered for further analysis. In general the participants reported high activity interest score(M = 3.66, SD = 0.78). This indicates that the proposed learning interaction was engaging for the users, in general.

11.4.5 Performance

The user performance was calculated from the answers given by the user to the three exercises presented in the learning interaction. The *activity score* was thus used to indicate the performance of the user during the learning interaction. Among all the participants, 7 participants were reported to have answered one question wrongly and only one participant got two given exercises wrong. Thus, the majority of the participants performed well throughout the game, correctly completing the given task of comparing the fraction values. However, looking at the participants who made mistakes in the given exercises, the errors were observed towards the end of the learning interaction suggesting that these users started with good performance and later ended up answering wrongly in the task. Out of the eight participants who had lower performance, seven of them made mistakes in the last two exercises. Hence, regarding the hypothesis **H1**, it cannot be concluded that the mixed regulation strategies implemented in the study had essentially improved the performance of the user during the activity.

Regarding the questions asked on the reflection phases, only four participants were reported to have wrongly answered at-least one of the reflection questions asked by the tutor, suggesting that the users were able to reflect on their performance successfully while engaging with the agents.

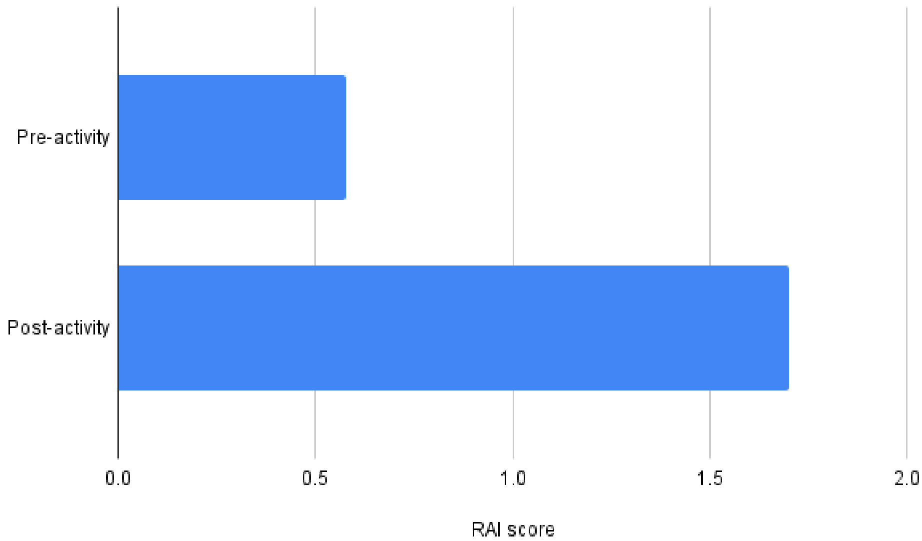

Figure 11.2: Change in mean RAI score of users along the learning interaction

11.4.6 Self-regulation behaviours

The subscales of SRQ-A showed good reliability scores for identified regulation (α*(Pre) = 0.78,* α*(Post) = 0.72*), intrinsic motivation (α*(Pre) = 0.75,* α*(Post) = 0.68*), introjected regulation (α*(Pre) = 0.62,* α*(Post) = 0.57*) and external regulation (α*(Pre) = 0.66,* α*(Post) = 0.63*) to calculate the RAI score (α*(Pre) = 0.68,* α*(Post) = 0.84*). The Relative autonomy index(RAI) scores, were calculated for all participants from the sub-scale scores and the means were compared by a paired samples t-test. The results from the analysis indicated that the RAI score, indicating the self-regulation potential of the users increases significantly after the learning interaction(*p = 0.03, M(Pre-RAI) = 0.58, M(Post-RAI) = 1.70*) (Figure 11.2) . Hence, this partly supports our hypothesis **H2** which suggests that the self-regulation of the user benefits from the learning interaction involving user-driven scaffolding using external regulation from the tutor and co-regulation from the peer agent during planning and reflection phases of the interaction.

