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Soutenir la motivation et l’engagement des apprenants de langue autodirigés non-académiques : une perspective neurophysiologique

par

Rémy El-Nemr

Pierre-Majorique Léger
HEC Montréal
Directeur de recherche

Constantinos Coursaris
HEC Montréal
Codirecteur de recherche

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Expérience Utilisateur

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Résumé

Quotidiennement, des millions de personnes débutent des cours de langues en ligne auto dirigés en dehors du cadre scolaire qu'ils ne finiront jamais. Le phénomène d'abandon d'apprentissage est extrêmement répandu dans l'apprentissage autodirigé (SDL), avec des taux d'abandon autour des 90%, ce qui menace la viabilité et profitabilité des plateformes d'apprentissage. La recherche actuelle indique que la démotivation des apprenants, un facteur inhérent du SDL et de l'apprentissage de langues, est une des raisons principales expliquant l'abandon des apprenants, indiquant l'importance de soutenir la motivation de ces derniers. À cet effet, la gamification s'est démarquée comme une méthode efficace de renforcer la motivation et l'engagement dans le milieu d'apprentissage académique. Or, son impact dans l'apprentissage non-académique de langues, prenant lieu sur des plateformes d'apprentissage en dehors des établissements académiques, est sous-étudié par la littérature en faveur des apprenants de langues dans un contexte académique, négligeant une partie importante de la population d'apprenants de langues. De plus, les mécanismes cognitifs sous-jacents aux effets positifs de la gamification dans l'apprentissage de langues sont très peu étudiés. Ce mémoire a pour objectif d'évaluer l'évolution de la motivation et de l'engagement d'apprenants de langues non-académiques autodirigés (naSDLL) avec et sans gamification, tout en expliquant son mécanisme à travers une perspective neurophysiologique longitudinale. Nous avons recruté 31 apprenants de français de niveau débutant pour une expérience d'apprentissage d'un mois dans laquelle nous avons mesuré leur engagement pendant des tâches d'apprentissage de langue au début de l'expérience avec l'éléctroencéphalographie (EEG) et l'oculométrie au début de l'expérimentation, leur motivation à 4 reprises hebdomadaires pendant un mois de SDL avec deux questionnaires (rIMMS et IMI), et leur engagement une seconde fois après leur expérience de SDL. Nos résultats révèlent que les apprenants gamifiés avaient une activité cérébrale en thêta et alpha significativement plus élevée, impliquant concrètement un meilleur traitement cognitif et une meilleure capacité de concentration lors de l'apprentissage de langues. De plus, les résultats révèlent une fréquence de fixations visuelles significativement plus basse chez les apprenants gamifiés après un mois d'apprentissage, ce qui implique un traitement de l'information visuelle plus efficace requérant moins d'efforts lors de tâches d'apprentissage de langues. Aucune différence significative entre les groupes n'a été trouvée quant à la motivation à travers le temps ainsi que la durée des fixations et le coefficient K.

Ces résultats suggèrent que la gamification permet de soutenir l'engagement des apprenants de naSDLL à travers le temps, mais que dégager son effet sur la motivation dans le contexte non-académique requiert d'avantages d'études. Nous contribuons à la littérature de la gamification en expliquant de quelles manières elle impacte positivement le processus d'apprentissage. Notre approche novatrice comble une lacune quant à l'utilisation d'outils neurophysiologiques dans la mesure de processus cognitifs. Nos résultats nous permettent également de formuler des recommandations actionnables aux créateurs de plateformes de naSDLL quant à l'implémentation de la gamification. Les mesures neurophysiologiques peuvent efficacement délimiter les mécanismes d'action de la gamification sur l'engagement, mais les dynamiques du SDL, notamment l'isolement, le manque de rétroaction et de figure d'autorité, doivent être prises en compte dans l'implémentation de gamification dans le naSDLL.

Mots-clés : Gamification, motivation, engagement, SDLL, SDL, EEG, andragogie, non-académique

Abstract

Everyday, millions of learners start their self-directed online language learning journey outside the traditional classroom, only to abandon it halfway through. This drop-out phenomenon is widespread in the realm of self-directed learning (SDL), with dropout rates orbiting around 90%, threatening the viability and profitability of language learning platforms. Current research indicates that learner demotivation, an inherent factor of the SDL environment, is one of the main reasons for which learners drop out, highlighting the importance of sustaining learners' motivation and engagement through time. To this end, gamification has proven to be fruitful in sustaining learner motivation and engagement in academic settings. However, its impact in non-academic learning, which takes place on learning platforms outside of academic institutions, is understudied in the literature, neglecting a sizable percentage of the population. Additionally, the cognitive mechanisms underlying gamification's impact on motivation and engagement are equally understudied. The objective of this thesis was to evaluate the evolution of motivation and engagement in self-directed non-academic language learning (naSDLL) with and without gamification while explaining its mechanism through a longitudinal neurophysiological perspective. We recruited 31 beginner-level French learners for a month-long language learning experience, in which we measured their engagement during language learning tasks at the start of the experiment with electroencephalography (EEG) and eye tracking, their motivation weekly on 4 occasions during a month of SDL with two questionnaires (rIMMS and IMI), and their engagement a second time after a month of SDL. Our results reveal that gamified learners had significantly higher theta and alpha brain activity, practically implying better cognitive processing and concentration during language learning tasks. Furthermore, the results reveal a significantly lower frequency of visual fixations in gamified learners after one month of learning, implying more efficient processing of visual information and less required processing effort during language learning tasks. No significant differences between groups were found in motivation over time, as well as in fixation duration and K coefficient. These results imply that gamification can sustain naSDLL learners' engagement over time, but that its effect on motivation in the non-academic context requires further study. We contribute to the gamification literature by explaining the ways in which gamification positively impacts the learning process. Our innovative approach fills a gap in the use of neurophysiological tools to measure cognitive processes. Our results also enable us to formulate actionable recommendations to creators of naSDLL platforms regarding the implementation of gamification. Neurophysiological measures can effectively delineate the mechanisms of action of gamification on engagement, but the dynamics of SDL, including isolation, lack of feedback and lack of authority figure, need to be considered when implementing gamification in naSDLL.

Keywords: Gamification, motivation, engagement, SDLL, SDL, EEG, andragogy, non-academic

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Apprentissage autodirigé: SDL

Apprentissage autodirigé en ligne: SDEL

Apprentissage de langue autodirigé non-académique: naSDLL

Non-academic language learners: naLL

Éléctroencéphalographie: EEG

Attention Relevance Confidence Satisfaction: ARCS

Revised Instructional Materials Motivation Survey: rIMMS

Self-Determination Theory: SDT

Intrinsic Motivation Inventory: IMI

Avant-propos

Ce mémoire fait partie de la maîtrise en sciences de la gestion - expérience utilisateur à HEC Montréal et a été approuvé par l'administration du programme. Les directeurs de recherche ont approuvé le format par article du mémoire, et les co-auteurs ont approuvé leur inclusion dans ce travail de recherche. Le premier article de ce mémoire se nomme " "Keep your streak alive": Sustaining non-academic language learners' motivation and engagement through gamification". Le deuxième article se nomme "Leaderboards, feedback and personalization: How to keep adult language learners outside the classroom engaged through gamification". Le projet de recherche a été approuvé en avril 2023 par le bureau du Comité d'éthique de la recherche de HEC Montréal (2023-5394) et a été conduit de façon éthique.

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Chapitre 1 : Introduction

Qui parmi nous n’a jamais tenté d’apprendre une langue étrangère sur internet dans son temps perdu? L'apprentissage autodirigé de langues en ligne non-académique (naSDLL) est apparu comme une force disruptive dans l'éducation linguistique à l’échelle internationale, modifiant fondamentalement la façon dont des millions de personnes abordent l'apprentissage d'une langue. Cette forme d’apprentissage, prenant lieu en dehors du contexte académique des établissements scolaires à partir d’applications et de sites internet, permet à quiconque disposant d’un appareil muni d’une connexion internet d’apprendre une langue étrangère à son rythme, et ce, sans les contraintes habituelles de la salle de classe. Des géants de l'industrie comme Duolingo, Busuu et Memrise comptaient plus de cent millions d'utilisateurs inscrits en 2023, reflétant l'attrait croissant des solutions d'apprentissage autonomes en dehors d’un contexte institutionnel encadré, comme un établissement scolaire. Bien que l'essor du naSDLL puisse être partiellement attribué aux récents confinements socio-sanitaires, sa croissance est loin d’un engouement temporaire. Le marché mondial de l'apprentissage des langues en ligne devrait connaître un taux de croissance annuel composé (TCAC) de 17,9 % de 2023 à 2032, passant de 23,16 milliards de dollars à environ 101,94 milliards de dollars (Digital Language Learning Market Size [2032], 2024).

En effet, le passage du format de cours de langues, traditionnellement en présentiel, vers un format en ligne sans instructeur est en partie dû à l'accessibilité et la démocratisation de l'apprentissage en ligne autodirigé (SDEL) et ses avantages pratiques: En supprimant les barrières financières, temporelles et spatiales propres à l’apprentissage académique, ainsi que les responsabilités envers les enseignants et les pairs et la pression exercée par ces derniers, le SDEL permet aux apprenants de prendre le contrôle total de leur parcours d'apprentissage, leur permettant d'atteindre leurs objectifs d'étude à leur propre rythme.

Bien que cette récréation de la salle de cours puisse sembler prometteuse sur papier, le SDL présente des défis considérables: les fournisseurs de cours en ligne continuent de faire face à de faibles taux de complétion de cours, représenté par des taux élevés d'abandon et par de faibles taux de complétion à travers le temps: près de 52% des apprenants s’étant inscrits à un cours en ligne n'accèdent jamais au contenu éducatif (Reich & Ruipérez-Valiente, 2019), et le taux d'abandon de cours auto dirigés est autour de 90% (Eriksson et al., 2017; Hew & Cheung, 2014; Xing & Du, 2018). L'abandon d'apprentissage est un défi considérable auquel n'échappent pas les plateformes d'apprentissage de langues, qui elles aussi témoignent d'un taux d'abandon généralement élevé (Garcia Botero et al., 2018; Krashen, 2014). Afin de garantir la viabilité financière des plateformes d'apprentissage de SDL en dehors du cadre académique, il est essentiel d'expliquer les raisons sous-jacentes au taux d'abandon élevé. Les recherches antérieures sur l'abandon d'apprentissage répandu dans le cadre du SDL ont démontré que les changements motivationnels des apprenants et leur manque de motivation ont un impact significatif sur les taux d'abandon (Aragon & Johnson, 2008 ; Kim, 2021; Zhu et al., 2020).

En effet, la motivation joue un rôle central dans la détermination du niveau de réussite et d'engagement des apprenants (Gottfried et al., 2001; Hartnett, 2016), exerçant une influence directe sur leur engagement - c'est-à-dire, sur leur implication active et soutenue dans leur propre processus d'apprentissage (Song & Hill, 2007) - et ce, dans divers environnements d'apprentissage en ligne (Alemayehu & Chen, 2023). La motivation des apprenants est considérée par de nombreux chercheurs comme un prérequis fondamental au succès dans les environnements d'apprentissage autodirigé (SDL) (Deci & Ryan, 1981; Fırat et al., 2018; Ali, 2020). La littérature actuelle a démontré à maintes reprises que la capacité des apprenants à rester motivés et engagés dans le SDL est entravée par l'absence de rétroaction immédiat, de conseils personnalisés et d'interaction sociale (Deci & Ryan, 1981; Hartnett, 2016; Wang et al., 2023). De plus, en l'absence d'une figure d'autorité pour fournir des devoirs et des suivis fréquents, les apprenants doivent compter sur leur propre motivation pour maintenir leurs efforts d'apprentissage et déployer des stratégies d'autorégulation efficaces. Ceux qui ont des niveaux de motivation plus élevés sont mieux équipés pour s'engager dans la pratique requise d'apprentissage autorégulé (Kizilcec et al., 2017), ce qui est crucial pour le succès dans le SDL. Ainsi, des apprenants moins motivés seraient plus portés à abandonner leurs cours en ligne, et les stratégies déployées par les plateformes d'apprentissage dans l'optique de soutenir la motivation de ces apprenants peuvent baisser le taux d'abandon (Lyyra et al., 2024).

Dans l'apprentissage des langues, les chercheurs s'accordent à dire que la motivation est l'un des facteurs les plus importants déterminant le succès de l'apprentissage (Gardner & Lambert, 1959; Dörnyei, 1998; Masgoret & Gardner, 2003; Zhang et al., 2020). Les apprenants de langues motivés pratiquent plus souvent leurs compétences langagières et maintiennent mieux leur processus d'apprentissage à long terme (Dörnyei, 1998; Ushida, 2006), or, il peut s'avérer difficile de soutenir la motivation des apprenants de langues auto dirigés en raison du caractère isolant du SDL. Ces difficultés sont amplifiées par le caractère démotivant propre à l'apprentissage de langues : les apprenants de langues feraient face à des défis personnels (évènements quotidiens, baisse d'intérêt…) ainsi que des défis reliés à l'environnement d'apprentissage (faible qualité du matériel d'apprentissage, style d'instruction mal adapté...) réduisant leur motivation d'apprentissage initiale tout au long de leur apprentissage (Dörnyei, 1998; Gardner, 2007).

Ainsi, afin de réduire le taux d'abandon des apprenants de SDL tout en améliorant leur performance d'apprentissage, prévenir et renverser leur déclin motivationnel semble être incontournable. À cet effet, tant les fournisseurs d'apprentissage en ligne que les chercheurs en éducation se sont graduellement tournés la *gamification* - l'application d'éléments de conception de jeux dans des contextes non-ludiques (Deterding et al., 2011) – dans l'objectif de garder les apprenants engagés et motivés tout au long de leur apprentissage. À première vue, l'implémentation de la gamification semble prometteuse dans l'optique d'améliorer la motivation et l'engagement des apprenants (Kapp, 2012; Dicheva et al., 2015). La gamification agirait positivement sur la motivation d'apprentissage en fournissant des objectifs et des rétroactions clairs (Hamari et al., 2014) et en créant un sentiment de progression et d'accomplissement, ce qui peut renforcer l'engagement de l'apprenant envers ses objectifs de manière soutenue à travers le temps (Sailer et al., 2017).

Considérant la nature évolutive de la motivation, la recherche actuelle a porté son attention sur son évolution à travers le temps dans un contexte gamifié. Plusieurs études indiquent un effet longitudinal positif sur la motivation et l'engagement des apprenants dans divers sujets d'apprentissage (Saleem et al., 2022), dont l'apprentissage de langues allant de quelques sessions d'apprentissage à 4 mois (Dehganzadeh & Dehganzadeh, 2020; Boudadi & Gutiérrez-Colón, 2020; Aguiar-Castillo et al., 2022). Or, cet impact ne semble pas être entièrement généralisable: nombreuses recherches démontrent un manque d'effet significatif et même un effet significativement négatif de divers éléments de gamification sur la motivation des apprenants notamment dans le contexte d'apprentissage formel (Hanus & Fox, 2015; Mavletova, 2015;

Mitchell et al., 2017), dans lequel on retrouve des activités d'apprentissage dirigées par un cadre institutionnel en classe et en ligne (UNESCO, 2012).

Dans le contexte autodirigé, l'implémentation des éléments de gamification suggère un impact positif sur l'engagement des apprenants (Palaniappan & Noor, 2022). La revue de littérature de Khalil et al. (2018) quant à l'impact de la gamification dans les MOOCs, un format de SDL, dénote un manque d'études empiriques mais souligne toutefois un effet sommairement positif sur la motivation et l'engagement des apprenants à travers le temps. Toutefois, il importe de souligner que la littérature est actuellement lacunaire quant aux études portant sur l'apprentissage autodirigé non-académique (naSDL): les revues de littérature portant sur l'impact de la gamification sur l'expérience d'apprentissage, incluant celles sur l'apprentissage de langues, soulèvent majoritairement des études dans lesquelles les participants sont des étudiants encadrés à divers niveaux d'éducation, allant du primaire aux études supérieures, et dans lesquelles le matériel d'apprentissage gamifié au cœur de la méthodologie de collecte de données est généralement issu ou diffusé dans un contexte académique formel comme une salle de classe (Alsawaier, 2018; Koivisto & Hamari, 2019; Saleem et al., 2022). Il est ainsi difficile de positionner la littérature de manière décisive sur l'impact de la gamification sur la motivation d'apprenants auto dirigés en dehors du cadre académique formel.

Afin de délimiter le mécanisme d'action sous-jacent à l'efficacité des éléments de gamification à l'échelle de la motivation, les recherches précédentes ont étudié les sous-composantes de la motivation selon divers modèles théoriques, notamment la théorie de l'autodétermination de Ryan et Deci (2000) : l'impact positif d'éléments de gamification est mesuré à l'aide de questionnaires quant à la perception d'autonomie, de compétence et de lien social des apprenants (Borras-Gene et al., 2016; Bovermann et al., 2018; Qiao et al., 2022). D'autres études considèrent modèle motivationnel ARCS de Keller (1987), mesurant l'impact de ces mêmes éléments à l'aide de questionnaires sur la perception d'attention, de pertinence, de confiance et de satisfaction des apprenants quant au matériel d'apprentissage (Özhan & Kocadere, 2020; Su & Cheng, 2015; Fazamin et al., 2015).

Quant à la mesure de l'impact sur l'engagement, les études ont tendance à reprendre la définition d'engagement d'apprentissage de Fredricks et al. (2004), selon laquelle l'engagement d'apprentissage se décompose en 3 dimensions : comportemental (participation et implication dans les activités scolaires), cognitif (le degré d'investissement dans l'apprentissage) et émotionnel (réactions positives et/ou négatives au cadre institutionnel d'apprentissage) (Fredricks et al., 2004). Les études de l'impact de la gamification sur l'engagement des apprenants reprennent, pour la plupart, les dimensions comportementales et cognitives, notamment à travers la mesure du temps passé sur les activités d'apprentissage, du nombre de contributions des apprenants, du nombre de visites de la plateforme d'apprentissage ainsi que du score de performance aux activités d'apprentissage (Looyestyn et al., 2017; Saleem et al., 2022).

Les méthodes de mesure de l'état motivationnel et de l'engagement telles qu'utilisées dans les recherches précédentes en gamification présentent des défis importants quand elles sont utilisées comme seules mesures de ces construits. D'une part, les mesures auto-rapportées, dominantes dans l'étude de la motivation des apprenants (Fulmer & Frijters, 2009), quoiqu'elles soient issues de théories et d'échelles validées, peuvent manquer de fiabilité en raison des potentiels biais des participants dans leur perception et expression de leur propre état mental (Paulhus & Vazire, 2007; Fredricks & McColskey, 2012). Les auto-évaluations sont sujettes à des biais de réponse et de mémoire, et il est possible que les apprenants ne puissent ou ne veulent pas partager leur état motivationnel avec précision (Fulmer & Frijters, 2009). Ces mesures négligent l'expérience interne et subjective vécue par les apprenants pendant l'acquisition de connaissances nouvelles et la résolution de problèmes, et demeurent ultimement superficielles quand il en vient à saisir l'état cognitif réel des apprenants. La revue de Greene et al. (2015) quant à l'utilisation de mesures auto rapportées dans la mesure de l'engagement dans l'apprentissage indique la nécessité d'une approche multidimensionnelle dans la mesure de l'engagement cognitif des apprenants.

Afin de mieux saisir l'état motivationnel et d'engagement des apprenants, les outils de mesure neurophysiologiques peuvent être bénéfiques en supplémentant les mesures auto rapportées avec des données plus objectives. Effectivement, il devient de plus en plus commun de capter l'état cognitif des apprenants pendant la réalisation de tâches d'apprentissage à l'aide d'outils comme l'électroencéphalographie (EEG) et l'oculométrie, deux outils de plus en plus populaires dans la détection de l'état motivationnel lors de l'apprentissage à partir de l'analyse de signaux d'activité cérébrale est possible à l'aide de l'EEG, et ce à un haut degré de fiabilité (Chattopadhyay et al., 2021). L'EEG s'avère être une méthode prometteuse dans la mesure de l'engagement cognitif des apprenants de manière continue, efficace et discrète (Li, 2021). De nombreux chercheurs ont utilisé l'indice de Pope et al. (1995) dans l'évaluation de l'engagement des apprenants (Charland et al., 2016; Apicella et al., 2022). Une récente étude de Juárez-Varón et al. (2024) emploie l'EEG afin d'évaluer les divers états cognitifs, notamment l'attention (la concentration sur une tâche en particulier), l'intérêt et l'engagement dans une expérience d'apprentissage gamifiée versus une expérience traditionnelle en classe (Juárez-Varón et al., 2024). Parallèlement, l'utilisation de l'oculométrie repose sur trois hypothèses fondamentales : l'attention visuelle comme base de l'engagement, une relation positive entre la durée de fixation et l'effort cognitif, et l'association entre la dilatation pupillaire et l'intensité de l'effort mental (Miller, 2015). Dans ce contexte, l'oculométrie offre plusieurs avantages, notamment l'analyse en temps réel des mouvements oculaires, une indication précise de la distribution de l'attention visuelle (Li, 2021). Ces mesures physiologiques peuvent capturer l'engagement et l'état motivationnel en temps-réel, apportant une nuance importante aux mesures auto rapportées qui sont facilement biaisées.

1.1 Objectifs et questions de recherche

La littérature actuelle présente des lacunes significatives dans le domaine du naSDLL gamifié. Tout d'abord, les études évaluant l'évolution de la motivation et de l'engagement des apprenants adultes dans le naSDLL gamifié sont rares, voire inexistantes. Comme mentionné précédemment, les études portant sur l'impact de la gamification dans l'apprentissage de langues portent majoritairement sur des contextes académiques, ce qui ne permet pas de décrire les dynamiques particulières du SDL. De plus, les recherches combinant les mesures auto-rapportées avec des données neurophysiologiques dans le cadre de l'apprentissage demeurent exceptionnellement limitées. En particulier, aucune étude n'a encore cherché à établir un lien de cause à effet entre la gamification et l'amélioration à travers le temps de la motivation et de l'engagement des apprenants. Cette absence de données empiriques souligne la nécessité d'approfondir la recherche dans ce domaine, afin de mieux comprendre les mécanismes sous-jacents à l'efficacité de la gamification dans le naSDLL.

Cette recherche présente donc deux objectifs:

1) Évaluer l’impact de la gamification sur l’évolution de la motivation et de l’engagement des apprenants dans une expérience longitudinale de naSDLL, c’est-à-dire, vérifier si la gamification a un impact significatif sur la motivation et l’engagement des apprenants à long-terme.
2) Identifier, à l’aide de mesures explicites et implicites, quelles sont les sous-composantes des construits de motivation et d’engagement les plus impactées par une implémentation de gamification dans une expérience de naSDLL longitudinale, c’est-à-dire, déterminer les mécanismes sous-jacents de la gamification impacte-t-elle la motivation et l’engagement des apprenants.

