Jun. 2025 Volume.2 • No.2

igee proceedings

Institute for Global Engagement and Empowerment (IGEE)
Yonsei University, Seoul, Korea

igee proceedings
Jun. 2025, Volume.2 No.2
Pages 53-147

#301 Appenzeller Hall, Yonsei University, Seoul, Republic of Korea

e-igee.org igee.yonsei.ac.kr geef-sd.org

pISSN: 3022-5183 eISSN: 3022-5191

Jun. 2025, Volume.2 No.2

igee proceedings

Aims and scope

IGEE Proceedings is an international, multidisciplinary, scholarly, peer-reviewed, and open-access journal that aims to publish original research, review, and perspective papers across all fields relevant to achieving the 17 United Nations Sustainable Development Goals (SDGs). We aim to foster a holistic and integrated approach to sustainable development research by bringing together various disciplines and fields. *IGEE Proceedings* intends to help researchers, policymakers, practitioners, and the general public understand how to ensure the well-being of current and future generations by addressing complex social, environmental, and technological problems that pose sustainability challenges, which cannot be tackled in isolation.

We welcome submissions from researchers worldwide, with an emphasis on promoting diversity, equity, and inclusion. *IGEE Proceedings* values research that helps develop a better conceptual base for understanding sustainability and the social responsibility of organizations/institutions across borders. We encourage authors to explore innovative approaches and practical solutions that advance sustainable development in various contexts, including local, regional, national, and global levels. Our ultimate goal is to contribute to sustainable development by disseminating high-quality research that informs policymaking, decision-making, and public awareness.

We are open to accepting papers related to the SDGs, and we encourage authors to address issues related to various aspects of the SDG Framework, including, but not limited to, sustainable development, climate change, energy, food systems, water, biodiversity, health, education, poverty, inequality, and peace.

IGEE Proceedings accepts papers that have been previously published (within one to two years), as long as they are revised and refined according to our aim and scope. We publish articles electronically in English throughout the year and compile them three times a year for electronic and print publication.

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Publisher Institute for Global Engagement & Empowerment at Yonsei University

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Published on June 30, 2025

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pISSN: 3022-5183 eISSN: 3022-5191

IGEE Proc 2025;2(2):53-54
https://doi.org/10.69841/igee.2025.011

Perspective

Realistic Positioning of Social Businesses to Stem Climate Incentive Distortions within the Existing Market Economy

Muhammad Yunus

Chief Adviser of the Interim Government of Bangladesh

It is widely acclaimed that the leadership of youth and marginalized communities is essential for creating sustainable development outcomes, particularly when women are empowered with some financial resources, along with basic training and policy guidelines. The development synergy that the country may experience is just enormous. In Bangladesh, what Grameen Bank initiated back in 1976, has now been included in the national development initiatives of many countries to ensure equity and justice. These initiatives are fully driven by women.

In my whole journey of life, I have personally experienced that youth can do amazing things, which are completely beyond the imagination of our generations. In Bangladesh, the young students led a mass uprising last July and August and stood against an autocratic and oppressive regime. Now, we dare to dream of a new Bangladesh because of the supreme sacrifices of thousands of young students. They stood for freedom and justice, based on their profound belief in liberalism, pluralism, and equity.

The ethos, wisdom, and courage of Generation Z are the guiding principles of a new Bangladesh, depending on which we dream to build an inclusive society to ensure equal opportunities for all. Though it is very hard to accept, the reality is that the world has failed to ensure climate justice and channel robust resources for climate adaptation and mitigation in the climate-vulnerable countries. Without tackling the climate crisis collectively, the global economy and development agenda can never be sustainable. We must act decisively on this for the benefit of the majority of the global population.

The transformative vision of a net-zero world has to be redeemed. I believe the world needs to engage in a shared vision of three zeros that we can materialize together: targeting zero poverty, zero unemployment, and zero net carbon emissions. A

Received: April 8, 2025 **Revised:** April 8, 2025
Accepted: May 8, 2025

world where a young person anywhere in the world will have opportunities to grow, not as a job seeker but as an entrepreneur. A world where young people can unleash their latent creativity despite all limitations, where an entrepreneur can optimally balance social benefits, economic profits, and responsibility towards nature, where social business can help an individual transcend beyond consumers and can ultimately catalyze social and economic transformation.

Time demands new attitudes, new values, and new compacts across communities and countries, across developed and developing countries alike, across all actors and stakeholders. If we are to realize such a course correction, we, the government, non-government, business, and philanthropies, have to work together. If we accept and accommodate social business within the existing economic structure, we can bring meaningful changes in the lives of the bottom half of the population in every society.

If we can realistically position social business, we can stem much of the climate incentive distortions within the existing market economy. We should renew our commitment from today that our actions and policies must bridge the divides and the gaps. It is the call of our shared journey to a sustainable future. For our next generation, it is our decision whether to take a side with an equity-based society or continue with the usual actions that widen the gaps.