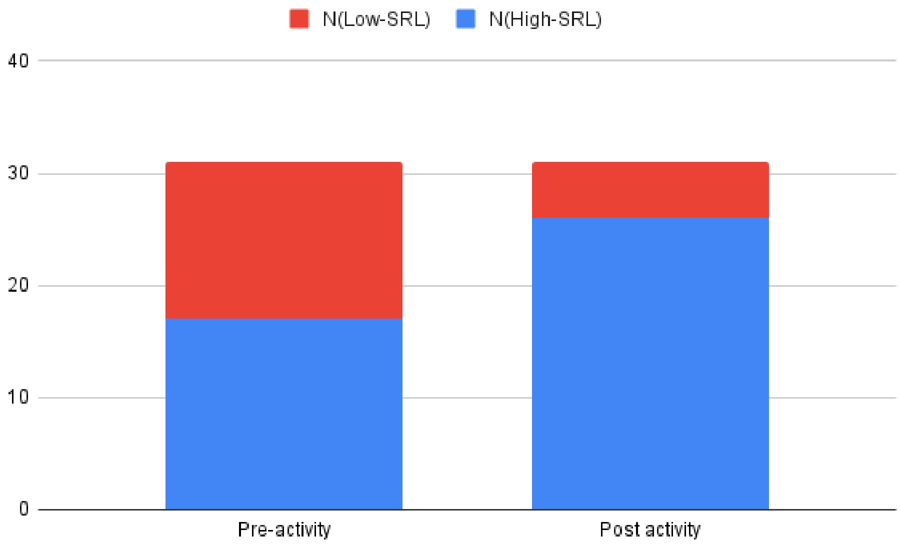

Figure 11.3: Change in number of users belonging to High-SRL and Low-SRL groups along the activity

The participants were divided into two groups, "High-SRL"and "Low-SRL" based on their RAI scores which indicated their self-regulation skills before and after the activity. Before the activity the participants were roughly equally distributed among the "High-SRL" group(*N = 17, M(RAI) = 2.19*) and the "Low-SRL" group(*N = 14, M(RAI) = 1.11*). After the activity a good number of users were observed to have improved their regulation as the "High-SRL" group (*N = 26, M(RAI) = 2.30*) had more users compared to the "Low-SRL" group (*N = 5, M(RAI) = -1.4*) (Figure 11.3). On looking at the change to the RAI score of the participants across the activity, it was observed that the 23 users were able to improve their self-regulation after the activity while 8 participants has lesser RAI score at the end of interaction than before. We can thus conclude that the interaction was able to promote self-regulation effectively in the users.

We then conducted an independent t-test to compare the "High-SRL" and "Low-SRL" groups after the learning interaction and found significant differences in the **intrinsic motivation** and **activity score** of the users (Figure 11.4). The users with higher self-regulation skills after the activity belonging to the "High-SRL" group showed significantly higher levels of intrinsic motivation (*p = 0.001, M(High-SRL) = 3.12, M(Low-SRL) = 2.0*) as compared to the "Low-SRL" group. However, the activity score of the "High-SRL" group of users were seen significantly lower (*p = 0.005, M(High-SRL) = 2.61, M(Low-SRL) =*

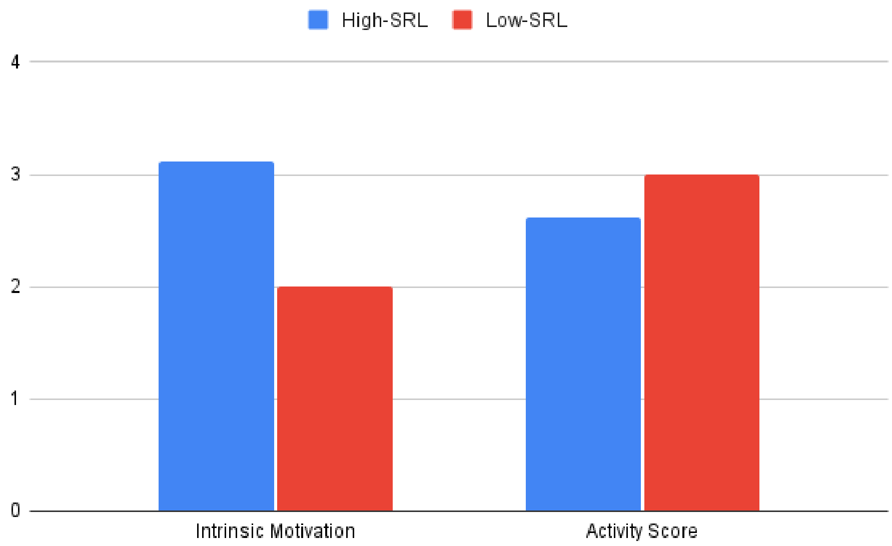

Figure 11.4: Significant differences between the groups of High-SRL and Low-SRL

3.0)) than that of "Low-SRL" users after the activity. This suggests that the improvement in regulation and intrinsic motivation in the learning activity did not translate into an improvement in the task performance.

11.4.7 User preferences

The learning interaction involved the user selecting the preferred agent at the beginning of planning and reflection phases for the three exercises performed. It was observed that the users predominantly preferred to have the tutor agent to provide support for the planning phases of the activity while for the reflection phase, there was a trend of seeking more help from the peer agent as the activity progressed (Figure 11.5). The users would have chosen to seek support from the tutor agent for the planning phase since the external regulation support in forms of direct hints and suggestions, which are focused on improving the performance of the user, were perceived more helpful than implicit knowledge support provided by the peer. Over the activity, more than 90% of the participants consistently selected tutor agent before the planning phase. This supports the hypothesis **H2** that the tutor agent is more likely to be preferred by the users for planning phase.