Ainsi, la question de recherche visant à répondre aux 3 objectifs de recherche mentionnés ci-haut est la suivante :

« *Dans quelle mesure la gamification de l’expérience de naSDLL impacte-t-elle l’évolution de la motivation et de l’engagement des apprenants adultes en dehors du cadre académique?* »

1.2 Contributions

D'un point de vue théorique, ce mémoire apporte une contribution significative à la littérature en offrant une compréhension approfondie de l'expérience d'apprentissage de naSDLL. Alors que les recherches existantes se sont principalement concentrées sur la gamification dans les contextes éducatifs de langues formels, tels que les salles de classe primaires et secondaires, l'enseignement supérieur et les programmes de formation professionnelle (Dehghanzadeh et al., 2021; Azzouz & Gutierrez-Colon Plana, 2020; Saleem et al., 2022; Saniyah, 2023; Slamet & Basthomi, 2024), notre étude se penche sur une population largement négligée : les adultes apprenant une langue en dehors d'un cadre institutionnel. Cette recherche vise à combler des lacunes importantes dans la compréhension de l'impact de la gamification sur l'expérience des apprenants adultes dans le naSDLL, en l'absence d'encadrement par un établissement scolaire ou un employeur. Nous explorons la dimension motivationnelle unique propre à cet environnement autodirigé, où les apprenants font face à des défis distincts de ceux rencontrés dans les contextes formels. Alors que les abandons dans un contexte institutionnel peuvent entraîner des conséquences importantes tant académiquement, professionnellement et financièrement, les conséquences d'un abandon dans le naSDLL sont souvent moins tangibles (en raison du moindre coût d'inscription, du manque de pression sociale...), ce qui peut influencer différemment la dynamique motivationnelle des apprenants.

D'un point de vue méthodologique, ce mémoire contribue à la littérature en comblant le manque notable de combinaison de mesures implicites avec des mesures explicites dans l'évaluation des construits de motivation et d'engagement. La plupart des recherches portant leur attention sur l'impact de la gamification sur la motivation et l'engagement des apprenants de langue en ligne utilisent des mesures subjectives et auto-rapportées comme les entrevues et échelles de mesure en guise d'outil principal de collecte de données (Azzouz & Gutierrez-Colon Plana, 2020; Dehghanzadeh et al., 2021; Nur Fitria, 2022). Le caractère subjectif de ces mesures peut limiter la validité et la fiabilité des résultats, car les perceptions des apprenants de leur propre motivation et engagement peuvent ne pas toujours correspondre à leurs états cognitifs et comportementaux réels (Paulhus & Vazire, 2007; Fredricks & McColskey, 2012). Quant aux mesures objectives, comme l'observation du taux de complétion de cours de langues, ces dernières manquent la profondeur requise à établir le portrait d'un phénomène hautement complexe tel l'évolution de l'engagement d'apprentissage à travers le temps. Pour pallier ces limitations, notre étude adopte une approche méthodologique novatrice en combinant des outils de mesure implicites, tels que l'oculométrie et l'électroencéphalographie (EEG), avec des mesures auto rapportée de la motivation d'apprentissage modèle selon motivationnel ARCS de Keller (1987) et la SDT de Ryan et Deci (2000). Cette approche multidimensionnelle vise à capturer de manière plus complète et nuancée les dynamiques motivationnelles et d'engagement des apprenants du naSDLL. En intégrant des données physiologiques objectives avec des mesures auto-rapportées, nous espérons obtenir une compréhension plus approfondie et fiable de l'évolution de la motivation et de l'engagement dans le contexte du naSDLL gamifié.

1.3 Structure du mémoire

Ce mémoire comporte trois chapitres. Le chapitre 1 représente l'introduction du mémoire, alors que le chapitre 4 représente sa conclusion. Considérant le format par articles de ce mémoire, les chapitres 2 et 3 représentent un article méthodologique (article 1) et un article managérial (article 2) respectivement. Cet article a été rédigé dans l'objectif d'être soumis au *International Journal of E- Learning & Distance Education.*

1.3.1 Présentation de l'article 1

Le premier article de ce mémoire se nomme " *"Keep your streak alive": Sustaining non-academic language learners' motivation and engagement through gamification.*" et les co-auteurs sont les suivants : Fateme Kiaei Alamdari, Jared Boasen, Shang Lin Chen, Ana Ortiz de Guinea Lopez de Arana, Constantinos Coursaris, Sylvain Sénécal et Pierre-Majorique Léger. Cet article utilise la collecte de données de l'expérimentation tenue entre mai et septembre 2023. Nous présentons dans cet article la problématique de recherche, une courte revue de littérature, la méthodologie de collecte et d'analyse de données, les résultats desdites analyses ainsi qu'une discussion et conclusion.

1.3.2 Résumé de l'article 1

L'apprentissage non-académique autodirigé des langues (naSDLL) est extrêmement populaire parmi les apprenants adultes. Alors que l'environnement de SDL offre de nombreux avantages, les apprenants ont tendance à souffrir d'une baisse de motivation et d'engagement, ce qui entraîne un taux d'abandon élevé. La gamification s'est révélée prometteuse pour soutenir la motivation et l'engagement, mais les études examinant son impact dans les contextes de naSDLL sont rares. Cette étude examine l'impact de la gamification sur l'expérience d'apprentissage au fil du temps par le biais d'une expérience entre sujets entre des apprenants gamifiés et non gamifiés à l'aide de l'EEG, de l'oculométrie et de données autodéclarées dans le cadre d'une expérimentation d'un mois dans le but d'étudier les mécanismes par lesquels la gamification affecte l'expérience de naSDLL. Nos résultats révèlent des schémas d'activité thêta et alpha significativement plus élevés pendant les tâches d'apprentissage des langues après un mois d'apprentissage gamifié, suggérant une amélioration de l'engagement cognitif, de l'encodage linguistique et de l'efficacité de l'apprentissage pendant les tâches d'apprentissage des langues. Les données de suivi oculaire indiquent un nombre de fixations plus faible pendant les tâches d'apprentissage des langues, ce qui suggère un effort cognitif moins important. Aucune différence significative n'a été observée dans les données relatives à la motivation d'apprentissage autodéclarée. La gamification peut donc contribuer à augmenter l'engagement dans l'apprentissage des langues en naSDLL, mais des recherches supplémentaires dans des environnements de naSDLL sont nécessaires pour délimiter son impact sur la motivation.

1.3.3 Présentation de l'article 2

Le deuxième article de ce mémoire se nomme "*Leaderboards, feedback and personalization: How to keep adult language learners engaged outside the classroom through gamification*" et les co-auteurs sont les suivants : Fateme Kiaei Alamdari, Jared Boasen, Shang Lin Chen, Ana Ortiz de Guinea Lopez de Arana, Constantinos Coursaris, Sylvain Sénécal et Pierre-Majorique Léger. Cet article managérial, destiné aux professionnels de l'industrie d'apprentissage de langues, présente les résultats principaux de notre recherche de manière simplifiée tout en fournissant des recommandations actionnables quant à l'implémentation de la gamification. Nous soulignons l'importance de considérer la dynamique unique du milieu autodirigé non-académique et recommandons d'intégrer des composantes de gamification propices à remédier aux points faibles du SDL. L'article a été rédigé dans l'objectif d'être soumis à la revue *EdTech*.

1.3.4 Résumé de l'article 2

Dans le contexte de l'intérêt croissant pour l'apprentissage autonome non académique des langues (naSDLL), maintenir la motivation et l'engagement de l'apprenant pour éviter qu'ils n'abandonnent reste un défi important afin d'assurer la viabilité économique des plateformes d'apprentissage. Notre étude a exploré l'impact de la gamification sur la motivation et l'engagement des apprenants au cours d'une expérience de naSDLL d'une durée d'un mois. Les résultats révèlent que la gamification peut améliorer des aspects spécifiques de l'engagement tout en discutant des dimensions uniques de la motivation dans les SDLL non académiques. Cet article fournit des recommandations pratiques pour les éducateurs et les concepteurs de plateformes afin de créer des expériences d'apprentissage gamifiées qui favorisent la motivation, l'engagement et l'efficacité de l'apprentissage à long terme pour le public en dehors du cadre académique de l'apprentissage des langues.

1.4 Contributions et responsabilités individuelles

Réaliser son mémoire au Tech3Lab est une opportunité de pouvoir compter sur le soutien d'une équipe de recherche expérimentée en collaborant avec elle à travers diverses étapes de ce périple. Le tableau 1 présente les différentes étapes ayant mené à la réalisation de ce mémoire, ainsi que ma contribution personnelle inscrite en pourcentage.

Tableau 1

Description des étapes, tâches et contribution de l'étudiant au projet de mémoire

Étapes	Tâches et contribution de l'étudiant
Développement de la question de recherche	Identification des lacunes dans la littérature – 80% (soutenu par les directeurs de recherche) Définition de la problématique – 80% (soutenu par les directeurs de recherche) Définition de la question de recherche – 80% (soutenu par les directeurs de recherche)
Revue de littérature	Recherche d'écrits – 100% Lecture et évaluation d'écrits – 100%
Conception de l'expérience	Développement des stimuli – 60% La plateforme expérimentale existait déjà (fournie par le partenaire industriel)

	Création des stimuli expérimentaux en dehors de la plateforme existante
	Développement du protocole expérimental – 75%
	Développement des tâches expérimentales & sélection des mesures (soutenu par l'équipe de recherche)
	Application au comité d'éthique – 75% (soutenu par l'équipe de recherche)
Recrutement des participants	Recrutement – 80%
	Développement du questionnaire de recrutement & de l'affiche (soutenu par l'équipe de recherche)
	Recrutement en personne et virtuel
	Gestion de l'horaire des sessions d'expérimentation
Prétests et collecte de données	Gestion des prétests et sessions d'expérimentation – 80% (soutenu par l'équipe de recherche)
Analyse de données	Extraction des données – 80% (soutenu par l'équipe de recherche)

	Nettoyage et pré-traitement des données – 100%
	Analyse des données – 65%
	Le statisticien et l'équipe de recherche se sont occupés d'une partie significative de l'analyse de données.
	Interprétation des données – 100%
	Écriture du mémoire – 100%
Écriture du mémoire	Écriture de l'article 1 – 100%
	Écriture de l'article 2 – 100%

Chapitre 2 : Article 1
"Keep your streak alive": Sustaining non-academic language learners' motivation and engagement through gamification.

Rémy El-Nemr[1], Fateme Kiaei Alamdari[1,2], Jared Boasen[1,4], Shang Lin Chen[1,2], Ana Ortiz de Guinea Lopez de Arana[2], Constantinos Coursaris[1,2], Sylvain Sénécal[1,3] and Pierre-Majorique Léger[1,2]

[1] Tech3Lab, HEC Montréal, Montréal, Québec, Canada
[2] Department of Information Technologies, HEC Montréal, Montréal, Québec, Canada
[3] Department of Marketing, HEC Montréal, Montréal, Québec, Canada
[4] Faculty of Health Sciences, Hokkaido University, Sapporo, Japan

Abstract. Non-academic self-directed language learning (naSDLL) is wildly popular among adult learners. As the self-directed learning (SDL) environment offers numerous advantages, learners tend to suffer from declining motivation and engagement, leading to high abandon rates. Gamification has shown promise in sustaining motivation and engagement, which is key to prevent attrition, but studies examining its impacts in naSDLL contexts are scarce. This study investigates the impact of gamification on the learning experience over time through a between-subjects experiment between gamified and non-gamified learners through EEG, eye tracking and self-reported data through a mixed-methods longitudinal design to investigate the mechanisms by which gamification affects the non-academic language learning experience. Our findings reveal significantly higher theta & alpha brain activity patterns during language learning tasks after a month of gamified learning, suggesting enhanced cognitive engagement, linguistic encoding and learning efficiency during language learning tasks. Eye tracking data indicates a lower fixation count during language learning tasks, suggesting lower required cognitive effort. No significant differences were observed in the self-reported learning motivation data. Gamification can thus help increase language learning engagement in naSDLL, but further research accounting for the unique dynamics of the naSDLL environment is required to delineate its impact on motivation.

Keywords: Gamification, non-academic language learning, self-directed learning, EEG, eye tracking, rIMMS, IMI

2.2 Introduction

Millions start learning a language on their own every day. Online language learning platforms have experienced significant growth in recent years, with industry leaders like Duolingo hundreds of millions of registered users, mainly thanks to their convenience, accessibility and lack of social pressure from instructors. Despite the welcome respite from the traditional classroom, self-directed language lessons providers consistently grapple with high attrition rates (Nielson, 2011; Barcena et al. 2015; Fuchs 2017), a challenge common to various topics such as programming, mathematics, linguistics and technology (Park & Choi, 2009; Reich & Ruipérez-Valiente, 2019; Narayanasamy & Elçi, 2020). Abandon rates of self-directed learning (SDL) courses gravitates around 90% (Eriksson et al., 2017; Hew & Cheung, 2014; Xing & Du, 2018), outlining the necessity to keep learners engaged through time. Past research has attempted to elucidate reasons for the high number of learners abandoning their journey and has listed several key persistence factors leading to SDL sustained success, chief among them being motivation.

Known as the commanding drive behind learning at all walks of life and in various educational contexts, researchers have long since confirmed motivation's crucial role in language acquisition (Dörnyei, 1998 ; Masgoret & Gardner, 2003; Humaida, 2012) & have recently confirmed its relationship to learners' persistent engagement within self-directed language learning (SDLL) (Song & Bonk, 2016; Lamb & Arisandy, 2020; Toffoli et al., 2023). On the flipside, continued engagement in online language learning is endangered by demotivating factors, most notably the isolated nature of SDL (Ryan & Deci, 2000; Hartnett, 2016; Wang et al., 2023) along the lack of agency towards non-academic language activities compared to academic contexts (Lyrigkou, 2019).

Accordingly, providers and researchers alike have dived into factors to keep learners engaged and have increasingly turned to gamification - the application of game-like elements to non-game environments (Deterding et al., 2011) - as it has proven promising in sustaining learner engagement and motivation. Gamification components such as leaderboards, rewards and personalization have a positive effect over learner engagement and motivation (Hamari et al., 2014; Koivisto & Hamari, 2019), with a dominant focus over its use in the academic context of schools and universities (Poondej & Lerdpornkulrat, 2019; Saleem et al., 2022). In these educational settings, gamification's impact over motivation and engagement in second-language acquisition (SLA) is generally positive (Dehghanzadeh et al., 2021; Kaya & Sagnak, 2022). While these are promising avenues, current gamification research in SLA has neglected the non-academic environment in favor of formal supervised learning environments, such as traditional classrooms, blended learning and online university courses (Muthmainnah et al., 2023; Dehghanzadeh et al., 2021). Gamification's impact has not yet been measured in the truly self-directed, non-academic learning environment, indicating an important lack in the literature.

Additionally, the current literature has failed to establish solid correlations between gamification, motivation and cognitive processes (Azzouz & Gutierrez-Colon Plana, 2020). Indeed, gamification's impact over motivation & engagement in language learning research has thus far been mostly limited to measures such as success rates, surveys, interviews and behavioral metrics (Azzouz & Gutierrez-Colon Plana, 2020; Dehghanzadeh et al., 2021; Nur Fitria, 2022), neglecting objective measures of gamification's impact on underlying cognitive processes related to in sustained engagement over time. Beyond the self-reported metrics employed in most of the gamification research, incorporating physiological measures such as eye-tracking and neuroimaging can provide deeper insights into learner engagement. Indeed, while engagement in learning task is generally associated with distinct brain activity patterns in theta, alpha and beta waves (Papanicolaou et al., 1986; Berka et al., 2007; Crivelli-Decker et al., 2018) and eye tracking data (Godfroid et al., 2020; Wang et al., 2021), the current measures of gamification's impact in learning contexts demonstrate a lack of in-the-moment, live measures of engagement.

This study attempts to bridge these gaps by assessing the impact of gamification on the evolution of adult learners' motivation and engagement in naSDLL, with the aim of combining objective measures of engagement to self-reported measures of motivation. Using Keller's motivational ARCS model, Ryan and Deci's SDT to measure motivation & physiological and behavioral measures of engagement, we present in this paper the results of a longitudinal experiment regarding the impact of leaderboard, feedback and personalization on the evolution of adult learners' engagement and motivation outside the academic learning context. This study seeks to answer the following research question:

RQ: **"**To what extent does gamification of the learning experience impact adult learners' learning motivation and engagement in a self-directed informal online language learning experience?"

We hypothesize that language learners will be more motivated and engaged throughout a gamified learning experience spread out over time. The impact of various gamification components will be evaluated through a combination of explicit and implicit measures to decompose gamification's key motivational and engagement mechanisms.

The following sections of this methodological article are as follows: In the background literature section, we present a brief history of SLA motivation, engagement and gamification in language learning. In the methods section, we describe our experimental design, recruitment process, participant profile, our longitudinal experimental protocol, our measures and analysis of longitudinal data. In the Results section, we provide statistical analyses regarding motivation & engagement data over time, including brain & eye gaze activity for engagement and self-report data for motivation. We present the implications of our results in Discussion and how they relate to existing literature, as well as theoretical, conceptual and practical contributions. We conclude this paper by reminding the research objective and our main findings, the main limitations of this research as well as potential avenues for future research.

2.2 Background literature

2.2.1 Motivation & demotivation in language learning

SLA researchers agree that motivation is one of the most important factors determining successful learning success (Gardner & Lambert, 1959; Dörnyei, 1998; Humaida, 2012; Zhang et al., 2020). Motivation is generally described as a complex, multifaceted concept (Zareian & Jodaei, 2015). Past SLA research has described motivation in accordance to two components: 1) motivation towards learning a language (Gardner, 2007), being the affective disposition to learn a language concentrating on integrative / intrinsic motivation (motivated by a genuine interest for the culture and speakers) and instrumental / extrinsic motivation (motivated by practical / material benefits) (Gardner, 2000; Zareian & Jodaei, 2015) and 2) classroom motivation, being the motivation towards the classroom or learning environment, which is influenced by factors inherent to the language class, such as teacher-student interactions, adequacy of learning materials and curriculum (Clément et al., 1994; Gardner, 2007; Dörnyei & Muir, 2019). Gardner (2007) argues that both integrativeness (learning a language out of genuine interest) and attitudes towards the learning situation (all factors related to the educational system, namely the immediate classroom setting) greatly impact motivation in SLA.

Language learning and classroom motivations are dynamic, ever evolving and fluctuating depending on learners' individual context (Waninge et al., 2014; Farahani & A. Rezaee, 2019). Throughout a learner's journey, personal factors (such as declining interest and busy schedules) impacting language learning motivation as well as classroom-related factors (such as low learning materials quality, isolation and inappropriate teaching style) impacting classroom motivation can lead learners to demotivation over time (Dörnyei, 1998; Kim, 2021; Ojong, 2024). In turn, demotivated learners become less engaged in classroom activities and discussions, which can have a negative impact on their learning progress (Wang & Guan, 2020). As demotivated learners become disengaged, they are less likely to participate actively, ask questions, or seek clarification, leading to gaps in their understanding of the language, resulting in a decline in language proficiency and overall academic performance (Falout et al., 2009; Hu, 2011). Furthermore, demotivated learners may experience reduced confidence in their language abilities, potentially leading to increased anxiety and a reluctance to use the target language in key acquisition activities such as communicative situations (Falout & Maruyama, 2004).

Numerous additional demotivating factors proper to the SDL environment impact language learning and classroom motivations over time, which ultimately reduces learner engagement. The absence of a supervised, external structure and SDL's isolated nature can make it challenging for learners to remain motivated over time (White, 2008; Cheng & Lee, 2018; Sun, 2014). Demotivated SDLL learners frequently report difficulties remaining engaged and committed to learning schedules (Cheng & Lee, 2018). The absence of teacher feedback and supervision in SDL, typically a key factor in fostering motivation and autonomy in traditional language learning (Ly, 2024), negatively impacts learning motivation (Vaičiūnienė & Kazlauskienė, 2023). In turn, demotivated language learners may showcase decreased persistence in their language learning efforts, reduced frequency of study sessions, and diminished intensity of engagement during learning activities (Cheng & Lee, 2018; Sun, 2014). It is crucial for naSDLL providers and researchers to investigate the dynamics of motivation, including its evolution and decline, as well as strategies to sustain motivation towards both the language learning process and towards the SDL learning environment.

2.2.2 Motivating learners through gamification

Gamification is defined as the use of video game elements in non-game environments (Deterding et al., 2011). Popular gamification components in language learning contexts include feedback, leaderboards, achievements/badges, levels, feedback, rewards, and goal setting (Dehganzadeh & Dehganzadeh, 2020; Luo, 2023; Wulantari et al., 2023). The implementation of gamification components has risen in popularity in recent years and has shown promise in sustaining motivation and engagement in online language learning settings, with favorable results at elementary, high school, and higher education levels (Dehghanzadeh et al., 2020; Kaya & Sagnak, 2022).

The popularity of gamification in the language learning context can be observed in platforms such as Duolingo, where learning a language is made interactive, enjoyable and competitive through the integration of various gamification components, namely leaderboards, feedback on performance, daily streaks, points and cultivating a sense of community (Shortt et al., 2023). Similarly, gamification components such as feedback, leaderboards, competition and personalization are frequently used in formal academic contexts, where the usage of gamified learning environments serves either as the main learning medium or as complementary learning materials (Dehghanzadeh et al., 2020). It is noteworthy to outline that the use of such gamification components primarily occurs in formal language learning environments (Muthmainnah et al., 2023; Dehghanzadeh et al., 2021).

While gamification seems promising at a first glance, specific gamification components can lead to different motivational outcomes (Sailer et al., 2017). To adequately address gamification’s motivating nature, past research has sought to decompose its impact on key language learning motivational dimensions. Gamification’s impact over language learning motivation is frequently studied in accordance with the Self-Determination Theory (SDT), which posits that intrinsic motivation is fostered when the following universal needs are met: autonomy (feeling in control of one’s learning process), competence (feeling capable of accomplishment) and relatedness (feeling connected to others) (Ryan & Deci, 2000). As SLA researchers argue that intrinsic motivation is primordial to language acquisition, as it leads to higher-quality learning, creativity, and persistence in language learning efforts (Dörnyei, 2005; Noels et al., 2000), gamification components can increase intrinsic motivation in language learning contexts by fulfilling these needs (Boudadi & Gutiérrez-Colón, 2020; Daliranfirouz et al., 2024; Shen et al., 2024).

Gamification can also increase motivation towards the classroom environment. This motivating impact has been researched in a variety of online learning contexts in accordance with the ARCS motivational design model (Keller, 1987), which theorizes that, to motivate learners, learning platforms must capture learner's interest (Attention), align with the learner's goals and needs (Relevance), build learner's belief in their abilities (Confidence) and make learners feel a sense of reward and fulfillment (Satisfaction) (Keller, 1987). Gamification components can increase classroom motivation by improving SDL platforms according to the ARCS model: leaderboards and badges capture learner attention (Sailer et al., 2017), personalized learning paths enhance learners' perceptions of relevance (Dichev & Dicheva, 2017), progressive difficulty levels foster confidence, and rewards following exercise completion reinforce learners' satisfaction (Koivisto & Hamari, 2019). Gamification components can thus mitigate language classroom demotivation inherent to the SDL environment by making it more captivating and compensate for the absence of instructor supervision.

2.2.3 Measures of motivation & engagement

Psychometric questionnaires are popular tools to measure motivation in gamified contexts (Almufareh, 2021; Cook & Skrupky, 2024; Ishaq et al., 2021; Ratinho & Martins, 2023). Researchers often measure learning motivation in accordance with Self-Determination Theory (SDT) and the ARCS model. Two widely used instruments are the Intrinsic Motivation Inventory (IMI) (Ryan et al., 1983) and the Instructional Materials Motivation Survey (IMMS) (Keller, 2010). The IMI has been reported to reliably measure gamified learners' intrinsic motivation, allowing researchers to select specific subscales of interest (Alahmari, 2021; Daliranfirouz et al., 2024; Shah et al., 2021; Shen et al., 2024). The IMMS, designed specifically for self-directed learning environments, has proven particularly useful in measuring gamification's impact on the

ARCS motivational dimensions (Huang & Hew, 2016; Li & Moore, 2018; Camacho-Sánchez et al., 2023).