If our commitment and firm action can inspire the youths, women, children, and marginalized people to have a dream of equity and justice, then our development initiatives will be sustainable. Rest assured that Bangladesh will continue to deliver its policies and actions to secure peace, prosperity, and justice for everyone.

Acknowledgments

At the Seventh Global Engagement and Empowerment Forum (GEEF), held at Yonsei University in South Korea from March 13 to 14, 2025,Muhammad Yunus delivered an impactful speech emphasizing the urgent need to transform our approach to achieving the Sustainable Development Goals (SDGs). Themed “Time for Action: Bridging Divides for a Sustainable Future,” the forum served as a vital platform for developing innovative solutions to global challenges and addressing delays in the implementation of the SDGs. This is a summarized transcript of Muhammad Yunus’s speech.

Muhammad Yunus

2006 Nobel Peace Prize Laureate

Muhammad Yunus was born on June 28, 1940. He is a Bangladeshi economist, the founder and managing director of Grameen Bank. In 2006, Muhammad Yunus and Grameen Bank were awarded the Nobel Peace Prize for their work to “create economic and social development from below”. On August 6, 2024, Yunus was appointed to lead an interim government in Bangladesh. Muhammad Yunus 2006 Nobel Peace Prize Laureate Grameen Bank's objective since its establishment in 1983 has been to grant poor people small loans on easy terms. Grameen Bank is an institution that pioneered microcredit, a method of banking where small loans are given to the poor possessing no collateral, mostly to women, for income-generating activities. It has helped them get out of poverty, establishing creditworthiness and financial self-sufficiency. In 1972, following studies in Bangladesh and the USA, Yunus was appointed professor of economics at the University of Chittagong. When Bangladesh suffered a famine in 1974, he felt that he had to do something more for the poor beyond simply teaching. He decided to give long-term loans to people who wanted to start their own small enterprises. This initiative was extended on a larger scale through Grameen Bank. According to Yunus, poverty means being deprived of all human value. He regards micro-credit both as a human right and as an effective means of emerging from poverty: “Lend the poor money in amounts which suit them, teach them a few basic financial principles, and they generally manage on their own”, Yunus claims.

Jun. 2025, Volume.2 No.2

igee proceedings

pISSN: 3022-5183 eISSN: 3022-5191

IGEE Proc 2025;2(2):55-57
https://doi.org/10.69841/igee.2025.013

Perspective

Women and Children: The First Victims in Times of Crisis

Denis Mukwege

Professor of Université Libre de Bruxelles

In a world at a crossroads, where geopolitical rivalries threaten our future, the theme chosen for this Forum " Time for Action: Bridging Divides for a Sustainable Future " has captured our attention. It highlights the pressing challenges of our time and invites us together to change the course of events.

The system of collective security and global protection of human rights established after the horrors of the Second World War has never been so tested. As we approach the 80th anniversary of the United Nations, the international order is being challenged and respect for human rights is being regressed throughout the world. As in all times of crisis, it is women and children who are the first victims.

While the UN Charter was based on sovereign equality between states and the principle of prohibiting the use of force, establishing a world order based on the rule of law, international law is being flouted every day. The global consensus on democracy, the rule of law and human rights seem to be crumbling under the growing weight of authoritarian and oligarchic regimes.

Indeed, in a growing number of situations, the powerful seek to impose their will over the force of the law. The result is a dangerous weakening of the rule of law both nationally and internationally. Heads of State and government disregard the basic principles of international law. They flout conventions relating to human rights and international humanitarian law on a daily basis and ignore the decisions of the International Court of Justice.

Furthermore, the frequent application of the principle of double standards illustrates the cynicism and hypocrisy of international diplomacy. This contributes to further undermining the credibility of the political world and institutions.

Ladies and Gentlemen,

This brief overview of the state of the world is worrying and full of uncertainties. The sources of division are numerous: between economically advanced countries and developing countries; between the Global North and the Global South; between liberal democracies that inspire trust and authoritarian dictatorships that spread fear; between those who advocate for law and

Received: March 12, 2025 **Revised:** April 9, 2025
Accepted: May 8, 2025

truth and those who opt for force and disinformation.

Moreover, while the fragmentation of the world has long been modelled on geography, it is clear that new divisions are emerging and changing international relations - particularly within the Western world. These divisions open the way to a likely reconfiguration of alliances and other forms of partnerships between countries and regional blocs.

Humanity and the planet are facing various existential threats, including the climate crisis, the proliferation of nuclear weapons, pandemics, and numerous conflicts. In the face of these global challenges that concern us all, it is worth remembering that the interdependence between countries and peoples has never been greater. We cannot stand by and accept the slow death of multilateralism based on the rule of law and respect for human rights. Moreover, a new global governance capable of responding to the major challenges of the contemporary world is slow to be established.