However, for the reflection phase there appeared to be a mixed and evolving trend on the preferences towards the agent suitable for reflection support. According to the hypothesis **H3**, we expected the user to seek support from the peer agent which actively exhibited self-regulation behaviours of thinking aloud and asking more questions. In contrast to our hypothesis, the more than 67% of the users preferred tutor agent through out the activity. However, the preference towards the peer agent for reflection phase was seen improving after each exercise. In the first exercise only 5 participants opted to seek help from the

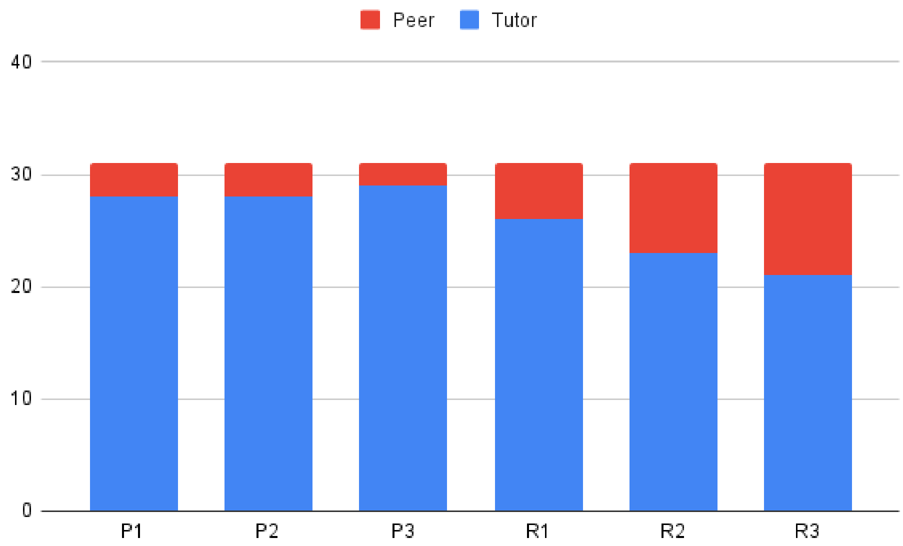

Figure 11.5: Evolution of user preferences for agents during planning and reflection phases in the activity.

peer while by the end of the third exercise, 10 participants were seen preferring the peer agent over the tutor. This suggests that the preference for the peer might improve as the user engage more in the interaction, but this can only be validated on having a long-term interaction study with the users. Thus, hypothesis **H3** could not be validated by the study results.

Tutor-oriented vs Peer-oriented Reflection phase

We looked at the group of participant's preferences for the reflection phase and categorised them into two, namely "Tutor-oriented" and "Peer-oriented" groups. The "Tutor-oriented" group ($N = 23$) depended on the tutor agent mostly for the reflection which involved external regulation strategies of direct hints, suggestions and explanations while the peer agent was limited to agreement and encouragement for the user. The "Peer-oriented" group ($N = 8$) had participants who preferred the peer agent to assist them in reflection through think aloud acts and implicit knowledge delivery through doubts and observations while the tutor was limited to acts of instruction and encouragement. On conducting an independent samples t-test based on the user preferences, it was found that the "Peer-oriented" reflection group had higher activity interest score as compared to the "Tutor-oriented" group ($p = 0.02$, $M(Tutor\text{-}oriented) = 3.47$, $M(Peer\text{-}oriented) = 4.18$) (Figure 11.6). This suggests that the users who engaged in co-regulation based reflection with prominently form the peer agent perceived the learning activity with greater interest.

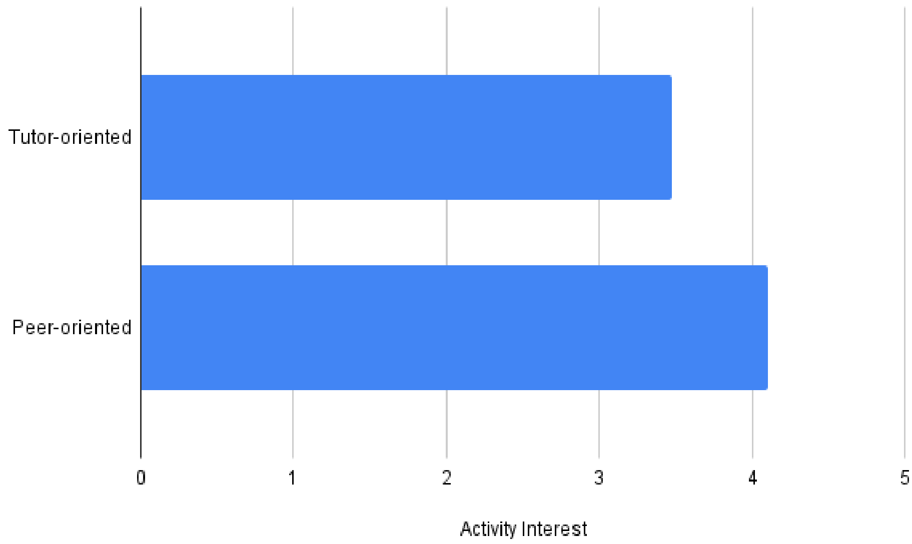

Figure 11.6: Activity interest across Tutor-oriented and Peer-oriented reflection groups.