Learning engagement is often measured through interviews, self-reported entries (Le, 2020; Korkealehto & Siklander, 2018), questionnaires (Korkealehto & Siklander, 2018; Qiao et al., 2023; Zhang, 2024). Quantitative measures of engagement frequently reprise Fredricks et al. (2004) behavioral (participation in academic, social, and extracurricular activities) & cognitive engagement (psychological investment in learning and mastery of skills) by measuring interactions with learning platforms (Yan et al., 2019; Taşkın & Kılıç Çakmak, 2023) and learning performance scores (Huang et al., 2019; Ardi & Rianita, 2022; Ariani & Afnita, 2024).

While these measures may provide valuable insights, they also present important limitations. Self-reported motivation measures are subject to various biases that may prevent participants from accurately sharing their true motivational state (Revzina, 2008; Fulmer & Frijters, 2009; Paulhus & Vazire, 2007; Fredricks & McColskey, 2012). As for engagement, as learners can be behaviorally engaged but cognitively unengaged (Li & Baker, 2016), current gamification research fails to accurately measure cognitive engagement (Silpasuwanchai et al., 2016), corresponding it instead to self-reported data and behavioral metrics (Looyestyn et al., 2017; Lumsden et al., 2016; Vermeir et al., 2020). The impact of gamification components on cognitive processes in SLA is not sufficiently supported empirically (Boudadi & Gutiérrez-Colón, 2020), highlighting the need for more objective measures of engagement in gamification research.

2.2.4 Neurophysiological measures of engagement

Neurophysiological measures can offer more objective indicators of cognitive engagement than self-reported and observational data. Popular neurophysiological measures in language learning contexts include electroencephalography (EEG), eyetracking, skin conductance and heart rate (Darvishi et al., 2022).

EEG has emerged as a reliable tool for quantifying attention and engagement levels during learning tasks (Berka et al., 2007; Klimesch, 2012). Cognitive engagement can be investigated through theta (4-8 Hz), alpha (8-12 Hz), and beta (15-29 Hz) oscillations. Increased theta power, particularly in frontal and fronto-medial regions, has been associated with sustained attention, working memory capacity, and successful encoding of new information, including lexical-semantic retrieval in language tasks (Cavanagh & Frank, 2014; Piai et al., 2016). Alpha oscillations have been shown to play a role in protecting against interference during information retention and in top-down control processes essential for language comprehension (Clayton et al., 2018; Klimesch et al., 1999; Bonnefond & Jensen, 2012). Beta oscillations have been correlated with enhanced cognitive processing, task engagement, and improved memory performance in learning contexts (Engel & Fries, 2010; Weiss & Mueller, 2012), with increased beta power in fronto-central regions, indicating higher levels of engagement during online learning tasks (Al-Nafjan & Aldayel, 2022). The measure of learners' engagement through EEG in gamified environments is growing: Derbali and Frasson (2010) investigated players' motivation during serious game play (a gamified learning environment) and found significant correlations between theta & beta waves and motivation through higher attention. Takács (2023) observed increased theta and alpha waves related to increased engagement in gamified learning and Scharinger et al. (2023) observed increased right parietal theta activity in gamified tasks that required more concentration. Examining changes in theta, alpha and beta brain activity can thus provide valuable insights into engagement during gamified language learning activities.

Eye tracking has also emerged as a valuable tool for measuring engagement through visual processing in learning contexts, offering insights into visual attention, cognitive load, and information processing (Lai et al., 2013; Jarodzka et al., 2017). This technology captures various eye movement metrics, including fixations, saccades, and pupil dilation, which can be indicative of learners' engagement and attention during learning tasks. Visual attention can be categorized into two main types: ambient and focal (Krejtz et al., 2016). Ambient attention involves a scanning pattern across stimuli, characterized by brief fixations and longer saccades. Conversely, focal attention is marked by longer fixations and shorter saccades, reflecting a more detailed and concentrated processing of stimuli (Krejtz et al., 2016). It is thus of interest to evaluate learners' visual attention. Fixation count (the number of times one's gaze is focused on a specific area of interest) and duration (the length of time one's gaze remains fixated) are particularly informative measures of engagement, as higher fixation counts and longer durations are generally associated with increased attention and deeper cognitive processing (Negi & Mitra, 2020; Godfroid et al., 2013; Rayner, 2009). Similarly, the k-coefficient has been used to evaluate engagement in learning contexts by quantifying the ratio between fixation duration and saccade amplitude. Negative k-coefficient values indicate ambient processing (shorter fixations followed by longer saccades), while positive values suggest focal processing (longer fixations followed by shorter saccades), providing insights into learners' attentional states and cognitive engagement (Krejtz et al., 2016). These eye tracking measures can provide valuable insights into learners' engagement with gamified environments by outlining how much visual attention each gamification component is getting.

2.3 Hypothesis development

In this study, we sought to measure and compare the evolution of language learners' motivation and engagement of two groups of learners tasked with learning at home on an online interface: The gamified group, subjected to recurrent gamification components (Feedback, leaderboard, customization), and the control group who were not exposed to gamification components. Therefore, nine hypotheses were proposed from the theoretical foundation described in this section further below to examine the impact of the gamification of the naSDLL learning environment on motivation and engagement. The proposed research model of this study is presented in Figure 1.

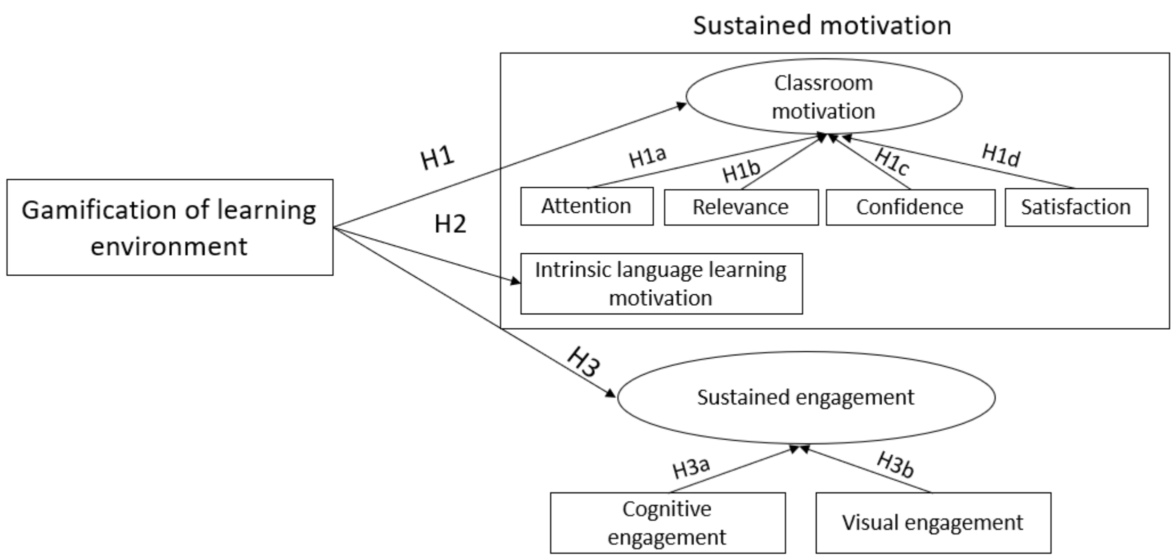


Figure 1. Proposed research model of this study.

As previously stated, SDL learners typically face important demotivating factors related to both personal and learning environment factors. These factors impact motivation towards learning a language and motivation towards the learning environment. Demotivation ultimately leads to disengagement from the learning process, with less interactions with the SDL platform and lower performance scores. To remediate this projected drop in motivation and engagement, we hypothesize the implementation of gamification components within the naSDLL experience can positively impact learners by sustaining motivation and engagement.

Firstly, we hypothesize that the gamification of the naSDLL environment can lead to increased classroom motivation (reflected by higher rIMMS scores of Attention, Relevance, Confidence and Satisfaction), with a durable effect through time:

H1: *Participants will present higher levels of classroom motivation throughout a month of naSDLL in a gamified learning environment than those after a month of naSDLL in a non-gamified learning environment.*

As we conceptualize classroom motivation in accordance with the ARCS model, we formulate the following hypotheses as to the impact of the gamified learning environment over its dimensions:

H1a: *Participants will present higher levels of attention throughout a month of naSDLL in a gamified learning environment than those in a non-gamified naSDLL learning environment.*

H1b: *Participants will present higher levels of relevance throughout a month of naSDLL in a gamified learning environment than those in a non-gamified naSDLL learning environment.*

H1c: *Participants will present higher levels of confidence throughout a month of naSDLL in a gamified learning environment than those in a non-gamified naSDLL learning environment.*

H1d: *Participants will present higher levels of satisfaction throughout a month of naSDLL in a gamified learning environment than those in a non-gamified naSDLL learning environment.*

Secondly, we hypothesize that the gamification of the naSDLL environment can lead to increased intrinsic language learning motivation:

H2: *Participants will present higher levels of intrinsic language learning motivation throughout a month of naSDLL in a gamified learning environment than those after a month of naSDLL in a non-gamified learning environment.*

Thirdly, we hypothesize that gamification components in naSDLL can lead to increased engagement after a month of gamified SDLL, reflected by 1) heightened cognitive engagement, translated by higher overall theta, alpha & beta oscillations and 2) heightened visual engagement, translated by higher fixation count, duration and k-coefficient during language learning tasks. We thus formulate the following hypotheses in relation to engagement:

H3: *Participants will present higher levels of engagement during language learning tasks after a month of naSDLL in a gamified learning environment than those after a month of naSDLL in a non-gamified learning environment.*

H3a: *Participants will present higher levels of cognitive engagement after a month of naSDLL in a gamified learning environment than those after a month of naSDLL in a non-gamified learning environment.*

H3b: *Participants will present higher levels of visual engagement after a month of naSDLL in a gamified learning environment than those after a month of naSDLL in a non-gamified learning environment.*

2.4 Methodology

The purpose of this study was to examine the longitudinal effect of gamification components in SDLL on the motivation and engagement of language learners. Thus, a longitudinal experiment was conducted to test the above hypotheses. The corresponding methodology is described in detail immediately below.

2.4.1 Experimental design

We implemented a longitudinal multimethod model with tasks carried out in both laboratory and natural settings, and was divided into 3 phases: Phase 1, Interim phase and Phase 2. Data collection occurred from early-July to mid-September 2023 in participant-specific cycles of 4 weeks. This cycle would start with the participants' first in-person experiment (Phase 1), in which they were tasked to complete usability and language learning tasks on a language learning interface. During these tasks, participants' brain activity and eye gaze data was collected. It is at the end of this 1st experiment that participants were sorted in the experimental or control groups. After this 1st visit, participants were tasked to complete learning exercises on the same language learning interface at home for 4 weeks (Interim). At the end of each week of learning at home, participants received an email instructing them to complete a questionnaire which served to measure their motivational state, as well as instructions for the upcoming week. The contents of this weekly e-mail represented the experimental manipulation. At the end of the 4 weeks, participants were invited to the second in-person experiment (Phase 2) which was experimentally identical to the first experiment a month prior, except for slightly different task content.

Figure 2 provides a visual representation to illustrate the succession of the 3 phases, including the main data collection methods employed. In the subsequent sections, we provide an overview of the experimental stimuli participants were exposed to throughout these 3 phases.

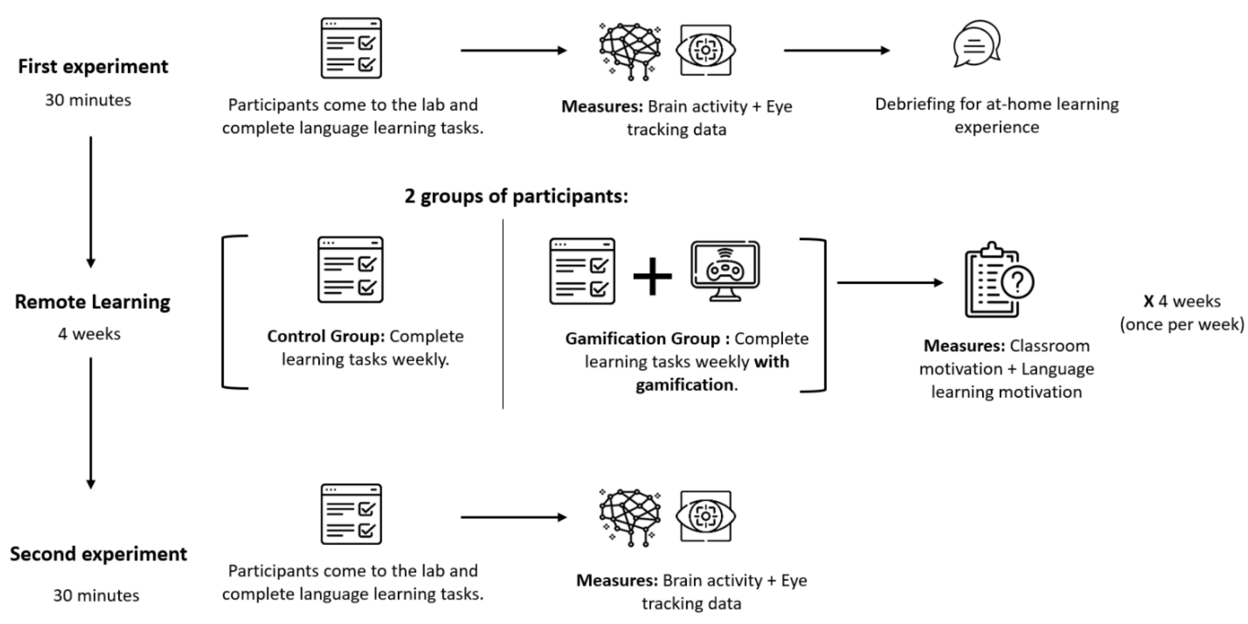


Figure 2. The research project's overall timeline decomposed into 3 phases: Phase 1, which corresponds to the first experiment, Remote Learning which corresponds to the at-home learning

portion of the research, and Second experiment, which corresponds to the final in-person data collection.

2.4.2 Participants

Our initial target group consisted of adults interested in improving their French language skills, with specific criteria to ensure an authentic learning experience. We specifically recruited participants at the beginner level in French to ensure meaningful engagement with the learning materials and interface. Since the e-learning interface and instructions were in English, proficiency in English was required, as second language acquisition research indicates the importance of advanced competency in the language of instruction (Ellis, 2015; Macaro et al., 2018). Exclusion criteria consisted of a history of psychological or psychiatric illness, use of glasses or contact lenses, dermatological conditions, or epilepsy, as these conditions can interfere with the quality of data collected (Luck, 2014; Holmqvist et al., 2011). An in-depth recruitment questionnaire was created to qualify eligible participants and hosted on the Qualtrics survey platform (Qualtrics, Provo, UT). In it, inclusion criteria described above were measured through yes-no questions, except for language competency levels. English and French proficiency were evaluated using the Common European Framework of Reference for Languages (CEFR) self-assessment grid (Council of Europe, 2020). The CEFR “defines six common reference levels (A1, A2, B1, B2, C1, C2), using “can do” descriptors to define the learner/user’s proficiency at each level.” (Council of Europe, 2020). Potential participants rated their English and French abilities across five categories: Listening, Reading, Spoken Interaction, Spoken Production, and Writing. The research team decided to exclude participants with an English level below B2 for English and above A2 for French on each scale to ensure adequate linguistic competency for an authentic learning experience.

The total compensation for this study was CAD 170, with CAD 50 for the 1st visit, CAD 10 for each week participants completed the learning tasks at home and CAD 80 for the 2nd visit. This compensation was identical for both the experimental and control group. This study was approved by the ethical review board of HEC Montréal (2023-5394).

Recruitment efforts included in-person recruitment at strategic locations like English-speaking university entrances and subway stations. Additionally, we printed posters in downtown Montreal and outwardly focused on publicizing the screening questionnaire through social media and community services for newly arrived immigrants. Our varied recruitment methods allowed us to reach 269 potentially eligible participants, of which 57 participants were recruited. 37 right-handed participants (Males = 20, Females = 17) between 21 and 40 years old (M ± SD: 27.70 ± 5.15 years) signed up for the first in-person experiment. While participants represented diverse professional backgrounds, the majority had completed or were pursuing university-level education. 6 participants dropped out of the experiment during the Interim phase, leaving us with 31 participants.

2.4.3 Procedure

2.4.3.1 First in-person experiment

Participants joined the research team at a laboratory dedicated to this research project. This session began with the collection of written and informed consent, followed by the measurement of participants' head sizes in preparation for the EEG cap. Participants were fitted with an appropriately sized EEG cap (EASYCAP, BrainProducts GmbH, Munich, Germany), equipped with a 32-ch electrode bundle (actiCAP, BrainProducts GmbH, Munich, Germany) adhering to the 32ch Standard Cap layout for actiCAP. The EEG bundle was then connected to the actiCHAMP plus amplifier and recording software (BrainVision Recorder, BrainProducts GmbH, Munich, Germany), with electrode gel applied and impedance checks conducted as per the manufacturer's guidelines. After conducting a final assessment of EEG data quality, the EEG recording was launched. The research team initiated the Observer/MediaRecorder softwares (Noldus, Leesburg, VA, United States) which triggered the start of synchronization between the data collection tools described previously, as well as a video recording of the participant’s face. A 90-second calibration period, during which participants fixated on a white cross at the screen's center, enabled the collection of baseline physiological activity data. To ensure precise synchronization of recorded psychophysiological data, we used the SyncBox hardware solution (Noldus Information

Technology BV, Wageningen, Netherlands). This device was connected via cables to all computers that recorded data, transmitting a TTL (Transistor-Transistor Logic) signal at regular 60-second intervals throughout the entire experiment. These TTL signals were uniformly received and interpreted by the data collection tools as event markers. For each participant, these synchronization markers were stored within a file in The Observer XT 11 (Noldus Information Technology BV, Wageningen, Netherlands). Once the Observer recording was launched, the research team proceeded with calibration of the eyetracker: the Tobii Pro Lab (Tobii AB, Danderyd, Sweden) eye tracker was calibrated with a 9-point calibration. The research team made sure to mark the start and end of the Tobii calibration to ensure the delay between the BrainVision and Tobii markers could be easily calculated in case the EEG data markers proved to be inaccurate. Once this calibration was completed, the screen recording through Tobii Pro Lab was initiated and the research team provided instructions for participants to start the experiment. A Qualtrics page was opened on the participant's computer, prompting them to enter their participant identification information which was provided by the research team.

Participants were asked to engage in a series of five tasks on a language learning interface, which the research team opened and closed at the start and end of each given task: Logging in to the e-learning interface and completing initial trials of a learning activity in Module 1 (Task 1), locating information on full-time and part-time programs within the interface's FAQ section (Task 2), identifying noun gender rules in the references section (Task 3), navigating from the references page to a learning activity in Module 1 and completing its initial trials (Task 4) and determining the time spent on a learning activity in Module 1 (Task 5). The interface in question was a live version of an existing language learning course provider. We present the interface and language learning tasks participants navigated during the experiment on figures 3-6 to provide visibility to the experimental stimuli used.

Table 1. Description of tasks during the 1st in-person experiment

Task	Type	Task instructions
Task 1	Navigation + Language learning	Go to Module 1 to complete the *Sont-ils possessifs?* learning activity (Module 1, Unit 4).
Task 2	Navigation	You would like to know how much time weekly you should invest in learning for each program.
Task 3	Navigation	You need to study noun gender rules.
Task 4	Navigation + Language learning	Go to Module 1 to complete *Quelle est votre réponse?* learning activity (Module 1, Unit 5).
Task 5	Navigation	You would like to know how much time you've spent on Activity *Sont-ils possessifs* of Module 1.

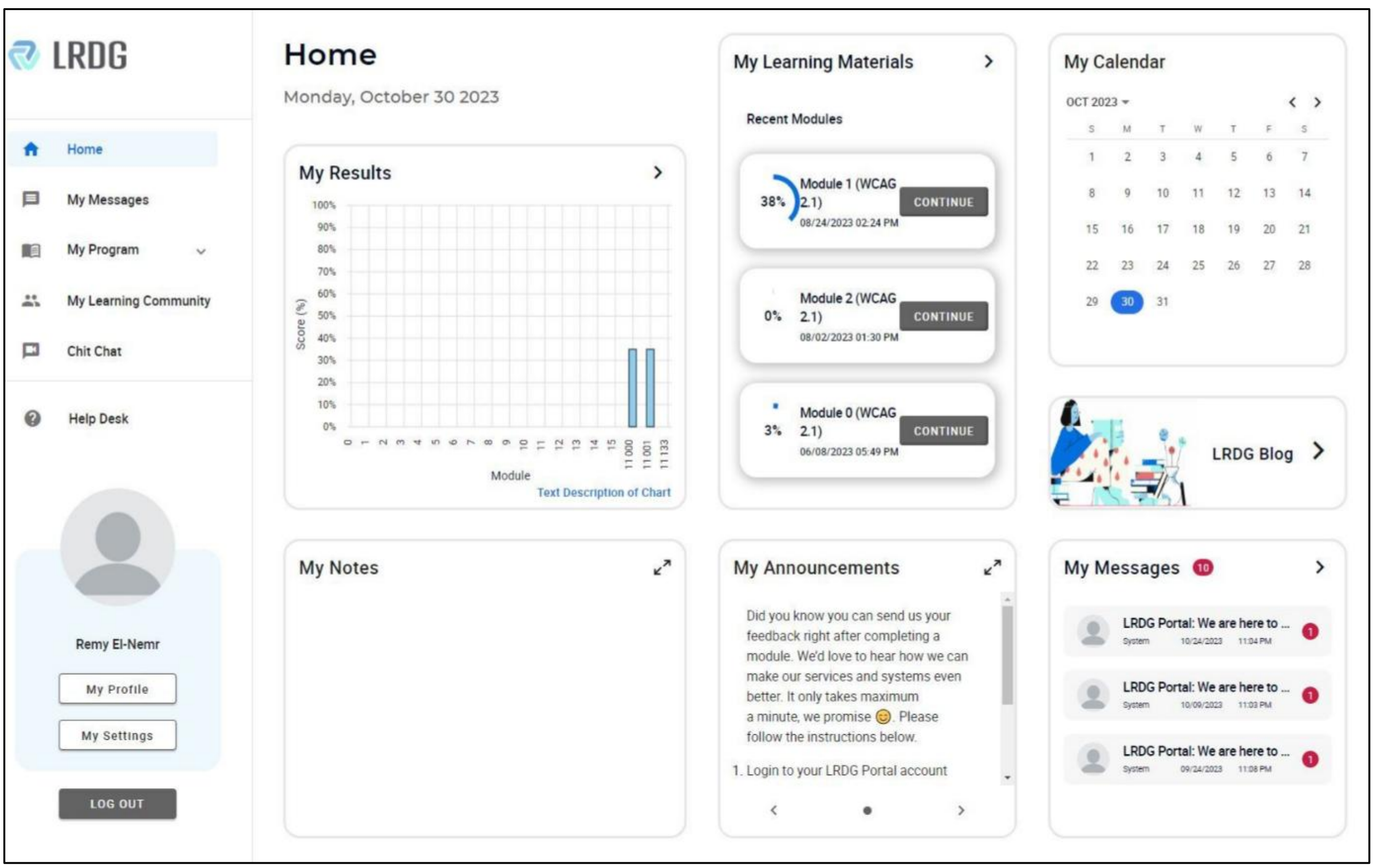


Figure 3. Dashboard of the language learning interface used by participants, giving access to various sections of the learning platform. A test account is logged into the portal, exhibiting the home page of the interface participants accessed repeatedly during in-person visits & remote learning.