11.5 Discussion

The study aimed at utilising the external regulation strategies emerging from the tutor and co-regulation behaviours demonstrated by the peer agent in promoting self-regulation and performance together in a shared learning interaction. The study divided the task of comparing fractions into three phases of planning, performance and reflection which are the relevant processes in self-regulated learning. The study also let the user choose the agent thus the related regulation mode which seemed suitable for the planning and reflection phases for each of the three exercises given. In general, the participants perceived the agent qualities of perceived intelligence and likeability positively even though there were no significant change in the agent perceptions after the activity. The entire learning interaction was also rated to indicate good interest and engagement in the learning activity. Regarding the role perception, all the participants perceived the virtual agent as tutor from the beginning of the interaction. For some participants who had a wrong perception about the virtual robot's role, the role perception got corrected after the activity indicating that the agent roles and behaviours were perceived by the users as intended during the learning interaction.

The hypothesis **H1** assumed the user-driven method of adaptive regulation scaffolding using the tutor and peer agents, to improve the task performance along with improved self-regulation after the activity. However, regarding the task performance, it was observed from the *activity score* that the majority of participants performed well in the activity. However, for some participants the performance worsened over the activity as they committed more mistakes in the given exercises, often at the end of activity. Hence, regarding the hypothesis H1, it cannot be concluded that the mixed regulation strategies implemented in the study had essentially improved the performance of the users during the activity.

Regarding the changes in self-regulation due to the regulation strategies from the agents during planning and reflection phases, it was observed that the RAI score, which indicated self-regulation skill of the user, improved significantly after the learning interaction. Also, a good number of participants who had poor self-regulation before the activity turned out to be well self-regulating users at the end of interaction. On comparing the groups of users with High and Low SRL skills, it was noted that the well regulated users had higher levels of intrinsic motivation. However, the improvement in self-regulation did not necessarily result in an improved task performance. The users belonging to "High-SRL" group were reported to have lesser activity score as compared to the others. Hence, the hypothesis **H1** which expected the self-regulation and performance of the user to improve from the adaptive regulation scaffolding remains only partly satisfied.

On looking at the way user preferences evolved during the different phases of the activity, it was evident that the tutor agent, which was performance-oriented through external regulation behaviours of providing direct hints and explicit knowledge support, was preferred better for the planning phases of the interaction. This predominant preference for the tutor agent can also be related to the fact that the role of tutor was presented with clearly higher competence than the peer which makes it more suitable for seeking knowledge support to solve the exercises. These results support the hypothesis **H2** which states that the users would prefer to seek external regulation support from the tutor during the planning phases of the task.

However, in the reflection phases, there was a mixed and evolving trend in choosing the agents. The majority of the users chose tutor agent for the reflection phase as well, thus not supporting the hypothesis **H3**, but an increasing preference towards peer agent was seen as the activity progressed. This can be associated with the aspect of automaticity in learning , which refers to the emergence of an automatic response pattern in cognitive, metacognitive and motivational processes in the user. According to Zimmerman and Kitsantas (2005), it is necessary to have some processes that must become automatic so that the users can actively employ regulation strategies with less cognitive load Boekaerts (2011). After a comparison between the user who choose the tutor and peer respectively for reflection phases, it was observed that the peer-oriented group expressed better interest in the learning activity. This suggests that the proposed user-driven method for adaptive regulation scaffolding can be effective in improving the self-regulation in the user but not necessarily the task performance. The observations from user preferences for agents in various phases of regulation suggest that external regulation strategies by the tutor are suitable for the planning phase and the users are more likely to engage in deeper co-regulation behaviours with the peer as they become familiar with the learning topic or the task.

11.6 Conclusion

This chapter described the user study on implementing a user-driven adaptive regulation scaffolding involving external regulation support from the tutor and co-regulation support from the peer agent simultaneously in a shared learning context. The study results suggested improvement in self-regulation of the users after engaging in the interaction in which the users were able to select the suitable agent and thus the kind of regulation for each phase of the task. However, the improved levels of self-regulation did not ensure an improved task performance in the users. The users with high self-regulation skills were observed to have higher intrinsic motivation and a lower task performance score. Regarding the user preferences, tutor agent was observed to be preferred consistently for the planning phase by the majority of the users while the users started seeking help from peer agent for reflection phase only once they were familiar with the task and the agents. The results and feedback from the study suggests that the proposed interaction, where the user was given freedom to choose the source for regulation support, is effective in engaging the participants as well as making them more aware of the distinct strategies and qualities associated with each agent and it's benefits for improving the regulation and performance.

The key points of this Chapter:

- The improvement in self-regulation did not necessarily result in an improved task performance for the users.
- The tutor agent, which was performance-oriented through external regulation behaviours of providing direct hints and explicit knowledge support, was preferred better for the planning phases of the interaction by the majority of users.
- The reflection phases showed prominent preference for tutor agent in the beginning and an increasing preference towards peer agent, as the activity progressed.

Part VI

Conclusion

Chapter 12

Conclusion and Perspectives

Contents

In the work presented in this thesis, we presented a multi-agent learning interaction involving different pedagogical agent roles providing distinct regulation strategies to promote self-regulation and performance in learners. The virtual agent presented in the role of tutor provided external regulation support to the learner through explicit feedback, suggestions and performance-oriented strategies. The virtual robot in the role of a peer learner demonstrated co-regulation strategies of thinking aloud, asking doubts, making mistakes and seeking help from the learning partners. Altogether, both agents facilitated the emergence of a socially shared learning interaction in which the learner, tutor agent and the peer learner functioned as a collective unit during the learning task, actively employing regulation processes of planning, monitoring and reflection to achieve the learning goals. The research work involved the design of a new collaborative learning task focused on self-regulatory processes, developing a novel humanoid robot to act as a peer learner and orchestration of the multi-agent interaction in the form of an engaging game based learning activity.

In this Chapter, we conclude this thesis by summarising our contributions in Section 12.1 and identifying the limitation of our work in Section 12.2. In Section 12.3, we also present the future perspectives on the proposed shared learning interaction and its various elements developed in SSRL context.

12.1 Summary of Contributions

The objectives of this research work were to understand how pedagogical agent behaviours can potentially be used to promote make the learner more self-regulated. The research questions that motivated our work were the following:

- **RQ1**: Does engaging in a shared learning interaction with multiple pedagogical agents providing distinct regulation strategies enhance self-regulation skills of the learner?
- **RQ2**: Do various roles of agents influence the learner's self-regulation and learning differently?

To address these questions we started by looking at various models of self-regulation which can be adopted for our research. During the course of the research, we became particularly interested in designing and understanding multi-agent learning interactions that seemed effective in persuading the users and keep them engaging on a task Kantharaju et al. (2018). Among various models of SRL, the socially shared regulation model of learning(SSRL) seemed to be the right fit for our work being the only theoretical model that considers multiple learning partners interacting together, regulating themselves and each other at the same time.

Dimensional framework of pedagogical agent roles in SSRL context
The initial phase of the research involved the definition of pedagogical roles in SSRL context and their associated multi-modal realisation. The proposed dimensional model for pedagogical agent roles defined the roles for external regulation and co-regulation based in the social attitude and regulation modes associated with the agents. The social attitude of agents were defined along the dimensions of dominance and friendliness while the regulation behaviour of the agents were defined by their competence and feedback characteristics. The roles of expert, tutor and motivator were considered as sources for external regulation and presented as More Knowledged learning partners characterised by higher competence and explicit feedback behaviours while the roles of peer agents such as peer collaborator, peer leader, peer follower, peer competitor and co-learner were characterised with lower or comparable competence levels with the learner and implicit modes of knowledge delivery and co-regulation behaviours such as thinking aloud and seeking help.

Development of FRACTOS learning task The second phase of the research involved the design of a multi-agent interaction based on shared learning which demanded a learning task facilitating self-regulatory processes as well as engaging the learner. Thus we designed and implemented a new learning task called FRACTOS, based on the mathematical concept of fractions, which involved the tasks of building, comparing and identifying fractions represented using virtual LEGO blocks. The FRACTOS task comprised of three phases dedicated for planning, performance and reflection for each exercised performed by the learner and allowed the agents to engage with the learner and provide distinct regulation support to the learner at each phase of self-regulation. Further studies and implementations done in this research work were based on the FRACTOS learning task, which turned out to be effective in orchestrating the learning interaction.

CardBot: Designing a new affordable humanoid robot platform for HRI studies On the course of our research, we came up with the design of a new humanoid robot platform called CardBot, aiming at using robots in learning interactions. The design and implementation of the robot ensured minimum effort and expertise in building and configuring a humanoid robot which is equipped with speech, basic gestures and expressive acts to engage socially with users. CardBot uses cardboard as its skeleton material to make the fabrication affordable, scalable and accessible. The verbal and non-verbal behaviours of the robot were capable of being controlled from a Unity3D based control interface, which made it suitable for use in Wizard of Oz interaction studies in HRI. The CardBot robot was used in the initial phases of our research and pilot studies conducted during the development of FRACTOS learning task, but the constraints and changes brought by the pandemic situation has limited the usage of CardBot in the final phases of our work, as we moved to virtual characters and online studies.