Figure 4. Module 1 of the language learning interface in which participants were tasked to complete 2 language learning tasks (Task 1 & Task 4). The figure showcases the main learning module participants were asked to access throughout the research projects' phases.

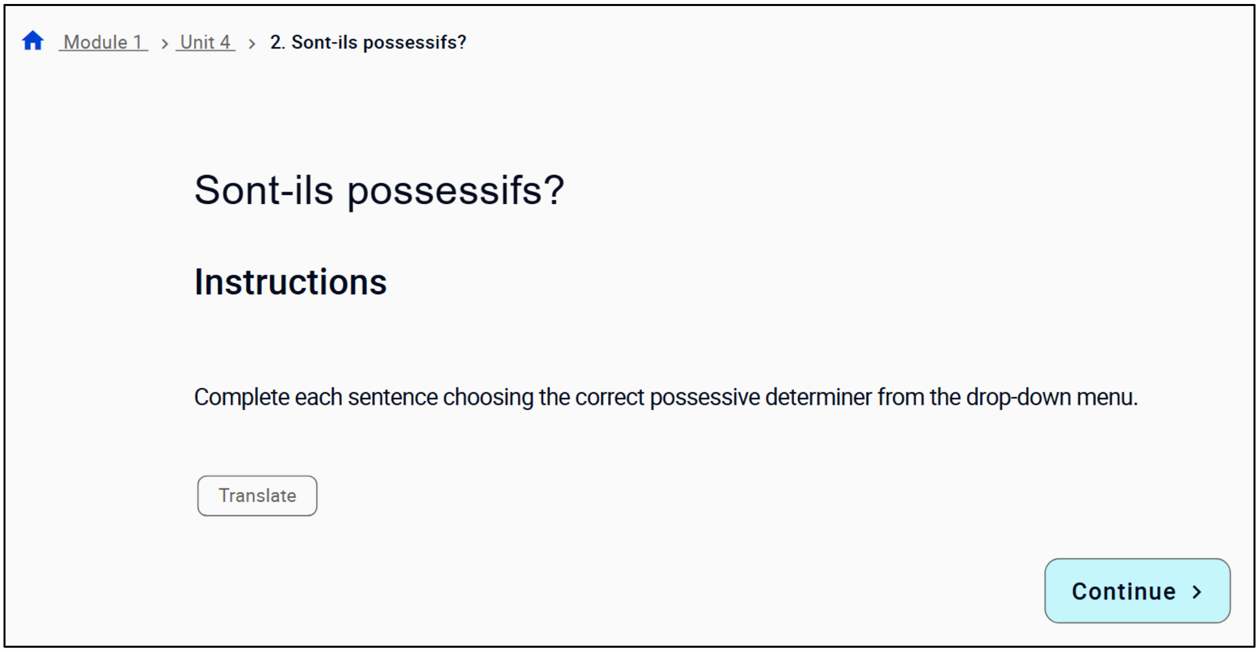


Figure 5. Instructions of one of the language learning activities (Task 1 in Table 1) participants were tasked to complete, during which their brain and eye gaze activity was measured.

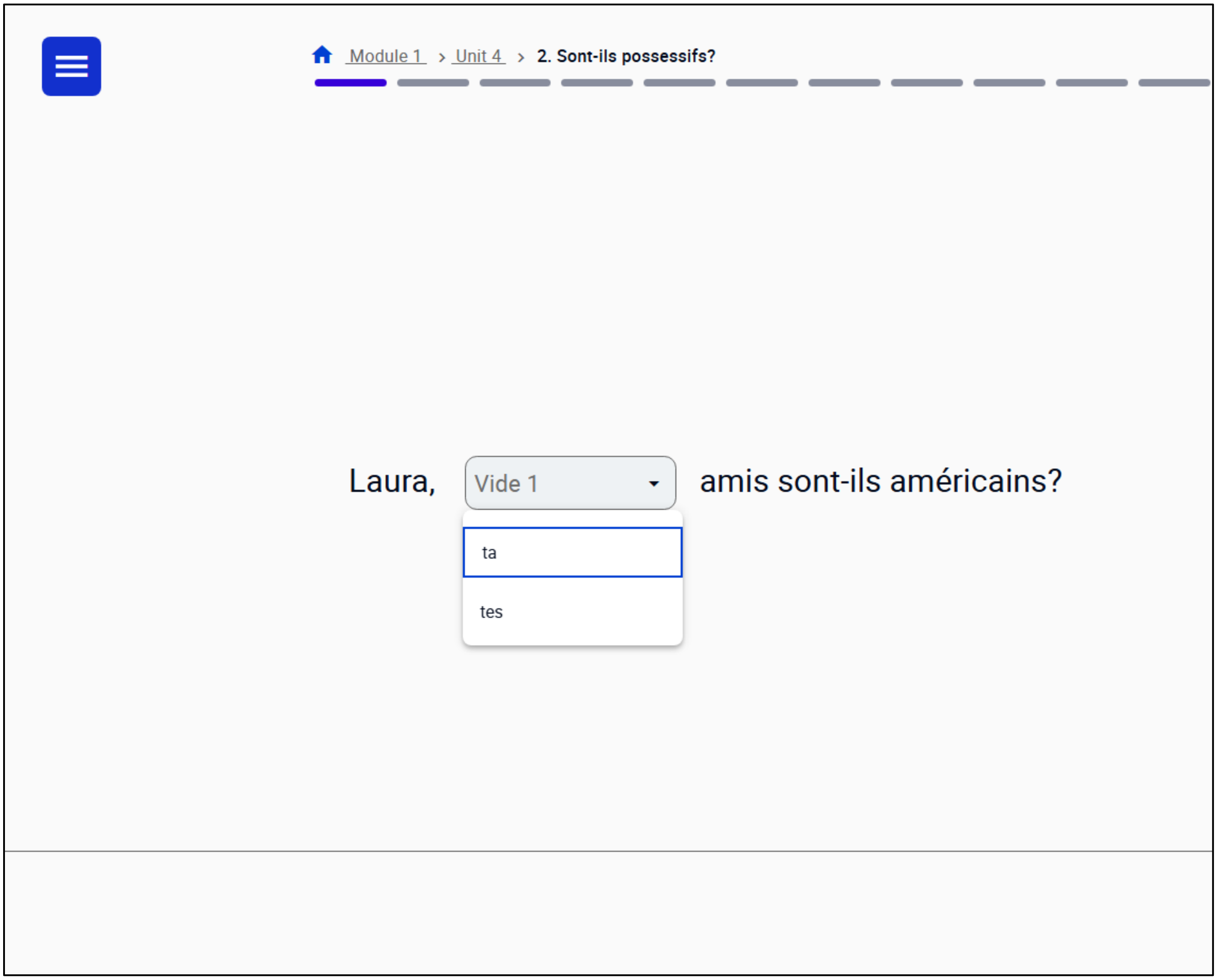


Figure 6. A trial of one of the language learning activities (Task 1) participants were tasked with completing. In this task (2nd activity of Unit 4 in Module 1), participants had to select the correct answer depending on their comprehension of the sentence, check whether their answer was correct and move on to the next task.

Questionnaire items were administered after each task, namely perceived effort measured with the Customer Effort Scale (CES) (Dixon et al., 2010) and perceived arousal and pleasure, measured with the Affective Slider (Betella & Verschure, 2016). The experiment was concluded with a usability questionnaire and a 15-minute user interview, during which the research team aimed to gain insights into participants' initial perceptions of the learning interface. These measures were meant for a third-party usability project in partnership with LRDG but were of no particular interest to the academic research project accomplished.

Upon the completion of all tasks, the research team concluded the session, saved all collected data, and removed the psychophysiological collection tools from the participant's head and hand. At this point, the research team debriefed participants using a script and an iPad to explain the remote experiment to come, which spanned four weeks. This experiment involved completing weekly learning activities according to a designated learning plan on the same e-learning interface used during the initial in-person visit. Participants also completed a questionnaire at the end of each week to provide feedback on their weekly experiences.

It is during the debriefing that differences between our control and experimental groups were introduced. Participants in the control group were informed they would receive a standard learning plan on a weekly basis, outlining the tasks to complete for each given week as well as a questionnaire at the end of each week (Figure 7).

You will be asked to complete learning tasks in LRDG's Module 1 over the course of 4 weeks on the interface you've used today. The learning tasks will take, at most, 2-3 hours weekly to complete.

You must follow the learning plan we send you each week by e-mail and fill in the questionnaire at the end of each week. **Here is an overview of the learning plan you will receive weekly** (*this is an example, you will receive the actual learning plan by e-mail shortly*) :

Unit 1	Vidéo complète du dialogue	« A » – « Z »	Comptez là-dessus!	En tout genre! (Partie 1)	L'article est déterminant
Unit 2	Dialogue scène 1	Habiter	Nous, les pronoms	Contractons! (Partie 1)	

Figure 7. Debriefing screen shown to participants in the control group on an iPad. In it, participants are shown the learning plan for the 1st week of at-home learning with text instructions, while the research team verbally provided in-depth explanations. The activities in Unit 1 and 2 are directly accessible from the language learning interface showcased in Figure 4. The table has a black row with no content in it as a header.

On the other hand, participants in the experimental group were first given the option to select a preferred learning dimension—either Grammar or Communication. Following their selection, participants were informed they would receive a customized learning plan highlighting recommended activities in blue, bold text. The research team decided to represent the personalized learning activities in this style to put emphasis on which activities were tailored to participants' learning needs and which were standard part of the learning curriculum. Participants were informed that they would receive weekly feedback on their activities from the prior week as well as being compared to other learners in their cohort (Figures 8, 9, 10).

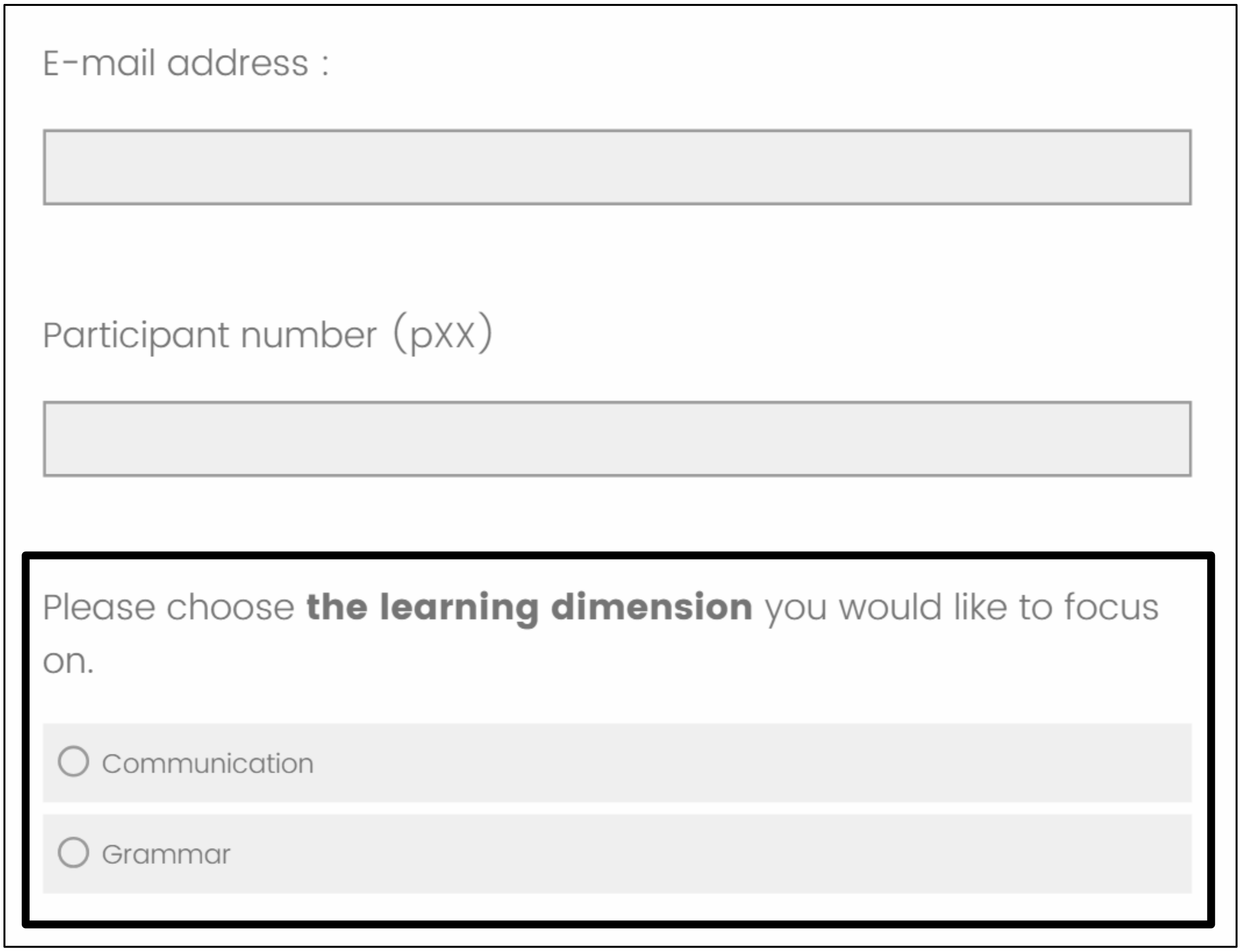


Figure 8. Debriefing page shown to participants in the experimental group. In addition to entering their e-mail address and their participant number (pXX, XX representing the participant number), participants assigned to the Gamified learning environment group were asked to choose a learning dimension to focus on throughout their upcoming at-home learning experience, which served to personalize their learning experience.

You will be asked to complete learning tasks over the course of 4 weeks on the interface you've used today. The learning tasks will take, at most, 2-3 hours weekly to complete.

You must consult the feedback we send you as well as follow the personalized learning plan we send you each week by e-mail and fill in the questionnaire at the end of each week. **Here is an overview of the feedback and personalized learning plan you will receive weekly** (*this is an example, you will receive the actual learning plan by e-mail shortly*) :

	Communication				
Unit 1	**Vidéo complète du dialogue**	**« A » – « Z »**	**Comptez là-dessus!**	En tout genre! (Partie 1)	L'article est déterminant
Unit 2	**Dialogue scène 1**	**Habiter**	**Nous, les pronoms**	Contractons! (Partie 1)	

Figure 9. Debriefing page shown to participants in the experimental group who had chosen the Communication dimension. The learning plan table is personalized with blue, bold highlights indicating which activities are recommended to participants based on their choice of learning dimension to focus on.

You will be asked to complete learning tasks over the course of 4 weeks on the interface you've used today. The learning tasks will take, at most, 2-3 hours weekly to complete.

You must consult the feedback we send you as well as follow the personalized learning plan we send you each week by e-mail and fill in the questionnaire at the end of each week. **Here is an overview of the feedback and personalized learning plan you will receive weekly** (*this is an example, you will receive the actual learning plan by e-mail shortly*) :

Grammar					
Unit 1	Vidéo complète du dialogue	« A » – « Z »	Comptez là-dessus!	En tout genre! (Partie 1)	L'article est déterminant
Unit 2	Dialogue scène 1	Habiter	Nous, les pronoms	Contractons! (Partie 1)	

Figure 10. Debriefing page shown to participants in the experimental group who had chosen the Grammar dimension.

Both groups of participants were asked to enter their email address and participant number via an iPad questionnaire and subsequently signed the compensation form for the first compensation in the form of a $50 e-transfer. Finally, the research team provided shampoo and towels for participants to remove the gel from their hair before accompanying them back to the building's exit.

2.4.3.2 Remote procedure

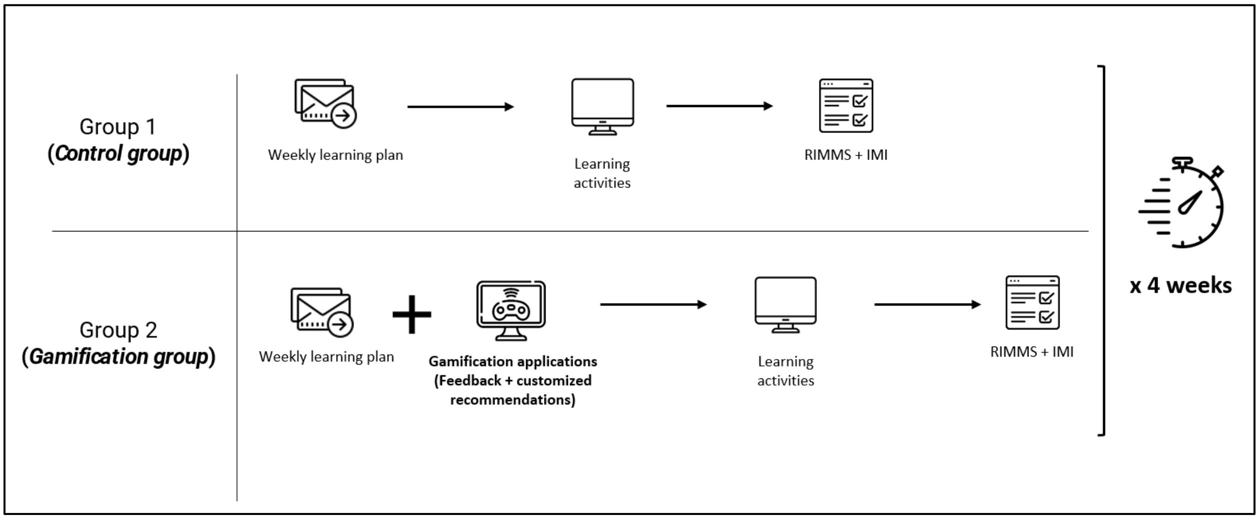


Figure 11. Timeline of the remote experiment and differences between the Control and Gamification group.

A few hours after the initial in-person experiment, the research team sent participants an onboarding email. which contained login credentials for the e-learning interface, as well as an initial learning plan and a 7-day deadline to complete it (Figure 12). In the case of participants in the experimental group, a personalized learning plan was provided in lieu of the standard learning plan, with specific activities highlighted based on their chosen learning dimension (Figure 13). However, participants were instructed to complete all activities, including those not highlighted.

Hello,

We thank you for your interest in participating in our study. As we've mentioned, for each week you complete the learning tasks, you will receive compensation worth $10 by Interac transfer.

To start your at-home learning journey, **you can access the LRDG Portal at the following link** : https://lrdgportal.com/login

Here are your identifiers for the portal :

- **Username** : tech3lab+P32@hec.ca
- **Password** : Kap!M2YL

For this week, please follow the learning plan below. (All learning units will be in Module 1, in *Redesigned Modules* of Learning Materials)

[redacted]					
Unit 1	Vidéo complète du dialogue	« A » – « Z »	Comptez là-dessus!	En tout genre! (Partie 1)	L'article est déterminant
Unit 2	Dialogue scène 1	Habiter	Nous, les pronoms	Contractons! (Partie 1)	

You will have until Wednesday August 2 by midnight to complete these activities at your own pace. Once you are done with the activities, you can wait to receive a follow-up e-mail from us.

We will send you an e-mail next week with :

- A short questionnaire to fill out as soon as you receive it. **Completing this questionnaire is MANDATORY to ensure your participation in the study and receive compensation**.
- A new learning plan.

Figure 12. First weekly e-mail sent to the Control group. The participant's identifiers to the portal are provided at the beginning of the e-mail, as well as the link to the LRDG portal. The learning plan, in the same style as shown in the 1st in-person experiment's debriefing, indicates which activities must be completed in the current week. Participants are given a weekly deadline to complete the activities & are informed they will receive another e-mail with a questionnaire and a new learning plan the following week.

Here are your identifiers for the portal :

- **Username** : tech3lab+P2@hec.ca
- **Password** : Qy9j!Fn!

All learning activities will occur in Module 1.

For this week, please follow the learning plan below. We recommend, based on your selection of learning dimension, to prioritize the *Communication* activities highlighted in blue (*you are still required to complete the non-highlighted activities*) **:**

Communication					
Unit 1	Vidéo complète du dialogue	« A » – « Z »	Comptez là-dessus!	En tout genre! (Partie 1)	L'article est déterminant
Unit 2	Dialogue scène 1	Habiter	Nous, les pronoms	Contractons! (Partie 1)	

You will have until Saturday, July 15th in the evening to complete these activities at your own pace. Once you are done with the activities, you can wait to receive a follow-up e-mail from our part.

We will send you an e-mail next week with :

- Feedback on your performance for the week;
- A new personalized learning plan (with activities highlighted in blue)
- A short questionnaire to fill out as soon as you receive it. **Completing this questionnaire is MANDATORY to ensure your participation in the study and receive compensation**.

Figure 13. First weekly e-mail sent to the Gamified group. While this e-mail is similar to the control group's, a key difference remains in the recommendation of learning activities. The participant in question had chosen the Communication dimension. Accordingly, each weekly e-mail provides a learning plan with highlighted recommended activities in the "Communication" table. Finally, differently to the Control group, the Gamified group participants are informed they will receive feedback on their performance for the week of learning in their next weekly e-mail.

To monitor participant progress, the research team used an Excel grid and an administrator account within the e-learning interface, tracking progress daily to ensure participants sustained their learning through time & calculate participants' average weekly score. As each participant-specific weekly deadline approached, the research team sent a follow-up email. For the control group, this email included a link to the questionnaire to be completed before commencing activities for the current week of learning, as well as a general learning plan for the week (Figure 14).

Hello,

Thank you for completing the third week of french learning on LRDG's interface.

Now, we ask you to please fill out this short questionnaire. **Completing this questionnaire is MANDATORY to ensure your participation in this study.**

https://hecmontreal.eu.qualtrics.com/jfe/form/SV_5BFiR3UdzehNnEO

Once the questionnaire is filled, you can start your final week of learning. **For this week, please follow the learning plan below.**

Unit 6	D'où viennent-ils?	Contractons davantage!	Trouvez l'intrus		
Unit 7	Revue du dialogue	Quiz du dialogue	Et le mot est?	Démêlez les énoncés	Faisons le tour du monde : un défi à relever

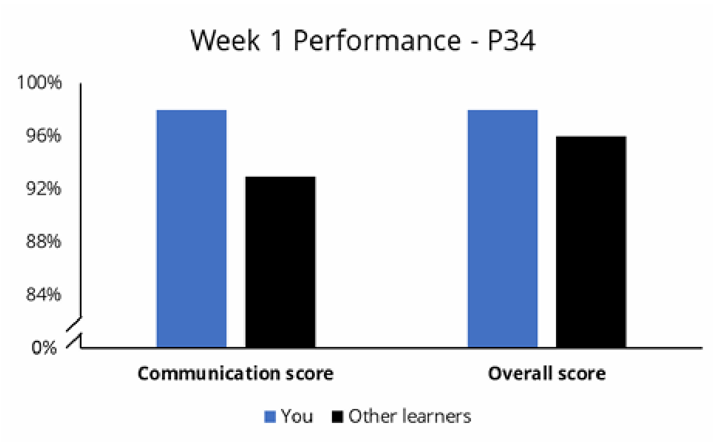
You will have until midnight Friday August 11 to complete these tasks at your own pace.