A multi-agent learning interaction for regulation scaffolding in SSRL context

The proposed multi-agent learning interaction aimed at promoting self-regulation behaviours in the learner through the roles of tutor and peer in SSRL context. Through this configuration of learning environment with multiple learning partners of different competency levels and regulation strategies, we wanted to explore how engaging in a learning task with various roles of agents can influence the self-regulation and performance of the learner. The learning interaction thus involved a human learner engaging in the FRACTOS learning task on building and comparing fractions, with a virtual tutor agent and a virtual robot peer agent. The tutor agent, presented as a more knowledged entity was characterised by moderate levels of dominance and friendliness and provided external regulation support through direct hints, explicit knowledge delivery and feedback etc. The peer agent facilitated co-regulation scaffolding through acts of thinking aloud, seeking help, asking doubts, making mistakes etc and was characterised with lesser competence and implicit feedback. The proposed shared learning setting becomes relevant as it emulates the learning interactions happening in real-world scenario such as classrooms where learning involves engaging with with multiple people such as teachers and co-learners.

User studies towards understanding self-regulated learning and agent perceptions of the learners in SSRL context
For our research on self-regulation using multiple roles of pedagogical agents engaging together in a shared learning activity, we addressed the research questions **RQ1** and **RQ2** through a series of user studies looking at the learner perceptions, self-regulation skills and performance during the activity.

1. Learner perception of agents and the activity
The first user study aimed at understanding the perception of agent roles, related qualities and the FRACTOS learning activity by the learners and to observe the proposed interaction is effective in promoting self-regulation and engaging the learners. Addressing **RQ1**, to understand how agents that focus on regulation can influence the learner, we hypothesised that:

- **H1**: Engaging in the learning interaction with tutor and peer agent would improve the learner's perception of agent qualities.

- **H2**: Positive perceptions of agent qualities and learning activity would encourage better self-regulation in learners.

The results from the study indicated improvement in the perceived intelligence of the tutor and peer agents after the activity while the likeability remained consistently good. In general, we observed good interest in the learning activity and most learners exhibited good regulation skills in the activity. Learners with higher self-regulation skills were observed to have associated higher perceived intelligence and higher likeability to the tutor agent before the activity and exhibited higher intrinsic motivation. Concerning the perception of pedagogical roles assigned to the agents, majority of the participants were able to associate the tutor and peer roles to the agents correctly, while few participants were confused over the role assigned to the virtual robot peer agent. This suggested a better design of peer agent behaviours to clearly convey the intended pedagogical role.

2. Impact of error making peer behaviours
According to the design of the learning interaction, it is necessary for the learner to associate the roles of tutor and peer to the intended agents in order to avoid misinterpretation of the regulation strategies and behaviours. To improve the perception of agent roles by the learner and clearly convey the competence levels of both agents, we introduced error making behaviours in the peer agent for our second user study. In this context, we hypothesized that:

- **H1**: Error making behaviour of the peer agent would promote correct perception of agent roles and associated qualities.

- **H1a**: The peer agent will be perceived to be less intelligent than the tutor agent after the activity.
- **H1b**: The learner's role perception of peer agent will improve after the activity.
- **H2**: Error making behaviours of the peer agent would promote better regulation in learners.

On analysing the data from the study we observed that the error making behaviour by the peer agent had significant effects on the perception of agent qualities as well as the associated pedagogical roles. The perceived intelligence of the only the tutor agent improved after the activity while that of the peer remained almost the same, hence establishing the intended competency level for the peer. Also, almost all participants who mistook the peer agent as a tutor before the activity gained correct perception of the agent roles on engaging in the activity. On comparing the finding from the study with the data from previous study, we observed that the perceived intelligence of the peer decreased on introducing error making behaviours which also resulted in a lower activity interest factor. Thus it appears that error episodes during the task not only can help in improving the role perception but also affect the learner engagement adversely if mistakes appear often.

3. Understanding effects of external regulation and co-regulation

The third study aimed to understand how the distinct modes of external regulation and co-regulation influence the learner differently while engaging in the proposed multi-agent learning interaction. To explore **RQ2**, to understand how different roles and related regulation strategies influence the learner, we hypothesised that:

- **H1**: Instructional discourse of external regulation strategies by the tutor agent would motivate performance-oriented learning behaviour in the learner
- **H2**: Demonstration of co-regulation strategies by the peer agent would motivate better regulation oriented learning behaviour in the learner

The study results indicated significant differences in self-regulation and activity performance between the groups that received each modes of regulation. It was observed that the activity score which indicated the performance level of the learner was significantly higher for the group that was directed by external regulation. The other group which received co-regulation strategies from the actively self-regulating peer agent was found to have better self-regulation skills, thus confirming our hypotheses. However, since an effective learning interaction should facilitate both self-regulation and performance in the learner, we then directed our research towards achieving a balance between both modes of regulation through the tutor and peer agents.

4. Learner-directed regulation scaffolding approach

The final user study allowed the learner to seek help from the preferred agent at various instances during the planning and reflection phases of the learning activity. We hypothesized that:

- **H1**: Adaptive regulation scaffolding driven by the learner preferences of agents during the activity will improve both the performance as well as self-regulation scores of the learners.
- **H2**: Learners would prefer to seek external regulation support from the tutor during the planning phases of the task.
- **H3**: Learners would prefer to seek co-regulation support from the peer during the reflection phases of the task.

The learner-driven scaffolding approach involved good interest in activity and positive perceptions of agent role and behaviours. After engaging in the learning activity, more learners exhibited higher self-regulation skills but the same did not happen in terms of task performance. Regarding the learner preference towards agents, it was observed that the learners predominantly preferred to have the tutor agent to provide support for the planning phases of the activity while for the reflection phase, there was a trend of seeking more help from the peer agent as the activity progressed.

In general, the results from the studies suggests the need for an adaptive regulation scaffolding based on the performance and self-regulation goals of the learner during the activity as well as conducting more long-term studies to understand how these goals evolve as the learning progress.

12.2 Limitations

The contributions presented in this thesis are not exempted from limitations. In the following paragraphs we discuss some limitations concerning the implementation of agent behaviours as well as the scenarios used in our experimental studies.

12.2.1 Agent and task limitations

Our approach to self-regulated learning in the context of shared learning with multiple agents in different roles and associated strategies demanded the learner to split their attentions between both agents as well as distinguish the agents in terms of their roles and related goals during the task. The learner often requires some time for familiarisation with the agents to gain clear understandings and attributions to the agents. However, in our studies, since we had to break the activity into different phases of planning, performance and reflection for each exercise performed, the introduction to the agents were often short and focused on the task. Regarding the learning topic of fractions which was initially aimed at child learners, some adult participants found the learning task to be less challenging and thus not very engaging. We had to increase the difficulty of the task exercises to make the learning task more interesting for the learners. Also, regarding the agent features, the participants often provided feedback that the animation and voice of the agents were not realistic.

12.2.2 Experimental limitations

Concerning the user studies, it was observed that conducting online studies made the interaction with the agents less intuitive as the participants had to perform some actions on the screen unrelated to the task(such as skipping to next video, enabling full screen view etc) that required them to navigate through the study. Also, since the participants were recruited online, we could not have control over the environment in which they were performing the study. These factors could have influenced the interest and perceptions of the learners as well. In the initial stages of our research, we intended to conduct the proposed interaction in laboratory setting with child learners interacting with agents on the screen and performing the task on a tablet. We had to adapt our setting to suit online studies due to the constraints of the pandemic, which resulted in compromises over the data that we could collect from the studies such as gaze, performance logs etc. Regarding the aspect of self-regulation, since the studies were conducted online, we had to resort to the use of questionnaires for measuring the regulation skills of the learner, which made it impossible to have an estimate of how learner self-regulation evolve during the activity. The studies conducted were also limited in terms of the duration of actual interaction with the agents and conducting more long term studies with multiple learning sessions could provide more insights on how agent perceptions and learner regulation change over time.

12.3 Future perspectives

In this section we envisage the future perspectives for pedagogical agent research in SSRL context and potential improvements to our implementations and approaches to ensure better regulation scaffolding.

12.3.1 Pedagogical role combinations for SSRL

The multi-agent interaction presented in this thesis involved the role of a tutor to facilitate external regulation and the role of peer to provide co-regulation. The dimensional framework of pedagogical roles in SSRL context, that we presented mentions different roles such as expert, motivator etc to represent More knowledged entities and different kinds of peer-related roles such as peer collaborator, competitor and learning companion to represent Less/equally competent entity in the learning interaction. Thus, various combinations of these roles can be experimented to understand how changes in the levels of dominance and friendliness can influence the learning differently than a tutor-peer learner pair.

12.3.2 Online measurement of SRL

As mentioned in the limitations of our work, measurement of SRL still remains as a challenging task Panadero et al. (2016). One of the future enhancement to the work should involve a real-time measurement of regulation states of the learner from multi-modal signals as well as engagement of the learner. For instance, the gaze behaviour of the learner can be used to estimate the level of attention on the activity as well as evolving preferences towards agents. Similarly, the trace measures from different phases of the task can also be used to inform about the performance and regulation goals of the learner during the interaction. There is also possibility to integrate 'online' measurement tools such as structured diaries and think aloud protocols during the activity which can act as an intervention and measurement tool for SRL at the same time .