Figure 14. Example of the Control group's 3rd weekly e-mail of at-home learning. The link to the questionnaire is provided, as well as a new learning plan under the same visual style as the previous ones.

In contrast, aside from the weekly questionnaire, the experimental group's emails instead contained textual and visual feedback on their performance, along with a customized learning plan. Participants who experienced delays in completing weekly activities or the questionnaire were contacted via a standardized email to ensure their continued participation in the study.

- You have scored **99%** on activities related to your targeted learning dimension of **Communication**, compared to **93% for all learners** (See the bar graph below). Keep up the great work!

- Your **overall mean score** across all activities was **98%**, compared to **96% for all other learners.** Great job!



Now, we ask you to please fill out this short questionnaire. **Completing this questionnaire is MANDATORY to ensure your participation in this study.**

https://hecmontreal.eu.qualtrics.com/jfe/form/SV_ex0mhlXK2hYunjw

Once the questionnaire is filled, you can start your second week of learning.

For this week, please follow the learning plan below. In accordance with your targeted learning dimension, we recommend to prioritize the *Communication* activities highlighted in blue (*you are still required to complete the non-highlighted activities*) **:**

Communication					
Unit 2	Indéfini-ment article!	Un(e) ou plusieurs			
Unit 3	Dialogue scène 2	Être	En tout genre (pt2)	Nouveau est un nouvel adjectif	Quel est votre numéro de téléphone?
Unit 4	Dialogue scène 3	Sont-ils possessifs?			

Figure 15. The 2nd weekly e-mail for participant 34 (P34) in the Gamified group. Feedback on weekly performance (score over 100%) in the Communication highlighted activities and the Overall weekly score is provided to the participant, with their performance compared to other learners.

During the final week of a participant's at-home learning journey, the research team arranged a date for the second in-person experiment, which was set to take place after the completion of the final week of learning. Following the agreement on a date and the successful completion of the final questionnaire, participants were invited to the second in-person experiment, which occurred at the same satellite laboratory at UQAM.

2.4.3.2 Second in-person experiment

This experiment was structurally identical to the first, except for slight differences in the tasks, additional questionnaire items and an entirely different interview. On their arrival, participants were asked to complete a demographics questionnaire before proceeding with the experiment. The setup of the data collection tools was identical as in the first in-person experiment. In contrast to the first experiment, Task 1 omitted the login process and consisted of completing a different learning activity in Module 2, task 2 consisted of finding information in the FAQ about whether the interface was compatible on a tablet, task 3 consisted of finding pronoun grammar rules in the references, task 4 consisted of finding and completing the first few trials of another activity in Module 2 from the references page, and task 5 consisted of estimating the time spent on an activity in Module 2. The topics of learning activities performed by participants in-person were covered throughout participants' at-home learning. These tasks were then followed by a usability questionnaire containing the same questions as in the first in-person experiment, except that the research team asked participants to answer it based on their overall experience on the interface at home. Participants then had to indicate their level of satisfaction and how likely they were to recommend the company and its services to friends or colleagues who may want to pursue French learning classes online, followed by an interview much like in the 1st experiment with additional questions to evaluate participants' appreciation of the language learning interface after a month of usage. Once participants had completed the second part of the experiment, the research team informed the participant that the experiment was over.

All collected data was saved, and the research team removed the psychophysiological collection tools off the participant's head and hand. At the end of the second in-person experiment, participants were thanked by the research team and the final compensation was confirmed. Participants were then accompanied to the building's exit.

2.4.4 Measures

We detail in this section the measures of engagement during language learning tasks (measured during the in-person experiments).

2.4.4.1 In-person measures

EEG data was continuously measured during language learning tasks at both in-person experiments. Indeed, as brain activity can be observed through various frequency bands, we measured brain activity in Theta (5-7 Hz), Alpha (8-12 Hz) and Beta (15-29 Hz) bands, as the literature generally indicates higher oscillations in these frequencies can indicate heightened engagement and attention in learning tasks (Derbali & Frasson, 2010; Al-Nafjan & Aldayel, 2022; Cavanagh & Frank, 2014; Bonnefond & Jensen, 2012). Our approach in extracting and analyzing brain activity is described in further detail in the Analysis section.

Eye-tracking data was measured at the same moments: during the same language learning tasks, we measured fixation duration (the length of eye fixations on the visual learning stimuli in milliseconds (ms)) (Man & Harring, 2019), fixation count (the frequency of eye fixations on the visual learning stimuli) (Godfroid et al., 2013), and the k-coefficient, which is "is derived by subtracting the standardized (z-score) fixation duration from the standardized amplitude of the subsequent saccade" (Krejtz et al., 2016) , all of which may indicate heightened engagement in learning tasks (Henderson et al., 2015; Negi & Mitra, 2020; Man & Harring, 2019; Guo et al., 2022; Krejtz et al., 2016).

2.4.4.2 Self-perceived scales

Questionnaire data was collected to measure the evolution of each participants' language learning & classroom motivation on a weekly basis. 4 week-specific questionnaires (Week 1, 2, 3 and 4) on the Qualtrics platform (Qualtrics, Provo, UT) and included in the weekly standardized e-mails.

Classroom motivation was measured by the *Revised Instructional Materials Motivation Survey* (rIMMS) (Loorbach et al., 2015), which was adapted to specifically measure classroom motivation in relation to the "learning materials" (Appendix 1). This questionnaire is a validated shorter version of the *Instructional Materials Motivation Survey* (Keller, 2010), stemming from Keller's ARCS Model of Motivational Design (Keller, 1987). Items were directed at the language learning platform and its contents. The rIMMS was selected for its shorter item count (12-items) compared to the IMMS (36-items) with high reliability, with the objective to reduce the probability participants would abandon the questionnaire halfway through.

Intrinsic language learning motivation was measured by using the interest/enjoyment subscale of Intrinsic Motivation Inventory (IMI) (Ryan, Mimis, & Koestern, 1983). The formulation of the 8 items of this subscale was adapted to reflect intrinsic motivation related to the language learning experience over the course of a given week. (Appendix 2)

Table 2. Operationalization of variables

Variables	Measures	Tool	References
Cognitive engagement	Theta (5-7 Hz)	Electroencephalography (EEG)	Cavanagh & Frank, 2014; Piai et al., 2016
	Alpha (8-12 Hz)		Bonnefond & Jensen, 2012
	Beta (15-29 Hz)		Rajamani et al., 2018; Al-Nafjan & Aldayel, 2022
	Fixation duration (ms)	Eye tracker	

			Man & Harring, 2019
Visual engagement	Fixation count		Godfroid et al., 2013; Rayner, 2009
	K-coefficient		Guo et al., 2022; Krejtz et al., 2016
Motivation	Classroom motivation	5-point Likert scale (rIMMS) – adapted to target naSDLL activities	Loorbach et al., 2015
	Language learning motivation	7-point Likert scale (IMI) – adapted to target naSDLL learning activities	Ryan, Mimis, & Koestern, 1983

2.4.5 Analysis

We conducted our analyses on IBM SPSS Statistics 27. The significance threshold was set at $p < 0.05$. Motivation score analysis included all 31 participants who had completed the study, while EEG and eye tracking data analysis consisted of 27 participants as 4 data files were lost to file corruption.

2.4.5.1 Motivation

Item-specific scores for each participant were extracted from each Qualtrics questionnaire under .CSV format. We then created an Excel file containing all participant data for all rIMMS and IMI items. Each column corresponded to an item at a given week. For instance, the first column indicated A3 scores at Week 1, the second A3 scores at Week 2 and so on. Average scores for all items across each week were then calculated. We thus ended up with 4 variables for each measure: for instance, Attention_W1, Attention_W2, Attention_W3 and Attention_W4 were our 4 variables for the Attention measure of the rIMMS. The same procedure was repeated for IMI1 through IMI7, except that two items (IMI3 & IMI4) were reversed, negatively formulated items, and were recalculated in accordance to the original scale's indications. A repeated measures (RM) General Linear Model (GLM) was used to analyze the effect of the independent variable Gamification (2) over the 4 dimensions of classroom motivation with Time (Week 1, 2, 3 and 4) as a factor, and another RM GLM was used to analyze the effect of Gamification over the intrinsic motivation score.

2.4.5.2 Engagement

A RM type 3 ANOVA was performed to analyze the impact of the independent variable Group over the engagement of learners on the Theta (5-7 Hz), Alpha (8-12 Hz) and Beta (13-30 Hz) frequency bands, as well as on the fixation duration, fixation count and K-coefficient during language learning tasks. Raw EEG data was recorded at 1000 Hz over 32 channels (and processed on Brainstorm (Tadel et al. 2011), an open-source application on the MATLAB platform (Mathworks, Natick, MA, USA). Preprocessing started with the creation of separate protocols for the Phase 1 and Phase 2 files using individual anatomy and one channel file per acquisition. We imported the .eeg files created by the BrainVision software at the moment of our data collection in each respective protocol. Once all participant files for Phases 1 and 2 were imported, we proceeded with the removal of noisy & dead channels through individual visualization of each data file, after which an Independent Component Analysis (ICA), specifically through the FastICA algorithm, was performed on each file to identify and remove artifacts related to eye blinks and cardiac activity. We conservatively removed one to two ICA components associated to strong artifacts in each given file. The cleaned data was then filtered using a band-pass filter (1-40 Hz), creating a new file for subsequent preprocessing. Event-related epochs were extracted from the band-pass filtered files, from a duration of -100 ms to 400 ms relative to markers set at 3-second intervals during both the 90-second baseline period and the two language learning tasks. All epochs underwent visual inspection, and those containing artifacts or noise (amplitude exceeding ±150 µV) were excluded from further analysis.

A time-frequency analysis was performed using Hilbert transformation on the preprocessed epochs for all participants across the frequency bands of interest: theta (4-8 Hz), alpha (8-12 Hz), and beta (13-30 Hz). Time-frequency envelopes were then averaged across epochs for each event and frequency band, resulting in 3 individual averaged files per participant: one for each language learning task and one for the baseline event. To ensure the EEG data was calibrated to each participant's phase-specific baseline brain activity, event-related synchronization/desynchronization (ERS/ERD) was calculated by normalizing the average signal of each task event relative to the baseline signal. Equation 1 represents the calculation:

$$x_{std} = \mu_x - \mu \times 100 \quad (1)$$

where x represents the time-frequency envelope's amplitude to be normalized, *std* the standard-deviation and μ the time average over the baseline period. In Brainstorm, we accomplished this by selecting the Baseline normalization (A=baseline) function in the Standardize process. We then averaged each standardized file from 0 to 3s, which gave us for each participant two averaged normalized files corresponding to our two language learning tasks in each phase. The final step in our preprocessing protocol consisted in averaging these two files to obtain a single averaged standardized file per participant for each phase corresponding to brain activity in both language learning tasks, preserving good channels present in both files. Proceeding this way enabled us to analyze brain activity data both outside and within Brainstorm: On one hand, we opened all participant’s averaged files individually in MATLAB to extract channel-specific theta, alpha and beta activity data to build our Excel dataset, which contained the average activity in Theta, Alpha and Beta in each preserved channel). This file was later imported in SPSS for the statistical analyses described further below. On the other hand, the individual averaged files were later used to produce topographical maps within the Control and Gamification groups (through arithmetic averaging directly in Brainstorm). These files were also preserved to execute statistical analyses within Brainstorm to compare brain activity between the two groups & produce topographical t-maps as described further below.

Eye tracking data was recorded at 600 Hz through the Tobii Pro Lab software. After data collection was completed, we defined Areas of Interest (AOIs) through the Tobii Pro Lab software (Tobii, Provo, UT) on the webpages corresponding to the language learning tasks, which were delimited with the same event markers as the EEG data event markers. Fixation duration, count and k-coefficient metrics were extracted from all participant files and compiled into a .tsv file.

A repeated measures (RM) ANOVA was conducted to analyze the effect of the independent variables: Gamification (2) (Gamified vs. Non-Gamified), Phase (2) (1^{st} vs 2^{nd} in-person experiment) and Channel (31) (only applicable to EEG analysis). Pairwise comparisons were performed using Holm correction for multiple comparisons when significant main effects or interactions were observed. FDR-corrected parametric t-tests were executed when specific frequency bands showcased significantly higher or lower activity in topographical t-maps comparing the gamified and control groups.

2.5 Results

2.5.1 Motivation

We indicate the evolution of classroom motivation and intrinsic language learning motivation questionnaire scores through time in the Gamified learning environment and Control groups, firstly covering descriptive statistics (M, SD, Cronbach's alpha) (Table 3), as well as the item-by-item correlation statistics (Appendix 3,4). Summarily, while our descriptive data generally showcases higher mean scores on our motivational scales for the experimental group, these differences are not significant as our results fail to highlight a significant between-subjects effect of gamification over classroom and language learning motivation, except for the Relevance measure, as participants in the Gamified learning environment group demonstrated a non-linear quadratic trend of Relevance scores through time. We immediately provide the main results of our RM analyses while outlining the significant differences that were revealed.

Table 3. Descriptive statistics (M, SD) & Cronbach's alpha of rIMMS and IMI scores for the Control & Gamified learning environment groups.

		Week 1			Week 2			Week 3			Week 4		
Gamified learning environment		*M*	*SD*	*α*	*M*	*SD*	*α*	*M*	*SD*	*α*	*M*	*SD*	*α*
Classroom Motivation	Attention	3.45	0.82	0.67	3.45	0.82	0.76	3.52	0.89	0.87	3.21	1.67	0.92
	Relevance	3.62	0.68	0.42	3.76	0.71	0.67	3.76	0.92	0.81	3.36	0.96	0.80
	Confidence	3.64	0.91	0.80	3.67	0.77	0.72	3.48	0.81	0.83	3.17	0.97	0.83
	Satisfaction	3.21	1.20	0.95	3.14	1.08	0.90	3.02	1.03	0.94	2.90	1.05	0.96
Language learning intrinsic motivation	Intrinsic motivation	4.46	1.24	0.92	4.45	1.33	0.95	4.34	1.95	0.90	4.20	1.25	0.90

Control		*M*	*SD*	*α*	*M*	*SD*	*α*	*M*	*SD*	*α*	*M*	*SD*	*α*
Classroom Motivation	Attention	2.88	0.82	0.70	2.88	0.67	0.71	3.21	0.79	0.83	2.74	0.78	0.78
	Relevance	3.59	0.94	0.89	3.38	0.89	0.86	3.36	0.83	0.82	3.31	1.00	0.90
	Confidence	3.14	1.00	0.77	3.00	1.02	0.87	3.29	1.01	0.89	3.10	0.86	0.91
	Satisfaction	3.02	1.15	0.92	2.95	0.89	0.92	2.90	1.00	0.96	2.83	0.93	0.89
Language learning intrinsic motivation	Intrinsic motivation	4.11	1.29	0.92	3.86	1.04	0.89	3.82	1.08	0.93	3.73	1.31	0.95

A RM ANOVA was conducted to examine the effects of time and gamification on classroom motivation, measured through 12 rIMMS items and language learning motivation, measured through seven IMI items.

2.5.1.2 Classroom motivation

H1: *Participants will present higher levels of classroom motivation throughout a month of naSDLL in a gamified learning environment than those after a month of naSDLL in a non-gamified learning environment.*

H1a: *Participants will present higher levels of* ***attention*** *throughout a month of naSDLL in a gamified learning environment than those in a non-gamified naSDLL learning environment.*

H1b: *Participants will present higher levels of* ***relevance*** *throughout a month of naSDLL in a gamified learning environment than those in a non-gamified naSDLL learning environment.*

H1c: *Participants will present higher levels of* ***confidence*** *throughout a month of naSDLL in a gamified learning environment than those in a non-gamified naSDLL learning environment.*

H1d: *Participants will present higher levels of* ***satisfaction*** *throughout a month of naSDLL in a gamified learning environment than those in a non-gamified naSDLL learning environment.*

Cronbach's alpha was calculated for each week of rIMMS administration to assess internal consistency over time in both groups - internal consistency was generally high throughout the 4 measured constructs across all weeks, except for the Gamified learning environment group's alphas at Week 1 for Relevance ($\alpha = 0.42$) and Attention ($\alpha = 0.67$). These low initial alphas align with the nonsignificant Week 1 rIMMS inter-item correlations (Appendix 3) for Relevance (R1-R6 r = 0.06) and Attention (A3-A10 r = 0.30). By Week 4, however, the Gamified group exhibited significant strengthening of these correlations (Attention r = 0.74–0.87. $\alpha = 0.92$; Relevance r = 0.46–0.64, $\alpha = 0.80$). On the other hand, inter-item correlations reveal sustained correlation coefficients in the Control group throughout the 4 weeks.

Table 4. Summary of rIMMS RM ANOVA test results.

	df	***F***	***p***
Time	(4, 77)	2.444	0.054
Time x Gamification	(12, 31)	1.01	0.441
Attention	(3, 78)	0.351	0.789
Relevance		1.290	0.284
Confidence		1.939	0.130
Satisfaction		0.062	0.980
Relevance (Time x Gamification)	(1, 80)	5.620	0.025*
Attention (Time)	(1, 80)	4.982	0.034*

* denotes significance at the < 0.05 level.

Mauchly's Test of Sphericity indicated that the assumption of sphericity was respected for all measures. Table 4 presents the main results of the RM ANOVA for rIMMS scores. Multivariate results regarding the within-subjects effect of Time did not reach significance (Pillai's Trace = 0.165, $F_{(12, 231)} = 1.118$, $p = 0.346$), though Roy's Largest Root = 0.127 revealed a borderline Time effect ($F_{(4, 77)} = 2.444$, $p = 0.054$). The Time by Gamification within-subjects test showed no statistical significance (Pillai's Trace = 0.149, $F_{(12, 231)} = 1.01$, $p = 0.441$). Similarly, univariate tests revealed no significance for Time * Gamification on Attention ($p = 0.789$), Relevance ($p = 0.284$), Confidence ($p = 0.130$) and Satisfaction ($p = 0.980$). However, within-subjects contrasts of Time * Gamification showed a significant quadratic trend for Relevance ($F_{(3, 78)} = 5.620$, $p =$

0.025) and a cubic trend for Time on Attention ($F_{(3,\ 78)}$ = 4.982, p = 0.034), which suggests a non-linear & complex pattern of evolution of these motivational constructs through time. While this is a significant result, it is not aligned with H1b as the Relevance scores are overall not significantly different between groups.

Considering the overall lack of significance in our motivation results, H1, H1a, H1b, H1c and H1d are not supported.

2.5.1.1 Intrinsic language learning motivation

H2: *Participants will present higher levels of intrinsic language learning motivation throughout a month of gamified SDLL than those after a month of non-gamified SDLL.*

Cronbach's alpha was calculated for each week of IMI administration to assess internal consistency over time in both the control and gamified groups, as both displayed high consistency scores throughout the 4 weeks of at-home learning. In the Control group, inter-item correlations (Appendix 4) remained stable, with consistently strong associations between items (IMI1-IMI2 r = 0.70–0.92, IMI6-IMI7 r = 0.67-0.93). On the other hand, the Gamified group exhibited decreasing inter-item correlations: IMI1-IMI3 weakened from r = 0.49 in Week 1 to r = 0.10 in Week 4. Conversely, correlations between IMI5 and IMI7 increased from r = 0.66 in Week 1 to r = 0.87 in Week 4.

Table 5. Summary of IMI RM ANOVA results.

	df	***F***	***p***
Time	(3,24)	0.727	0.546
Time x Gamification	(3,24)	0.272	0.845
Time x Gamification	(2.276,78)	0.178	0.863
Intrinsic Motivation	(1,26)	0.50 0.514 0.139	0.146 0.480 0.712
Gamification	(1,26)	1.346	0.256

Mauchly's Test of Sphericity indicated that the assumption of sphericity was violated (W = 0.622, p = 0.039), therefore Greenhouse-Geisser corrections were applied. Multivariate analyses revealed no significant within-subjects effect of Time on Intrinsic Motivation (Pillai's Trace = 0.083, $F_{(3, 24)}$ = 0.727, p = 0.546). Analysis of the within-subjects effects of Time by Gamification also revealed no statistical significance (Pillai's Trace = 0.033, $F_{(3, 24)}$ = 0.178, p = 0.289), and within-subjects contrasts for Time × Gamification on Intrinsic Motivation showed no significant linear ($F_{(1, 26)}$ = 0.50, p = 0.146), quadratic ($F_{(1, 26)}$ = 0.514, p = 0.480), or cubic trends ($F_{(1, 26)}$ = 0.139, p = 0.712). Between-subjects effects of Gamification revealed no statistical significance ($F_{(1, 26)}$ = 1.346, p = 0.256).

H2 is thus not supported.

2.5.2 Engagement

H3: *Participants will present higher levels of engagement during language learning tasks after a month of naSDLL in a gamified learning environment than those after a month of naSDLL in a non-gamified learning environment.*

Table 4 illustrates the descriptive statistics of cognitive and visual engagement data. In summary, our analyses reveal significantly higher Theta and Alpha power percentage in the gamified group at Phase = 2 (Theta: M = 11.69%, SD = 12.97% ; Alpha: M = -10.02%, SD = 17.20%) compared to the control group (Theta: M = 2.81, SD = 17.53% ; Alpha: M = -24.46, SD = 21.83%). As for eye gaze activity, fixation duration during language learning tasks was significantly lower in the Gamification group at Phase = 2 (M = 135.92, SD = 58.44) compared to the Control group (M = 149.3, SD = 59.58). In the subsequent sections, we provide in-depth results as well as visualizations of the main differences between the two groups after a month of language learning at home.

Table 6. Descriptive statistics of brain activity (theta, alpha, beta %) and eye gaze activity (fixation count, fixation duration and k-coefficient) by Group and Phase.

Phase	Group	Theta (%)	Alpha (%)	Beta (%)	Fixation count	Fixation duration (ms)	K-Coefficient
		M ± SD *N*	*M ± SD* *N*	*M ± SD* *N*	*M ± SD* *N*	*M ± SD* *N*	*M ± SD* *N*

1	Gamified learning environment	10.72 ± 15.44 *N* = 802	-10.84 ± 19.69 *N* = 798	1.50 ± 22.76 *N* = 810	250.04 ± 32.40 *N* = 28	301.21 ± 69.60 *N* = 28	-0.25 ± 0.30 *N* = 28
	Control	5.28 ± 18.09 *N* = 802	-13.54 ± 21.9 *N* = 798	-3.25 ± 23.61 *N* = 810	250.67 ± 31.09 *N* = 30	228.73 ± 91.73 *N* = 30	-0.27 ± 0.28 *N* = 28
2	Gamified learning environment	11.69 ± 12.97 *N* = 604	-10.02 ± 17.20 *N* = 617	3.83 ± 23.95 *N* = 604	273.31 ± 34.88 *N* = 26	135.92 ± 58.44 *N* = 26	-0.3 ± 0.25 *N* = 26
	Control	2.81 ± 17.53 *N* = 761	-24.46 ± 21.83 *N* = 788	-2.58 ± 19.70 *N* = 785	270.67 ± 38.34 *N* = 30	149.3 ± 59.58 *N* = 30	-0.31 ± 0.27 *N* = 30

Note. *N* corresponds to the number of data points available. For Theta, Alpha and Beta, N represents the sample of data for each channel in both language learning tasks. For fixation count, duration and K-coefficient, N represents the overall number of on-screen visual stimuli considered in the analysis.

2.5.2.1 Cognitive engagement

H3a: *Participants will present higher levels of cognitive engagement throughout after a month of naSDLL in a gamified learning environment than those after a month of naSDLL in a non-gamified learning environment.*

As described in the Analysis section, we analyzed brain activity during language learning tasks at Phase = 1, which corresponds to the 1st visit, and Phase = 2, which corresponds to the 2nd visit. We examined the Theta (5-7 Hz), Alpha (8-12 Hz) and Beta (15-29 Hz) frequency bands and detail the results of our analyses below. To provide a visual representation of our results, we showcase brain activity in each frequency band through topographical maps, in which red represents higher brain activity & blue represents lower brain activity in the specified frequency bands (Figures 16-20).

2.5.2.1.1 Theta brain activity

Table 7. Summary of RM ANOVA results for Theta brain activity.

	df	***F***	***p***
Gamification	(1,2750)	4.24	0.0396*
Phase	(1,2749)	14.43	0.0001**
Channel	(30,2720)	21.18	< 0.0001***

Gamification x Phase	(1,2748)	26.94	< 0.0001***
Gamification x Channel	(30,2690)	1.55	0.0297*
	df	***t***	***Adjusted-p (Holm)***
Gamified vs Control (Phase = 2)	2748	-2.65	0.0402*

* denotes significance at the < 0.05 level, ** at the < 0.01 level, and *** at the < 0.001 level.

A RM Type 3 ANOVA of theta (5-7 Hz) showed a significant effect of Gamification ($F_{(1, 2750)} = 4.24$, $p = 0.0396$), Phase ($F_{(1, 2749)} = 14.43$, $p = 0.0001$) and Channel ($F_{(30, 2720)} = 21.18$, $p < 0.0001$). Theta activity generally decreased in the control group between the two phases (Table 6) (M = 5.28, SD = 18.09 in Phase 1; M = 2.81, SD = 17.53 in Phase 2), while it slightly increased in the gamified group (M = 10.72, SD = 15.44 in Phase 1; M = 11.69, SD = 12.97 in Phase 2). There were also significant Gamification by Phase ($F_{(1, 2748)} = 26.94$, $p < 0.0001$) and Gamification by Channel interactions ($F_{(30, 2690)} = 1.55$, $p = 0.0297$). Pairwise comparisons revealed that Theta oscillations were significantly higher in the gamified group during language learning tasks in the second experiment (M = 11.67, SD = 12.97) compared to the control group during the same experiment (M = 2.81, SD = 17.53) (Table 6) ($t(2748) = -2.65$, $p = 0.008$, *Holm-adjusted* $p = 0.0402$) (Table 7). Topographical t-maps reveal increased overall theta activity (represented by concentrated red areas in Figure 16), specifically in the fronto-central, fronto-parietal and occipital regions and parietal regions in the experimental group at the second experiment (Figure 16).

An independent one-tailed parametric test between the Gamification and Control groups at Phase 2 resulted in a t-map showing significant FDR-corrected differences across multiple electrode sites. The strongest effects ($q = 0.014$) were observed in central (C3), fronto-central (FC6), temporal (T8), parietal (P4), centro-parietal (CP6), and fronto-temporal regions (FT9 and FT10), while additional significant differences were found in fronto-central (FC2, $q = 0.020$; FC5, $q = 0.047$), temporal (T7, $q = 0.020$; TP10, $q = 0.033$), parietal (P8, $q = 0.047$), centro-parietal (CP1 and CP2, $q = 0.047$), and frontal (F7, $q = 0.048$) regions. These differences are illustrated topographically in Figure 17 and summarized in Table 8.

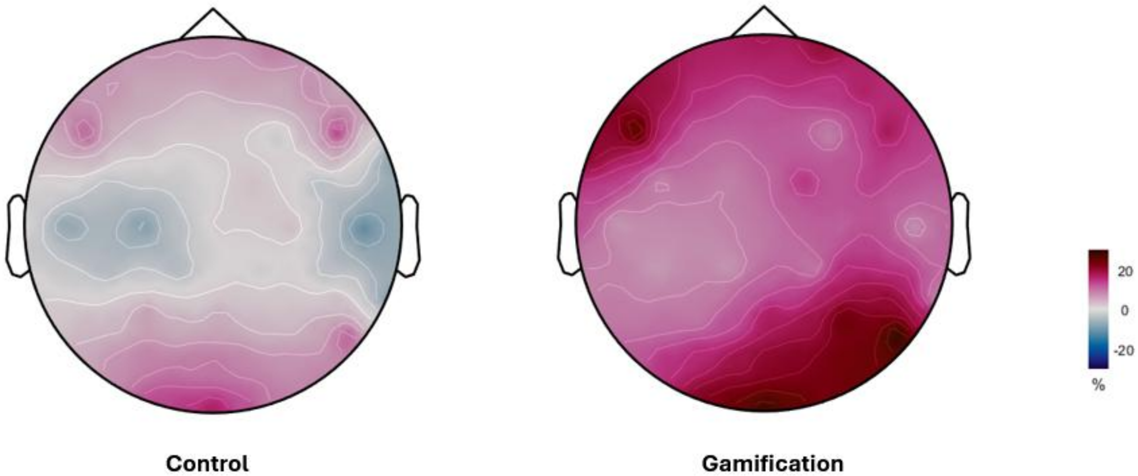


Figure 16. EEG topography of theta (5-7 Hz) activity for the Control group (left) and the Gamified learning environment group (right) with a shared scale at Phase = 2

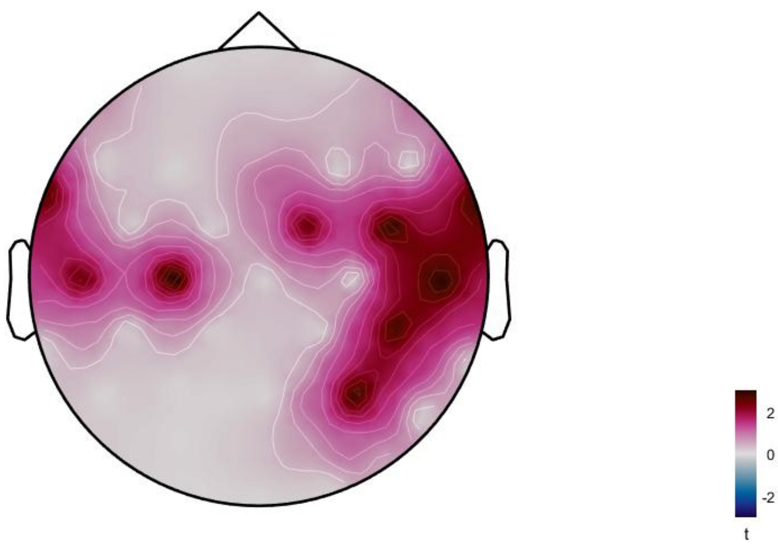


Figure 17. Topographical t-map showing significant differences in theta activity between Gamified learning environment and Control groups at Phase = 2 after FDR correction (q < 0.05). Areas where relative brain activity is higher are represented by the dark red spots.

Table 8. Summary of significant FDR-corrected Theta channel differences in one-tailed parametric test between Gamified and Control groups at Phase = 2.

Electrode	*q*
C3 FC6 T8 P4 FT9 FT10	0.014*
FC2 T7	0.02*
TP10	0.033*
P8 CP1 CP2 FC5	0.047*
F7	0.048*

* denotes significance at the < 0.05 level.

2.5.2.1.2 Alpha brain activity

Table 9. Summary of RM ANOVA results for Alpha brain activity.

	df	*F*	*p*
Gamification	(1,2796)	3.08	0.0792
Phase	(1,2796)	128.76	< 0.0001***
Channel	(30,2767)	21.18	< 0.0001***
Gamification x Phase	(1,2795)	140.78	< 0.0001***
Gamification x Channel	(30,2737)	0.81	0.7606
	df	***t***	***Adjusted-p (Holm)***
Gamified vs Control (Phase = 2)	2795	-2.83	0.0233*

* denotes significance at the < 0.05 level, ** at the < 0.01 level, and *** at the <0.0001 level.

RM Type 3 ANOVA of alpha (8-12 Hz) did not show a significant main effect of Gamification ($F_{(1, 2797)} = 3.08$, $p = 0.0792$), but showed a significant effect of Phase ($F_{(1, 2796)} = 128.76$, $p < .0001$) and Channel ($F_{(30, 2767)} = 12.39$, $p < .0001$). Alpha activity generally became more suppressed in the control group between the two phases (M = -13.54%, SD = 21.90% in

Phase 1; M = -24.46%, SD = 21.83% in Phase 2), while the gamified group showed relatively stable alpha activity across phases (M = -10.84%, SD = 19.69% in Phase 1; M = -10.02%, SD = 17.20% in Phase 2). A significant Gamification by Phase interaction was found ($F_{(1, 2795)} = 140.78$, $p < 0.0001$) with no other interactions found. Pairwise comparisons revealed that, much like in theta, alpha oscillations were significantly higher in the gamified group during language learning tasks on the second experiment compared to the control group ($t(2795) = -2.83$, $p = 0.008$, Holm-adjusted $p = 0.0233$). The control group exhibited strong alpha suppression across most regions, with minimal variation in its distribution, while the gamification group showcased a heterogeneous oscillation pattern, with less alpha suppression particularly in central and right parietal areas (Figure 18). Topographical t-maps for alpha oscillations revealed significant differences in activity between the gamification and control groups during Phase 2 (Figure 19). Using the two-stage sharpened FDR correction method ($q < 0.05$), significant channels were identified across multiple regions. The strongest effects ($q = 0.033$) were observed in parietal (P4), fronto-temporal (FT10, FT9), fronto-central (FC5, FC2), temporal (T7), frontal (F3, F4), and central (Cz) regions. Additional significant differences ($q = 0.0498$) were found in fronto-central (FC1, FC6), temporal (T8, TP10, TP9), central (C3, C4), frontal (F7), frontopolar (Fp1, FP2), and parietal (P3, P7) regions.

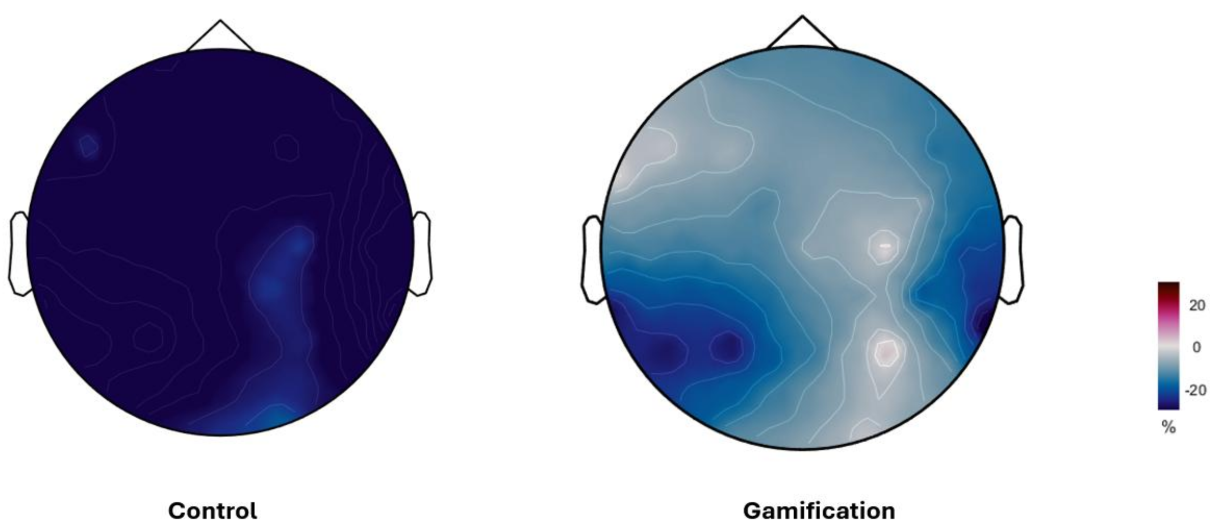


Figure 18. Figure 18. EEG topography of alpha (8-12 Hz) activity for the Control group (left) and the Gamified learning environment group (right) with a shared scale at Phase = 2.

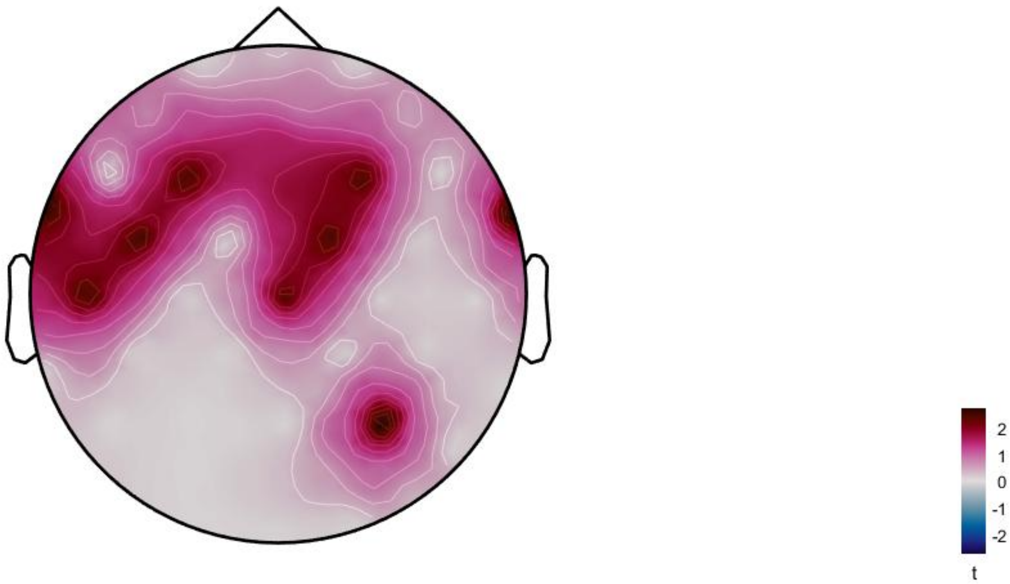


Figure 19. Topographical t-map showing significant differences in alpha activity between gamified and control groups at Phase = 2 after FDR correction ($q < 0.05$)

Table 10. Summary of significant FDR-corrected Alpha channel differences in one-tailed parametric test between Gamified and Control groups at Phase = 2 (*q > 0.05)

Electrode	***q***
P4	
FT10	
FT9	
FC5	
T7	0.033*
F3	
FC2	
F4	
Cz	
FC1	
T8	
FC6	
C3	
TP10	
F7	
Fp1	0.0498*
F7	
TP9	
C4	
FP2	
P3	
P7	

* denotes significance at the < 0.05 level.

2.5.2.1.3 Beta brain activity

Table 11. Summary of RM ANOVA results for Beta brain activity.

	df	***F***	***p***
Gamification	(1,2766)	1.41	0.235
Phase	(1,2766)	2.39	0.1223
Channel	(30,2736)	12.89	< 0.0001***
Gamification x Phase	(1,2764)	1.09	0.296
Gamification x Channel	(30,2706)	2.2	0.0002**
	df	***t***	***Adjusted-p (Holm)***

Gamified vs Control (Phase = 2)	2764	-7.08	0.8128

* denotes significance ** at the < 0.01 level, and *** at the <0.0001 level.

RM Type 3 ANOVA of beta (15-29 Hz) showed no significant effect of Gamification ($F_{(1, 2766)}$ = 1.41, p = 0.235) nor of Phase ($F_{(1, 2765)}$ = 2.39, p = 0.1223) but showed a significant effect of Channel ($F_{(30, 2736)}$ = 12.89, p < 0.0001). There was no significant Gamification by Phase interaction ($F_{(1, 2764)}$ = 1.09, p = 0.296) but there was a significant Channel by Gamification interaction ($F_{(30, 2706)}$ = 2.2, p = 0.0002). Pairwise comparisons revealed no significant differences in beta oscillations between the gamification group (M = 3.83, SD = 23.95) and the control group (M = -2.58, SD = 19.70) (Table 6) ($t(2764)$ = -7.08, p = 0.008, Holm-adjusted p = 0.8128). The control group showed a mixed pattern of beta modulation, with decreased activity in left frontal regions and increased activity in right temporal and posterior regions, while the gamification group displayed more widespread beta oscillations, particularly in right temporal and parietal regions (Figure 20). Two-stage sharpened FDR correction revealed no significantly different beta oscillations at any given channels for the Gamified group (The closest q-value found was q = 0.0745 for TP10, P3, P7 & TP9).

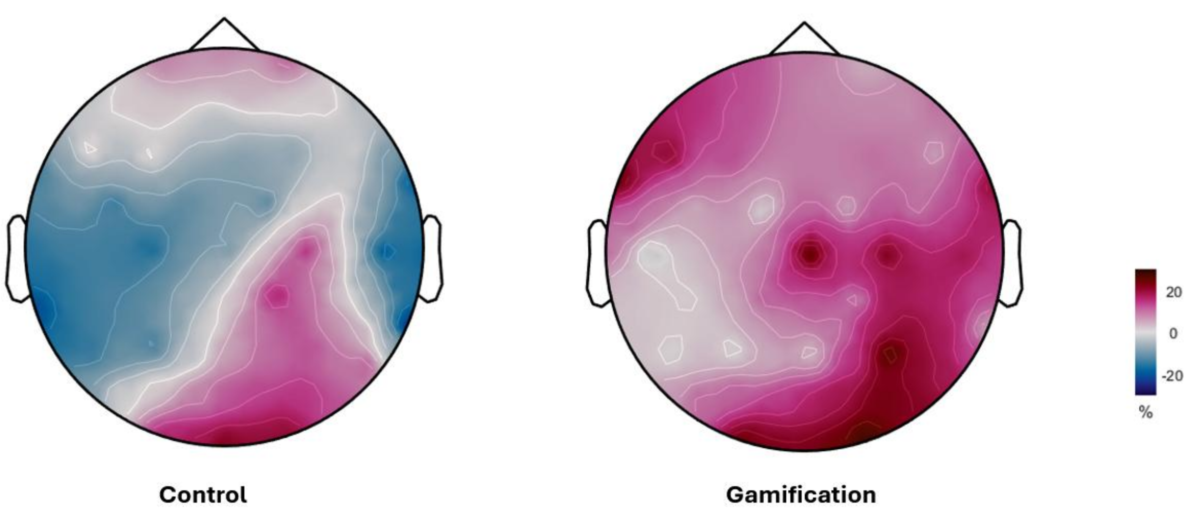


Figure 20. EEG topography of beta (15-29 Hz) activity for the Control group (left) and the Gamification group (right) with a shared scale.

Considering the significance of our analyses indicating higher Theta (5-7 Hz) and Alpha (8-12 Hz) activity as well as the borderline significance of Beta (15-29 Hz) heightened activity, our results suggest an overall greater level of brain activity and thus cognitive engagement.

H3a is thus supported.

2.5.2.2 Eye tracking

H3b: *Participants will present higher levels of visual engagement throughout after a month of naSDLL in a gamified learning environment than those after a month of naSDLL in a non-gamified learning environment.*

Table 12. Summary of RM ANOVA results for eye-tracking data.

		df	*F*	*p*
Fixation duration	Phase	(1,81)	15.63	0.0002**
	Gamification		0.02	0.877
	Gamification x Phase		0.17	0.6848
Fixation count	Phase		94.69	< 0.0001***
	Gamification		3.14	0.08
	Gamification x Phase		11.3	0.0013**
K-Coefficient	Phase	(1,75)	1.16	0.2841
	Gamification		0	0.9684
	Gamification x Phase		0.01	0.9129

* denotes significance at the < 0.05 level, ** at the < 0.01 level, and *** at the < 0.001 level.

A RM Type 3 ANOVA for fixation duration revealed a significant main effect of phase ($F_{(1, 81)}$ = 15.63, p = 0.0002), but no main effect of Gamification ($F_{(1, 81)}$ = 0.02, p = 0.877), nor a Phase by Gamification interaction ($F_{(1, 81)}$ = 0.17, p = 0.6848). While the descriptive data summarized in Table 6 indicates an increase in fixation durations from Phase = 1 to Phase = 2 in both the control group (M = 250.67 ms, SD = 31.09 at Phase 1; M = 270.67 ms, SD = 38.34 at Phase 2) and the gamified learning environment group (M = 250.04 ms, SD = 32.40 at Phase 1; M = 273.31 ms, SD = 34.88 at Phase 2), no significant Gamification by Phase interaction was found ($F_{(1, 81)}$ = 0.17, p = 0.6846).

A RM Type 3 ANOVA for fixation count revealed a strong significant main effect of Phase ($F_{(1, 81)}$ = 94.69, p < 0.0001), no significant main effect of Gamification ($F_{(1, 81)}$ = 3.14, p = 0.08), and a significant Phase by Gamification interaction ($F_{(1, 81)}$ = 11.13, p = 0.0013). As indicated in Table 6, Fixation counts decreased significantly from Phase 1 to Phase 2 in both groups but were more pronounced in the gamified group (M = 301.21 fixations, SD = 69.60 at Phase 1; M = 135.92 fixations, SD = 58.45 at Phase 2) compared to the control group (M = 228.73 fixations, SD = 91.73 at Phase 1; M = 149.30 fixations, SD = 59.59 at Phase 2).

A RM Type 3 ANOVA for k-coefficient revealed neither Phase ($F_{(1, 75)}$ = 1.16, p = 0.2841) nor Gamification ($F_{(1, 75)}$ = 0, p = 0.9684) had a significant main effect. No significant interaction of Gamification by Phase was found ($F_{(1, 75)}$ = 0.01, p = 0.9129). Descriptively, Table 6 indicates mean k-coefficient values were negative across both phases and groups (Control: M = -0.27, SD = 0.26 at Phase 1; M = -0.31, SD = 0.23 at Phase 2; Gamified: M = -0.25, SD = 0.13 at Phase 1; M = -0.30, SD = 0.22 at Phase 2), reflecting a consistent ambient attentional style across conditions.

Therefore, considering the more significant decrease of fixation duration in the gamified learning environment group compared to that of the control group and the lack of significance between groups regarding fixation duration and k-coefficient, H3b is not supported.

Figure 21 represents the updated conceptual framework, indicating which hypotheses were supported fully, partially or not supported. Table 5 summarizes the hypothesis testing results according to the results presented above.

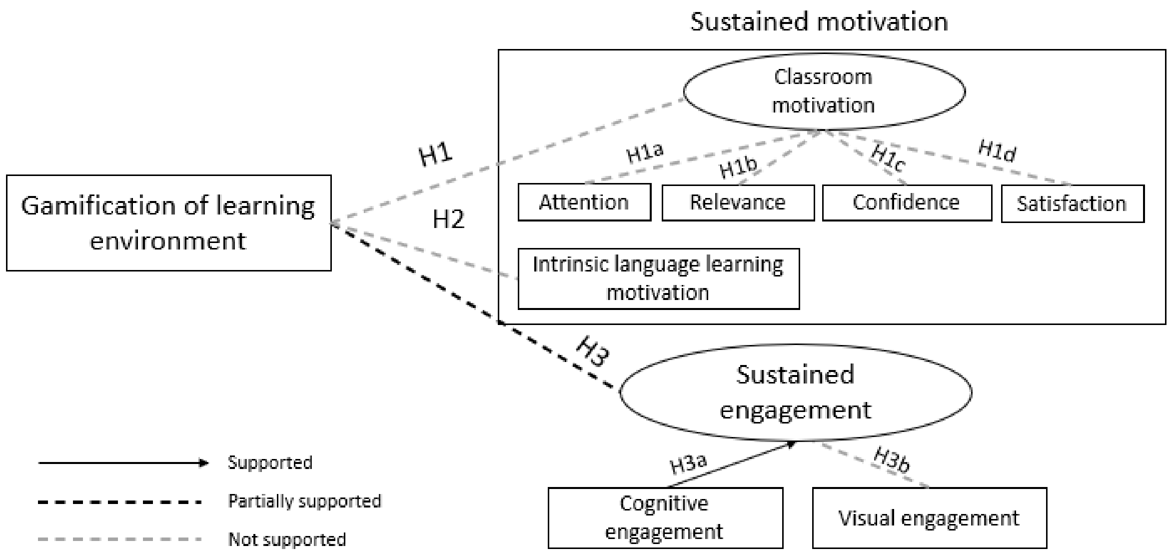


Figure 21. Updated proposed research framework with supported, partially supported and not supported hypotheses.