12.3.3 Automaticity and Adaptive scaffolding

The results from the studies conducted has suggested the need for a balance between focus on regulation and performance in a shared learning interaction. In one of our studies, the improvement in regulation came at the cost of a drop in task performance while the learner preferences towards peer agent that focused on regulation goals were seen to be improving as the activity progressed. Automaticity in learning refers to the emergence of an automatic response pattern in cognitive, metacognitive and motivational processes in the learnerZimmerman and Kitsantas (2005) Boekaerts (2011). As the learner becomes more familiar with the activity and competent in the learning topic, some goals and strategies may be activated or triggered directly by environmental cues, without awareness or additional cognitive load of the learner Pintrich (2000). In our research, we used the tutor agent focusing on external regulation to orient the learner towards improving task performance through direct hints and instructions. The peer agent demonstrating regulation strategies in the interaction instead focuses in promoting regulation behaviours in the learner. To strike a balance between these two modes of regulation, it would require us to have more understanding on the learner behaviours and task performance for inferring about the appropriate regulation mode and the suitable agent to deliver the support at any instant. Implementing such a system would make the proposed shared learning interaction more effective in terms of enhancing the aspects of regulation as well as agent behaviours in the future.

Part VII

Annexes

Appendix A

Publications and Dissemination

The publications in International Conferences and Workshops include:

- Krishna, S., Pelachaud, C. and Kappas, A., 2019, July. Towards an adaptive regulation scaffolding through role-based strategies. In Proceedings of the 19th ACM international conference on intelligent virtual agents (pp. 264-267).
- Krishna, S., Pelachaud, C. and Kappas, A., 2020, March. FRACTOS: Learning to be a better learner by building fractions. In Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction (pp. 314-316).
- Krishna, S. and Pelachaud, C., 2020, March. CardBot: Towards an affordable humanoid robot platform for Wizard of Oz Studies in HRI. In Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction (pp. 73-73).
- Krishna, S. and Pelachaud, C., 2022, March. Learner perceptions of a multi-agent learning interaction in socially shared regulation context. In Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction. (**Under review**)

The publication in National Workshops include:

- Krishna, S. and Pelachaud, C., 2020, June. Learning to be a Better Learner With a Virtual Tutor And a Robot Peer. In Workshop sur les Affects, Compagnons artificiels et Interactions.

Appendix B

Questionnaires

Negative Attitudes towards Robots Scale (NARS) - 5 point Likert scale

- The words 'Robot' or 'Virtual agent' means nothing to me.
- I would feel uneasy if I had to do my work with help of a robot or a virtual agent.
- I would feel nervous using a robot or a virtual agent in front of other people.
- I don't like a robot or a virtual agent making judgments about things.
- I would not feel comfortable talking with a robot or a virtual agent.
- I would feel very nervous just standing in front of a robot or a virtual agent.

GODSPEED - 5 point Likert scale

- Alice is competent / Bot is competent.
- Alice is knowledgeable / Bot is knowledgeable.
- Alice is intelligent / Bot is intelligent.
- I like Alice / I like Bot.
- Alice is pleasant / Bot is pleasant.
- Alice is friendly / Bot is friendly.

Academic self-regulation Questionnaire (SRQ-A) - 4 point Likert scale

- I play the game because I want to learn new things.
- I try to answer hard questions to find out if I'm right or wrong.
- I do the game because it's fun.
- I enjoy playing the game.
- I try to answer hard questions because it's fun to answer hard questions.
- I try to do well in the game because I'll feel bad about myself if i don't do well.
- I try to answer hard questions because I'll feel bad about myself if I don't try.
- I try to answer hard questions because I want others to think I'm smart.
- I try to do well in the game because that's what I am supposed to do.
- I play the game because that's the rule.
- I try to do well in the game because I will get in trouble if I don't.

Intrinsic Motivation Inventory (IMI) - 5 Point Likert Scale

- I thought this was a very interesting game.
- I felt like I was enjoying the game while I was doing it.
- I think this game is important for my improvement.
- I am willing to do this game again because I think it is somewhat useful
- I think this was a very boring game.
- It is possible that this game could improve my studying habits.

Role perception questions

- Which role do you think would describe the behaviour of Bot accurately?
- Which role do you think would describe the behavior of Alice accurately?

Knowledge test

- How many red blocks can make the fraction 5/2?
- Which fraction is larger? 3/2 or 5/4?
- Which coloured blocks are needed to make 3/8 fraction? Green or Blue?

Demographics

- What nationality do you feel shapes your cultural identity?
- Is English your first language?
- What is the highest level of education you have completed?
- What is your gender?
- What is your age?

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