Table 13. Summary of hypothesis testing according to results.

Hypothesis	Status
H1	Not supported
H1a	Not supported
H1b	Not supported
H1c	Not supported
H1d	Not supported
H2	Not supported
H3	Partially supported
H3a	Supported
H3b	Not supported

2.6 Discussion

The objective of this study was to investigate the impact of gamification on adult learners' motivation and engagement in a naSDLL context. Using a combination of self-reported motivational measures, physiological data and behavioral metrics, this study sought to assess how gamification influences engagement and motivation over time. While the results partially supported the hypotheses, they also revealed gamification's nuanced effects (and lack thereof) that warrant further exploration.

H1 hypothesized that gamified participants would demonstrate higher classroom motivation scores as measured through the rIMMS. This hypothesis was not supported as H1a, H1b, H1c and H1d failed to meet significant p-values in univariate and multivariate RM ANOVA tests, but our analyses revealed non-linear trends for Relevance through Time in the gamified learning environment group. This suggests that participants' motivation related to the relevance of the learning materials evolved in a non-linear fashion, initially increasing only to go back to baseline values after a few weeks, potentially reflecting an initial novelty effect of the learning materials that waned over time. The lack of overall support for H1 gives thought to the inherent motivational challenges of SDL. While gamification is often shown to positively impact classroom motivation in traditional educational settings (Hamari et al., 2014; Koivisto & Hamari, 2019), classrooms are inherently motivating due to their structured and social nature. In contrast, SDLL is inherently demotivating, as it is characterized by isolation and a lack of external accountability (Ryan & Deci, 2000; Hartnett, 2016), which may limit gamification's ability to sustain motivation over time. Further research is thus required to properly identify gamification's motivating components outside the instructor-led language learning process.

H2 hypothesized that participants in the gamified condition would demonstrate higher language learning motivation (IMI) compared to controls after one month of SDLL. However, this hypothesis was not supported by the results, as our analyses revealed no significant impact of gamification on IMI scores through time. Considering gamification's proven role in sustaining motivation in language learning contexts, other factors may be at play. The nature of our experiment may have biased participants' initial intrinsic motivation to learn a language by providing sizable financial compensation. External rewards, such as the significant monetary compensation provided in this study, undermine intrinsic motivation by shifting focus from the inherent enjoyment of an activity to the external incentive (Deci et al., 1999; Lepper et al., 1973). SDT (Ryan & Deci, 2000) supports this interpretation, emphasizing that extrinsic rewards perceived as controlling can reduce autonomy and intrinsic motivation. Additionally, our experimental design may lack ecological validity with the pressure exercised by both the compensation and the activity requirements to remain in the study.

H3a hypothesized that participants learning in a gamified naSDLL environment would exhibit higher cognitive engagement, translated by higher brain activity in the theta (5-7 Hz), alpha

(8-12 Hz), and beta (15-29 Hz) frequency bands, compared to the control group. Our findings mostly supported this hypothesis, as theta and alpha oscillations showed meaningful patterns, while beta oscillations generally did not exhibit strong significant differences, except for parietal and temporal regions which displayed borderline significance.

Theta oscillations, associated with task engagement, memory encoding, and attentional control (Klimesch, 1999; Crivelli-Decker et al., 2018; Cavanagh & Frank, 2014), demonstrated a significant main effect of Phase and Gamification by Phase interaction. Theta activity decreased over time in the control group but remained stable in the gamified group, suggesting that gamification may sustain cognitive engagement during language learning tasks. This aligns with prior research linking theta oscillations to sustained attention and working memory integration (Berka et al., 2007; Sauseng et al., 2010). In language learning contexts, theta activity supports lexical retrieval and the integration of new linguistic information into long-term memory (Bastiaansen & Hagoort, 2015). Topographical t-maps revealed that these effects were localized to fronto-central and parietal regions, which are implicated in attention processes and visuospatial working memory (Sauseng et al., 2010). The sustained theta activity observed in the gamified group may therefore reflect deeper engagement with learning materials and enhanced cognitive processing.

Alpha oscillations, often linked to attentional suppression and cognitive efficiency (Clayton et al., 2018; Klimesch, 1999), also demonstrated a significant main effect of Phase and a Gamification by Phase interaction. Alpha suppression, which is characterized by reduced alpha power, was more pronounced in the control group during Phase 2, reflecting greater mental effort or difficulty sustaining engagement (McKee et al., 1973). In contrast, the gamified group exhibited relatively stable alpha activity across phases, which may indicate more efficient resource allocation and reduced cognitive load (Bays et al., 2015). Increased alpha power has been observed in skilled language learners as a marker of task automaticity and reduced mental effort (Kepinska et al., 2017). Additionally, alpha oscillations play a critical role in memory processes by inhibiting irrelevant information, allowing learners to focus on task-relevant stimuli (Tuladhar et al., 2007; Jensen & Mazaheri, 2010). The gamified group's less pronounced alpha suppression may reflect their ability to maintain focus without overloading attentional capacity.

Beta oscillations showed no significant main effects or interactions for neither phase nor gamification. While pairwise comparisons revealed no differences between groups, t-maps indicated more widespread beta activity in the gamified group during Phase 2, particularly in right temporal and parietal regions. However, these effects did not survive FDR correction at the defined significance level, which suggests they may not be robust.

H3b hypothesized that participants learning in a gamified naSDLL environment would exhibit higher visual engagement, translated by higher fixation duration, count and k-coefficient compared to the control group. This hypothesis was partially supported, as our analyses revealed a significant Gamification by Phase interaction for fixation count, but no main effect of gamification on other measures. Both groups exhibited a sharp decline in fixation count from Phase 1 to Phase 2, but this decrease was more significantly pronounced in the gamified group. While we initially hypothesized that the gamification group would exhibit higher fixation count, this result may be indicative of improved task efficiency or reduced cognitive load in the gamified condition. More difficult tasks often result in a higher fixation count as individuals require more time to process information (Dahhan et al., 2014; Keskin et al., 2020; Volden et al., 2018). Gamification may thus help learners more efficiently process information in language learning tasks.

Fixation durations increased from Phase 1 to Phase 2 across both groups, suggesting deeper visual processing as participants became more familiar with the task structure at hand (Godfroid et al., 2020). However, the absence of a Gamification by Phase interaction indicates that the gamification components employed in this study did not significantly influence fixation duration.

The k-coefficient results revealed no significant effects of phase or gamification, with consistently negative values across conditions reflecting an ambient attentional style throughout the study. This suggests that participants primarily relied on broad visual scanning behavior rather than focal attention, which aligns with the nature of our language learning tasks—selecting correct answers from a list. However, gamification did not appear to enhance attentional focus on specific answers or task-relevant stimuli.

These findings offer significant methodological, conceptual and practical contributions. The below sections discuss our research’s contributions on these various angles.

2.6.1 Contributions

Firstly, we contribute to the literature by suggesting, through our experimental design, an innovative and holistic approach to measuring engagement and motivation through time. Gamification research has counted on the exclusive use of self-reported data to measure motivation and engagement, which may keep researchers from adequately capturing evolving motivational states. Our combination of implicit and explicit measures allowed us to delineate gamification's engaging mechanisms despite no significant results in terms of our questionnaire data, indicating that neuroscience tools can prove useful where self-reported data may be limited. This is particularly important in SLA & gamification literature, as researchers have pointed out the current measures of engagement & motivation fail to truly grasp their cognitive dimension. Had we sufficed with questionnaires or other surface-level measures, we may have completely missed the impressive and profound impact our implementation of gamification had over time.

Beyond validating and popularizing the use of EEG and eye tracking, we contribute to the literature by establishing baseline observations for longitudinal gamified language learning experiences. As we have identified brain regions and specific channels showcasing significantly stronger brain activity in the gamified group during language learning tasks, our findings may provide a starting point for future neurophysiological research to target specific areas of interest in the brain that may be involved in SLA task engagement. Our findings thus also contribute to conceptually defining how gamification acts upon cognitive mechanisms related to learning engagement and efficiency. The consideration of brain and eye gaze activity provides a renewed perspective into how the self-directed learning experience evolved, going beyond the exclusive use of superficial measures.

While our questionnaire analyses did not yield significance, their use remains instrumental in painting a cohesive portrait of what motivation is. Few studies recognize the unique dimensions of self-directed language learning motivation. By decomposing it into its topic-oriented and learning environment-oriented components, we contribute to a more rigorous conceptualization of motivation in the SDLL context. Future research may benefit from our framework as being more exhaustive of the different factors that may impact the concept of motivation. Conceptually, the spotlight is placed on the different sorts of motivation and engagement that are at play in relation to the SDL environment - the notion of classroom motivation is too often neglected in favor of intrinsic motivation alone, despite literature indicating attitudes towards the classroom also impact motivation in SLA.

Our mixed methods longitudinal design provides a unique methodological contribution, as it outlines a novel measure of complex subjective experiences through time. Aside from our study, no gamification research has followed the evolution of naSDLL learners' engagement and motivation in such a longitudinal experimental design. This matters as most gamification research focuses on academic populations in which gamification's impact may be impacted by other motivating and engaging mechanisms of the traditional classroom. Through our study, we aim to contribute to the understanding of non-academic language learners (naLL), a considerable and significant population, given the ever-increasing advancements of learning technologies and their democratization. Current literature on this type of learners is scarce, which limits the understanding of motivation and engagement dynamics through time. We thus contribute to the literature by illustrating how gamification may impact the motivation and engagement of naSDLL learners. While gamification is generally seen as a strong motivator, our non-significant results paint a different picture – one in which the motivation dynamics are radically different from those of students supervised by teachers or even academic / institutional authority.

Beyond the context of learning, keeping attrition low in a research project requiring hours of participation both at home and in-person as well as using neurophysiological tools that may come off as intimidating is a considerable achievement in of itself. Through a rigorous experimental protocol that enabled us to seamlessly follow participants' at-home learning, we present a major advancement to longitudinal research methodology in gamification and language learning. It is thus not only possible to minimize participant attrition in such longitudinal protocols but considering the evolving nature of motivation and engagement that requires over-time measures, it is highly suggested to improve current data collection standards. We believe our research may facilitate this movement in the literature by illustrating our successful methodological approach in this regard.

Finally, we contribute to the practice of gamification in language learning platforms by explaining the long-term effects of various gamification components, namely feedback, competition and personalization, in the naSDLL environment. Understanding the impact of these components given the unique nature of naSDLL is key to efficient gamification implementation. Our findings can assist language courses providers and educators better understand the engaging impact of gamification, ultimately improving retention rates over time which may positively impact the financial viability of naSDLL platforms.

2.7 Conclusion

SDL offers learners flexibility and autonomy but is often hindered by high attrition rates and motivational challenges. Unlike traditional classroom settings, it lacks the social interaction, structure, and external accountability that typically sustain engagement. Gamification, with its proven track record of enhancing motivation and engagement through game-like elements, has shown potential in formal language learning contexts. However, its effectiveness in naSDLL environments remains underexplored, particularly in terms of its impact on the evolution of naSDLL learners' motivation and engagement.

This research evaluated the effects of gamification on motivation and engagement in naSDLL using a combination of self-reported measures (IMI and rIMMS) and physiological data (EEG, fixation count, duration and k-coefficient). Our findings revealed several promising results. EEG results showed that gamification helped sustain theta and alpha activity over time, reflecting stable cognitive engagement and potentially more efficient resource allocation and reduced cognitive load in the gamified group compared to controls. Eye tracking data further indicated that gamification may improve task efficiency, as evidenced by sharper declines in fixation count over time. However, the overall impact of gamification was limited. Neither IMI nor rIMMS scores showed significant improvements over time in the gamified condition compared to controls, suggesting that gamification did not universally enhance motivation across all dimensions. Similarly, beta oscillations showed no meaningful differences between groups, indicating that gamification did not significantly influence higher-order executive functions, and gamification failed to impact our other eye tracking measures. These results suggest that while gamification can positively impact specific aspects of engagement and motivation, it may lack a broader impact in informal SDLL contexts.

2.7.1 Limitations & future research

Several limitations of this research must be acknowledged. First, the sizable financial compensation offered to participants may have influenced their motivation to learn a language, potentially shifting their focus from learning a language to completing the study for monetary reward. This could have undermined our measures of intrinsic motivation, as suggested by the overjustification effect (Deci et al., 1999; Lepper et al., 1973). Secondly, the experimental nature of the study raises concerns about the ecological validity of our results: while gamification showed limited effects in this controlled lab setting, its impact may differ in real-world contexts where learners engage with gamified platforms over longer periods and in more naturalistic environments without extrinsic motivators or the pressure to sustain one's participation in a study. Another limit was that our implementation of gamification was not integrated directly into the learning materials, but in frequent e-mail communications. Finally, as we did not control for participants' initial levels of intrinsic motivation at the start of the study, differences in initial intrinsic motivation could have influenced how participants responded to gamification, potentially biasing our self-report results.

Future studies should aim to balance the challenges of conducting controlled lab-based experiments with the need for ecological validity in naSDLL research. While lab settings are essential for employing advanced tools like EEG and eye tracking in gaining profound insights into cognitive and attentional processes, they may not fully capture the authentic dynamics of naSDLL. Researchers may consider combining lab-based methods with longitudinal designs that track learners' motivation and engagement over extended periods in naturalistic settings. Additionally, future studies should control for learners' initial levels of intrinsic motivation to better understand how baseline differences influence responses to gamification. Finally, future research must move beyond the sole usage of surface-level metrics such as self-reported data. The integration of neurophysiological can provide a more comprehensive understanding of how gamification impacts motivation and engagement in diverse learning contexts as demonstrated in this study.

2.7.2 Final remarks

Keeping learners engaged in complete isolation is a sizable challenge that must be addressed, as failure to do so can result in financial losses for providers and missed learning opportunities for individuals. Our results demonstrate that gamification's impact on engagement extends beyond what learners may consciously report - it profoundly influences their ability to sustain attention and remain focused during learning tasks. These results may have gone unnoticed if we had sufficed with the age-old overreliance on self-report measures alone. Further research is needed to fully understand the cognitive mechanisms underlying gamification's impact on naLL - an all-too-neglected population in gamification research. Exploring how gamification can be optimized to address the unique challenges of non-academic SDLL will be essential for designing more effective and engaging learning experiences for the general public.

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Appendix

Appendix 1

Rate your learning experience (Not true, Slightly true, Moderately true, Mostly true, Very true), based on the learning activities you've completed in the previous week, according to the following statements:

A3	The quality of the writing helped me to hold my attention.
A6	The way the information is arranged on the pages helped keep my attention.
A10	The variety of reading passages, exercises, illustrations… helped keep my attention on the learning activities.
R1	It is clear to me how the content of these learning activities is related to things I already know.
R6	The content and style of writing in the learning activities convey the impression that its content is worth knowing.
R9	The content of the learning activities will be useful to me.
C5	As I worked on the learning activities, I was confident that I could learn the content.
C7	After working on the learning activities for a while, I was confident that I would be able to pass a test on them.
C9	The good organization of the content helped me be confident that I would learn this material.

S2	I enjoyed these learning activities so much that I would like to know more about this topic.
S3	I really enjoyed studying these learning activities
S7	It was a great pleasure to work on such well-designed learning activities.

Appendix 2

For each of the following statements, please indicate how true it is for you (1 = Not true at all - 7 = Very true).

IMI1	I enjoyed doing these learning activities very much.
IMI2	These learning activities were fun to do.
IMI3	I thought these were boring learning activities. (R)
IMI4	These learning activities did not hold my attention at all. (R)
IMI5	I would describe these learning activities as very interesting.
IMI6	I thought these learning activities were quite enjoyable.
IMI7	While I was doing these learning activities, I was thinking about how much I enjoyed them.

Appendix 3

Adapted rIMMS item-by-item Pearson correlation for the Control and Gamified learning environment groups at each given week.

Control		Week 1			Week 2			Week 3			Week 4		
		A3	A6	A10	A3	A6	A10	A3	A6	A10	A3	A6	A10
Attention	A3	1	0.44	0.34	1	0.37	0.67*	1	0.78*	0.66*	1	0.42	0.56*
	A6	0.44	1	0.58*	0.37	1	0.37	0.78*	1	0.50	0.42	1	0.64*
	A10	0.34*	0.58	1	0.67	0.37*	1	0.66	0.50	1	0.56	0.64	1
		R1	R6	R9	R1	R6	R9	R1	R6	R9	R1	R6	R9
Relevance	R1	1	0.78*	0.66*	1	0.68*	0.57*	1	0.44	0.48	1	0.67*	0.69*
	R6	0.78*	1	0.82*	0.68*	1	0.81*	0.44	1	0.88*	0.67*	1	0.90*
	R9	0.66*	0.82*	1	0.57*	0.81*	1	0.48	0.88*	1	0.69*	0.90*	1
		C5	C7	C9	C5	C7	C9	C5	C7	C9	C5	C7	C9
Confidence	C5	1	0.63*	0.57*	1	0.78*	0.63*	1	0.84*	0.81*	1	0.92*	0.68*
	C7	0.63*	1	0.37	0.78*	1	0.69*	0.84*	1	0.54*	0.92*	1	0.68*
	C9	0.57*	0.37*	1	0.63*	0.69*	1	0.81*	0.54*	1	0.68*	0.68*	1
		S2	S3	S7	S2	S3	S7	S2	S3	S7	S2	S3	S7
Satisfaction	S2	1	0.86*	0.78*	1	0.80*	0.88*	1	0.95*	0.89*	1	0.76*	0.56*
	S3	0.86*	1	0.77*	0.80*	1	0.72*	0.95*	1	0.85*	0.76*	1	0.85*
	S7	0.78*	0.77*	1	0.88*	0.72*	1	0.89*	0.85*	1	0.56*	0.85*	1
		Week 1			Week 2			Week 3			Week 4		

Gamified learning environment													
		A3	A6	A10	A3	A6	A10	A3	A6	A10	A3	A6	A10
Attention	A3	1	0.70*	0.30	1	0.67*	0.52	1	0.69*	0.69*	1	0.87*	0.74*
	A6	0.70*	1	0.35	0.67*	1	0.40	0.69*	1	0.74*	0.87*	1	0.79*
	A10	0.30	0.35	1	0.52	0.40	1	0.69*	0.74*	1	0.74*	0.79*	1
		R1	R6	R9	R1	R6	R9	R1	R6	R9	R1	R6	R9
Relevance	R1	1	0.06	0.18	1	0.38	0.10	1	0.51	0.47	1	0.63*	0.46
	R6	0.06	1	0.79*	0.38	1	0.70*	0.51	1	0.88*	0.63*	1	0.64*
	R9	0.18	0.79*	1	0.10	0.70*	1	0.47	0.88*	1	0.46	0.64*	1
		C5	C7	C9	C5	C7	C9	C5	C7	C9	C5	C7	C9
Confidence	C5	1	0.63*	0.61*	1	0.52	0.61*	1	0.74*	0.68*	1	0.58*	0.71*
	C7	0.63*	1	0.49	0.52	1	0.29	0.68*	1	0.61*	0.58*	1	0.71*
	C9	0.61*	0.49	1	0.61*	0.29	1	0.68*	0.61*	1	0.71*	0.71*	1
		S2	S3	S7	S2	S3	S7	S2	S3	S7	S2	S3	S7
Satisfaction	S2	1	0.82*	0.81*	1	0.81*	0.78*	1	0.81*	0.85*	1	0.84*	0.90*
	S3	0.82*	1	0.93*	0.81*	1	0.67*	0.81*	1	0.87*	0.84*	1	0.96*
	S7	0.81*	0.93*	1	0.78*	0.67*	1	0.85*	0.87*	1	0.90*	0.96*	1

* Correlation is significant at $p > 0.05$ (2-tailed)

Appendix 4

Adapted IMI item-by-item Pearson correlation for the Control and Gamified learning environment groups at each given week.

Control

	Week 1							Week 2						
	IMI1	IMI2	IMI3	IMI4	IMI5	IMI6	IMI7	IMI1	IMI2	IMI3	IMI4	IMI5	IMI6	IMI7
IMI1	1	0.92*	0.66*	0.88*	0.50*	0.73*	0.76*	1	0.86	0.80	0.76	0.66	0.64	0.35
IMI2	0.92*	1	0.64*	0.86*	0.41	0.67*	0.79*	0.86*	1	0.74*	0.67*	0.53	0.56*	0.40
IMI3	0.66*	0.64*	1	0.77*	0.40	0.34	0.38	0.80*	0.74*	1	0.89*	0.50	0.34	0.13
IMI4	0.88*	0.86*	0.77*	1	0.29	0.10	0.51	0.76*	0.67*	0.89*	1	0.46	0.39	0.07
IMI5	0.50*	0.41	0.40	0.29	1	0.86*	0.52	0.66	0.53	0.50	0.46	1	0.84*	0.56*
IMI6	0.73*	0.67*	0.34	0.10	0.86*	1	0.72*	0.64*	0.56*	0.34	0.39	0.84*	1	0.67*
IMI7	0.76*	0.79*	0.38	0.51	0.52	0.72*	1	0.35	0.40	0.13	0.07	0.56*	0.67*	1
	Week 3							Week 4						
	IMI1	IMI2	IMI3	IMI4	IMI5	IMI6	IMI7	IMI1	IMI2	IMI3	IMI4	IMI5	IMI6	IMI7
IMI1	1	0.70*	0.57*	0.75*	0.69*	0.79*	0.84*	1	0.87*	0.57*	0.78*	0.70*	0.85*	0.84*
IMI2	0.70*	1	0.40	0.62*	0.58*	0.66*	0.64*	0.87*	1	0.60*	0.73*	0.72*	0.92*	0.84*
IMI3	0.57*	0.40	1	0.74*	0.43	0.43	0.44	0.57*	0.60*	1	0.72*	0.87*	0.58*	0.56*
IMI4	0.75*	0.62*	0.74*	1	0.75*	0.63*	0.66*	0.78*	0.73*	0.72*	1	0.67*	0.69*	0.66*
IMI5	0.69*	0.58*	0.43	0.75*	1	0.85*	0.78*	0.70*	0.72*	0.87*	0.67*	1	0.72*	0.69*
IMI6	0.79*	0.66*	0.43	0.63*	0.85*	1	0.93*	0.85*	0.92*	0.58*	0.69*	0.72*	1	0.89*

IMI7	0.84*	0.64*	0.44	0.66*	0.78*	0.93*	1	0.84*	0.84*	0.56*	0.66*	0.69*	0.89*	1
Gamified learning environment	Week 1							Week 2						
	IMI1	IMI2	IMI3	IMI4	IMI5	IMI6	IMI7	IMI1	IMI2	IMI3	IMI4	IMI5	IMI6	IMI7
IMI1	1	0.76*	0.49	0.80*	0.70*	0.84*	0.57*	1	0.86*	0.75*	0.65*	0.93*	0.91*	0.77*
IMI2	0.76*	1	0.54*	0.86*	0.63*	0.71*	0.50	0.86*	1	0.84*	0.88*	0.78*	0.81*	0.62*
IMI3	0.49*	0.54	1	0.62	0.66	0.65	0.50*	0.74	0.84	1	0.82	0.68	0.66	0.55
IMI4	0.80*	0.86*	0.62*	1	0.64*	0.79*	0.41	0.65*	0.88*	0.82*	1	0.54*	0.57*	0.44
IMI5	0.70*	0.63*	0.66*	0.64*	1	0.73*	0.66*	0.93*	0.78*	0.68*	0.54*	1	0.91*	0.81*
IMI6	0.84*	0.71*	0.65*	0.79*	0.73*	1	0.73*	0.91*	0.81*	0.66*	0.57*	0.91*	1	0.83*
IMI7	0.57*	0.50	0.50	0.41	0.66*	0.73*	1	0.77*	0.62*	0.55*	0.44	0.81*	0.83*	1
	Week 3							Week 4						
IMI1	1	0.85*	0.31	0.17	0.89*	0.84*	0.83*	1	0.92*	0.10	0.38	0.83*	0.82*	0.62*
IMI2	0.85*	1	0.35	0.24	0.85*	0.87*	0.82*	0.92*	1	0.29	0.57*	0.95*	0.87*	0.85*
IMI3	0.31	0.35	1	0.91*	0.41	0.42	0.29	0.10	0.29	1	0.51	0.27	0.07	0.33
IMI4	0.17	0.24	0.91*	1	0.29	0.38	0.21	0.38	0.57*	0.51	1	0.65*	0.42	0.46*
IMI5	0.89*	0.85*	0.41	0.29	1	0.79*	0.83*	0.83*	0.95*	0.27	0.65*	1	0.90*	0.87*
IMI6	0.84*	0.87*	0.42	0.38	0.79*	1	0.87*	0.82*	0.87*	0.07	0.42	0.90*	1	0.81
*IMI7	0.83*	0.82*	0.29	0.21	0.83*	0.87*	1	0.62	0.85*	0.33	0.46	*0.87*	0.81*	1

* Correlation is significant at p > 0.05 (2-tailed)

Chapitre 3 : Article 2
Leaderboards, feedback and personalization: How to keep adult language learners outside the classroom engaged through gamification.

Abstract. In the context of increasing interest in non-academic self-directed language learning (naSDLL), sustaining learner motivation and engagement to keep learners from dropping out remains a significant challenge. Our study explored the impact of gamification on learners' motivation and engagement over a month-long naSDLL experience. The findings reveal that gamification can enhance specific aspects of engagement while discussing the unique dimensions of motivation in non-academic SDLL. This article provides actionable recommendations for educators and platform designers to create gamified learning experiences that foster long-term motivation, engagement, and learning efficiency for the public outside the academic setting of language learning.

3.1 Introduction

How many hopeful adults begin learning a language online, only to drop out after a few weeks? Non-academic self-directed language learning (naSDLL) has become increasingly popular in recent years, with millions of learners turning to online platforms to acquire new languages at their own pace. Platforms such as Duolingo and Babbel offer convenience and accessibility, allowing users to study anytime and anywhere. However, self-directed learning (SDL) faces a critical challenge: many learners abandon their studies prematurely, leading to high attrition rates that impact both learners' personal goals and ultimately, the financial viability of learning platforms. Researchers have sought to explain this widespread attrition phenomenon and have linked it to declining motivation through time. Unlike traditional classroom settings, SDL lacks social interaction, structured guidance, and accountability towards, factors that are key to maintaining motivation. These characteristics of SDL may lead language learners to abandon their course.

So, how do we keep learners engaged through time when it is so easy to just quit when motivation wanes? Gamification - the application of game-like elements such as rewards, leaderboards, and personalized feedback - has emerged as a promising solution to this problem. By making learning more enjoyable, gamification aims to sustain motivation and prevent learner dropout. While research has shown gamification's positive effects in traditional educational contexts like classrooms with a teacher and peers present, its impact on non-academic language learning environments remains underexplored. Moreover, much of the existing research focuses on self-reported measures such as surveys or interviews, which may not fully capture the complex nature of engagement during learning tasks.

To better understand gamification in this context and explore whether it is worth it to implement gamification in non-academic language courses, our research investigated how gamification influences motivation and engagement in a month-long naSDLL experience, using both motivation questionnaires and advanced tools such as electroencephalography (EEG) and eye tracking.

Our study evaluated whether gamification components, namely feedback on weekly performance, comparing to other learners through a leaderboard graph and personalization of a weekly learning plan based on participants' learning goals, contributed to sustaining learners' motivation to learn French over a month, and whether these components had a lasting impact over learners' engagement during learning tasks. Ultimately, the findings of our research described below aim to support language courses providers and practitioners in implementing efficient

gamification components, guaranteeing an escape from the ever-present demotivation curse these learners face.

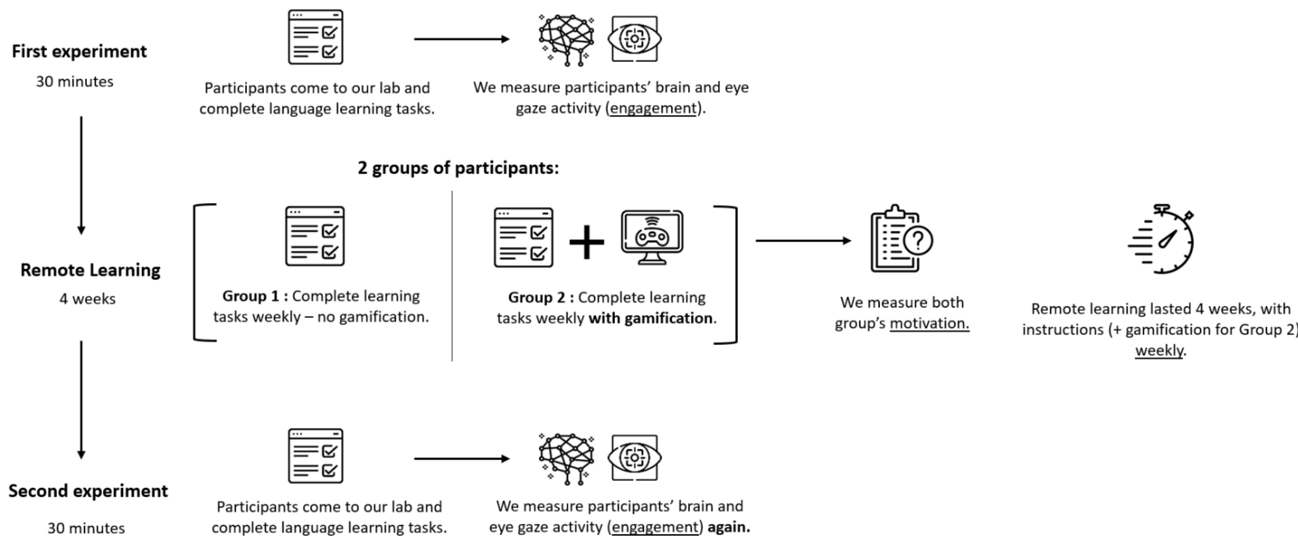

Figure 1. Timeline of the experiment detailing the first experiment, remote learning and second experiment after 4 weeks.

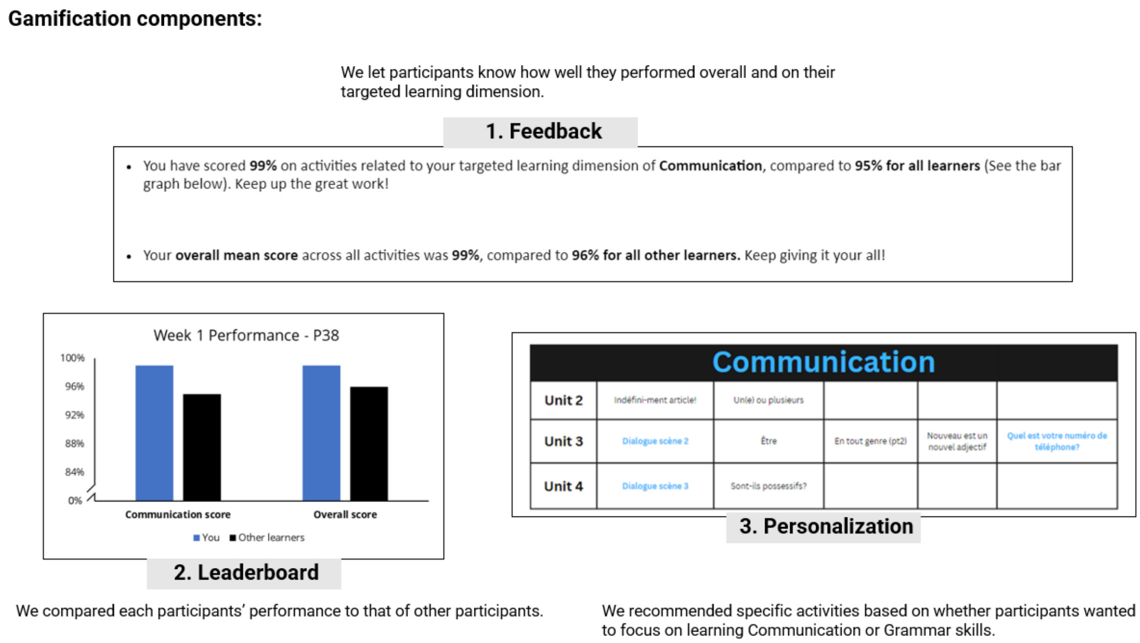

Figure 2. Representation of our gamification components.

3.2 Enhancing engagement in learning tasks

One of the key findings of our study was that gamification had a significant impact on learners' ability to stay engaged during language learning tasks. Using cutting-edge tools like EEG, we observed that participants in the control group, who learned without gamification, showed a noticeable decline in brain activity in areas linked to engagement and information processing after a month of regular, non-gamified language learning at home. In contrast, being exposed to gamification maintained steady brain activity in these areas as participants completed language tasks, suggesting that gamification helped them stay focused and engaged throughout the learning process. More specifically, learners in the gamified group showed stable levels of theta brain activity over time, which indicates a state of high engagement through better attention and memorizing during learning, while theta activity significantly decreased through time in the non-gamified group, reflecting lesser engagement.

From a practical perspective, this finding highlights the crucial role gamification features can play in keeping non-academic SDLL learners engaged. Unlike traditional classrooms, SDL environments lack supervision and accountability towards the teacher and peers, making it easier for learners to become distracted or disengaged. Gamification components such as progress tracking, challenges, and personalized content can encourage learners to engage further with naSDLL learning interfaces and remain attentive throughout their sessions by providing clear goals and rewards for task completion.

For example, progress tracking can give learners a sense of accomplishment by visualizing their achievements over time, while personalized learning tracks can adapt to their goals and keep tasks stimulating without becoming overwhelming. Additionally, incorporating elements that simulate social interaction, such as leaderboards, can help mitigate the feeling of isolation and create a sense of shared progress among learners. These strategies can reduce the likelihood of disengagement while promoting sustained attention and focus throughout the learning experience.

3.3 Enhancing efficiency in learning tasks

Our findings also revealed differences in alpha brain activity, which is associated with mental effort and cognitive efficiency. Learners in the gamified condition displayed stable alpha activity across phases, while the control group experienced strong alpha suppression, which is linked to increased mental effort or cognitive load, suggesting that learners without gamification found it harder to stay engaged as tasks progressed. In contrast, stable alpha activity in the gamified group indicates that gamification helped reduce cognitive efforts by making tasks feel less demanding and more manageable.

This finding outlines the importance of structured and personalized learning paths that guide learners step-by-step through their tasks & may reduce cognitive demands by breaking complex activities into smaller, more manageable chunks, which in turn can optimize learning performance and reduce the chance of dropping out. Making learning more efficient and less straining is especially crucial in naSDLL, where adult learners must juggle with other more pressing personal and professional responsibilities. Additionally, these implementations of gamification may compensate for the absence of an instructor (as they typically provide assignments and a structured learning syllabus), which can be particularly disengaging. For instance, Duolingo's trusty owl mascot provides learners with support, encouragement and structured learning steps, making the language learning process not only fun but ultimately more engaging. Guiding learners through gamified learning paths can thus also embody the supervisory role a teacher typically plays in the traditional classroom.

We've also observed that participants in the gamification group had a significantly lower fixation count (equating to less frequent eye gaze fixations around the screen while completing language learning tasks) compared to the control group. This reduction, typically a sign that learning takes less efforts, concords well with our brain activity results and suggests that gamification may lead learners to better focus on relevant information while avoiding unnecessary distractions. To this end, rather than focus on metrics such as time spent on a learning interface (which is not necessarily indicative of how engaged learners are), it may be more worthwhile for practitioners to instead focus on implementing gamification components that help learners study more intelligently while compensating for the weaknesses of the SDL environment. Tooltips, hints and practice modes are other gamification components that can serve this end, which may replace the guidance and office-hours typically provided by instructors in traditional settings.

3.3 Motivating learners in naSDLL

While we initially hypothesized that gamification would increase motivation towards learning a language and towards learning in the SDL context, our findings indicate it had a limited impact. Using validated classroom and language learning motivation scales, we observed no significant differences in overall motivation scores between the gamified and control groups over time. A surprising result to be sure, as gamification is often hailed for its ability to enhance motivation in traditional educational settings, our findings suggest that its motivating dynamics may be different in naSDLL.

In traditional classrooms, these components often foster competition and collaboration, but in SDL's isolated, self-regulated environment, their impact may be diminished. Our participants had limited information about their peers beyond their performance, and our gamification components lacked to provide a replacement for the support and supervision typically offered by an instructor in the classroom setting, which likely reduced the motivating nature of the gamification components presented. Addressing non-academic SDLL's solitary nature through gamification may be the key to sustain learner motivation.

For instance, Duolingo offers to visit other learners' profiles, see their streaks and the languages they're interested in learning, which in turn may help learners feel less solitary, introduce a sense of personal competition and lead to sustained engagement over time. By doing so, SDLL providers can simulate the positives of traditional language lessons while still preserving the autonomy and freedom that makes it so alluring to millions of learners. Other platforms like Kahoot create personal rapport with other learners during the learning process in real-time by directly showcasing differences in scores following each answered question. By implementing similar social-based components, naSDLL providers can simulate the positives of traditional language lessons while still preserving the autonomy and freedom that makes it so alluring to millions of learners.

In making sense of our lack of results regarding motivation, it is important to keep in mind that participants' motivation to learn a language may have been impacted by our very experiment. Indeed, to keep participants involved in our study, we compensated them for each week of learning successfully completed (regardless of performance), which may have biased their initial motivation. This phenomenon is known in the literature as the "overjustification effect", where a learners' intrinsic motivation may decrease after receiving an external reward.

While it is not a direct result of our analysis, we recommend for practitioners to focus on fostering participants' genuine interest in learning a language rather than provide them with extrinsic motivators. Offering rewards is a popular gamification features in several learning platforms, but it may not be the sole viable long-term strategy in non-academic SDLL. Its implementation should be accompanied by other gamification components that can nurture intrinsic motivation to learn & act on the weaknesses of SDLL, such as the ones mentioned above.

3.4 Conclusion

Our findings suggest that feedback, leaderboards and personalization can increase learning engagement through time. Gamification has a deep and lasting impact through time over engagement in naSDLL. We have showcased the importance of accounting for the unique dynamics of non-academic SDLL when implementing gamification. We thus recommend that practitioners and designers involved in creating gamified learning platforms integrate feedback, leaderboards and personalization, as they have been proven to help keep learners engaged, while also considering the various gamification components mentioned above that may address the isolating, demotivating nature of naSDLL.

Chapitre 4 : Conclusion

L'objectif de ce mémoire était d'évaluer l'impact de la gamification sur l'évolution de la motivation et de l'engagement des apprenants de langue autodirigés en dehors du cadre académique à travers une perspective neurophysiologique. À cet effet, la question de recherche était la suivante :

« *Dans quelle mesure la gamification de l'expérience de naSDLL impacte-t-elle l'évolution de la motivation et de l'engagement des apprenants adultes en dehors du cadre académique?* »

4.1 Résultats principaux

Les résultats de l'article 1 suggèrent que la gamification peut avoir un impact sur l'engagement des apprenants de langue adultes en dehors du cadre académique, mais que son impact sur la motivation de ces derniers, tant la motivation intrinsèque que la motivation vis-à-vis de l'environnement autodirigé, était limité. En effet, l'analyse des données cérébrales lors de tâches d'apprentissage de langue espacées par le temps indique que l'activité cérébrale des apprenants dans le groupe contrôle était significativement plus basse dans les fréquences Thêta et Alpha après un mois d'apprentissage de langue autodirigé comparativement à celle des apprenants dans le groupe expérimental. Ces résultats suggèrent un meilleur engagement pendant les tâches d'apprentissage, une meilleure capacité à éliminer les distractions, mais surtout, que la gamification peut protéger les apprenants du déclin de l'engagement à travers le temps. Nous avions également mesuré la durée des fixations oculaires, leur fréquence ainsi que le coefficient-K, indiquant une variation dans le type d'attention lors de ces mêmes tâches. Les résultats indiquent que la fréquence des fixations oculaires était significativement plus basse dans le groupe expérimental. Ce résultat, quoique n'étant pas initialement hypothétisé, suggère une potentielle réduction de l'effort visuel et cognitif requis à compléter des tâches d'apprentissage, ce qui s'aligne avec les résultats d'activité cérébrale. Finalement, quant aux scores motivationnels en lien avec le SDL d'une durée de 4 semaines, aucune différence significative n'a été trouvée entre les 2 groupes. Nous avons toutefois constaté une relation non-linéaire entre l'application de gamification et les scores de perception de pertinence du matériel d'apprentissage, ce qui implique que les composantes de gamification, notamment la personnalisation du parcours d'apprentissage, ont pu avoir un impact sur l'évolution de la dimension motivationnelle de pertinence du matériel aux objectifs d'apprentissage.

L'article 2 représente un article managérial dans lequel les résultats de l'article 1 sont passés en revue et contextualisés selon les particularités de naSDL. L'effet de nos implémentations de gamification est discuté en fournissant des pistes actionnables tenant compte des particularités uniques du milieu autodirigé non-académique aux professionnels du milieu afin d'augmenter la motivation et l'engagement des apprenants, ce qui permettrait un moindre taux d'abandon et, ultimement, une meilleure viabilité financière de ces dernières.

4.2 Contributions

Cette section illustre les contributions de ce mémoire dans la théorie et la pratique.

4.2.1 Contributions théoriques

Ce mémoire enrichit la littérature quant à l'impact de la gamification dans le naSDLL. Comme souligné plus tôt, la littérature actuelle de gamification a négligé cette forme d'apprentissage de langues malgré qu'elle soit très répandue en faveur de recherches dans le milieu académique. Plus spécifiquement, ce mémoire documente l'impact de rétroactions, compétition et personnalisation comme composantes de gamification sur l'engagement et la motivation des apprenants de langues en dehors du cadre académique, indiquant qu'elles peuvent impacter l'engagement des apprenants à long-terme. De plus, ce mémoire contribue à la littérature neurophysiologique de la gamification en mettant de l'avant des mesures objectives de l'engagement des apprenants. Nous avons mis de l'avant les régions du cerveau les plus impactées par notre manipulation expérimentale, ce qui contribue à expliquer le mécanisme par lequel la gamification a un impact sur l'expérience d'apprentissage. Alors que la littérature actuelle tend à se suffire de mesures auto-rapportées et de performance, nous avons démontré que l'utilisation d'outils neurophysiologiques comme l'EEG et l'oculométrie peut déceler un impact de la gamification sur les processus cognitifs sous-jacents à l'engagement lors de tâches d'apprentissage alors que les questionnaires seuls n'ont pas pu trouver d'effet significatif.

4.2.2 Contributions pratiques

Pratiquement, ce mémoire soutient les professionnels et les fournisseurs d'apprentissage de langues. Premièrement, nous indiquons que les composantes de gamification implémentées dans notre manipulation expérimentale ont eu un effet sur l'engagement des apprenants, ce qui peut guider la prise quant à quels éléments de gamification seraient à implémenter dans de réelles interfaces d'apprentissage dans l'objectif ultime de réduire le taux d'attrition des apprenants. D'autre part, nous soulignons la manière selon laquelle les dynamiques du naSDLL diffèrent de celles de la salle de classe de langues traditionnelle et comment les composantes de gamification ayant un effet dans cette dernière puissent ne pas avoir le même impact dans le milieu non-académique. Plus précisément, un accent est mis sur l'isolation sociale que peuvent ressentir les apprenants de langue auto dirigés, et nous fournissons des pistes actionnables quant à l'amélioration de composantes de gamification à cet effet.

4.3 Discussion

Négliger la motivation et l'engagement des apprenants auto dirigés résulte en un haut taux d'abandon de cours, ce qui impacte non seulement la qualité de l'apprentissage, mais aussi les revenus des plateformes de naSDLL. Les résultats de ce mémoire suggèrent que la gamification est un outil précieux dans le soutien de l'engagement des apprenants de naSDLL, mais que les composantes implémentées dans notre recherche n'ont pas eu d'impact sur la motivation des apprenants. Il importe donc de considérer les dynamiques uniques au contexte non-académique afin de soutenir les apprenants dans leur expérience d'apprentissage.

4.3.1 Limitations

Ce mémoire présente 3 limitations générales à considérer.

Premièrement, nous n'avons pas mesuré le niveau initial de motivation d'apprentissage de langues de nos participants, ce qui peut avoir impacté les mesures motivationnelles à travers l'étude. Deuxièmement, toujours en lien avec notre design expérimental, le fait que nous ayons fourni une compensation financière considérable aux participants (de l'ordre de 170 CAD), tant pour les expériences en personne que pour le SDL pendant les 4 semaines, aurait pu introduire un motivateur extrinsèque, ce qui peut avoir biaisé la motivation intrinsèque de l'apprentissage de langue. Finalement, le simple fait d'avoir tenu une expérience élaborée avec des conditions de succès requises auprès des participants (afin de garantir ladite compensation) peut avoir en partie dénaturé la validité écologique de nos résultats, particulièrement en lien avec la motivation perçue rapportée par les participants.

4.3.2 Avenues de recherche

Considérant que la majorité des études de gamification se basent sur un apprentissage académique, la littérature pourrait se pencher davantage sur le naSDLL. Comme ce dernier est souvent qualifié par une isolation sociale, un manque de rétroaction et un manque de pression exercée par une figure d'autorité comme un instructeur ou un établissement, les futures recherches pourraient se concentrer sur les composantes de gamification propices à résoudre ces enjeux. Les futures études quant à l'impact de la gamification pourraient également continuer de miser sur des outils de mesure neurophysiologiques innovants comme l'EEG et l'oculométrie.

4.3.3 Remarques finales

L'industrie du naSDLL est en plein essor. Soutenir la motivation et l'engagement des apprenants demeure une étape incontournable dans la réduction du nombre d'abandons. Les dynamiques du contexte non-académique doivent être prises en compte dans l'implémentation de la gamification afin de pallier les faiblesses du milieu autodirigé.

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