There is therefore an urgent need to act with determination to bridge existing gaps and build bridges to lay the foundations for a sustainable and united future. Such a process should be done through policies of equity, inclusion, and diversity. Because above all, it is necessary to ensure that no one is sidelined or excluded. Indeed, respect for human rights for all must be part of the solution.

It is in this context that the imperative of reforming or even renovating the international system was at the heart of the debates of the 79th United Nations General Assembly. On the occasion of the "Summit for the Future", the Secretary-General rightly stated that: "we cannot shape the future of our grandchildren with a system designed for our grandparents ". The adoption of the "Pact for the Future" is a step in the right direction to reform and strengthen the multilateral system in order to face the existential threats and challenges of the 21st century.

This imperative of reforms aimed at restoring citizens' confidence in global institutions will have to go through a reform of the Security Council and international financial institutions. In addition, better representation of developing and emerging countries within international decision-making bodies will have to put an end to the marginalization of Africa.

Ladies and Gentlemen,

At the heart of this divided and changing world, marked by cynical geopolitics and an era of impunity, lies the Democratic Republic of Congo (DRC). The DRC is currently facing a serious existential crisis following the latest war of aggression and occupation waged by the Kigali regime in collusion with the M23, a rebel armed group.

Since late 2021, the Rwandan army, comprising an estimated 4,000 to 7,000 troops according to the UN, and its M23 ally, have seized various territories in North Kivu Province, openly defying fundamental principles of international law and the United Nations Charter. This region is highly coveted for its natural resources - including strategic minerals essential for the digital and clean energy transition. They are plundered in the DRC, then laundered and exported to the global market through Rwanda via opaque channels and transnational crime networks.

Over the past 30 years, repeated wars have claimed over 6 million Congolese lives. This latest Rwandan aggression in eastern Congo, violating the Congolese territory, integrity and sovereignty, poses a serious risk of regional escalation and has dramatically worsened an already dire humanitarian situation. The conflict has displaced nearly 4 million people over the past 14 months and left thousands dead. Last January, more than 3,000 people were killed during the siege of Goma, the capital of North Kivu. Conflict-related sexual violence is also on the rise in the DRC: in 2023, the United Nations reported more than 123,000 cases of sexual and gender-based violence. That is 1 case every 4 minutes!

It is in this context that we welcomed the recent visit of the Prosecutor of the International Criminal Court to Kinshasa, Mr. Karim Khan. He stressed that no party to the conflict has a blank check for committing crimes under the Rome Statute. In the DRC, crimes have ranged from widespread attacks against civilian populations and humanitarian actors, including UN peacekeepers and other regional forces, to bombings of displaced persons' camps. There are forced and mass population transfers, the recruitment and use of children as child soldiers, and the abduction of wounded individuals from hospitals. The list is long, and impunity should not be tolerated by the community of Nations that has turned a blind eye to the Congolese tragedy for too long now!

Since the resurgence of the M23/RDF coalition in the fall of 2021, reactions have either been timid or entirely absent. This bitter reality underscores once again the double standards at play, placing the DRC on a list of hypocrisy and international negligence.

Despite overwhelming evidence collected by experts reporting to the UN Security Council, confirming the presence of Rwanda on the Congolese territory for a long time, it was only with the adoption of the Security Council Resolution 2773 on February 21, 2025, less than a month ago, that

Rwanda was explicitly named as the aggressor and occupier.

The resolution urges the parties to “an immediate and unconditional ceasefire” and “calls on the Rwandan Defense Force to cease supporting the M23 and to immediately withdraw from the territory of the Democratic Republic of Congo, without preconditions.” While this development is essential, we regret that these calls are not backed by a robust UN sanctions regime. To date, Rwanda has disregarded and dismissed the resolution.

These initiatives must be better coordinated and strengthened. Urgent and decisive measures must be adopted to put an end to Rwanda's systemic violations of international law and human rights, and to force it to withdraw its troops from the Congolese territory.

Ladies and Gentlemen,

As we have seen, the contemporary world is faced with numerous existential challenges. However, we believe that there is no inevitability in these crises. It is often in times of challenges or crises that solutions emerge. We are confident that this Forum will provide a platform for high-level dialogue to contribute to a better, fairer, more equitable, and more peaceful world, particularly in the heart of Africa, which is bleeds every day.

I wish you productive discussions during these meetings and thank you for the actions you will take to bridge divides and build a sustainable future.

Acknowledgments

At the Seventh Global Engagement and Empowerment Forum (GEEF), held at Yonsei University in South Korea from March 13 to 14, 2025, Denis Mukwege delivered an impactful speech emphasizing the urgent need to transform our approach to achieving the Sustainable Development Goals (SDGs). Themed “Time for Action: Bridging Divides for a Sustainable Future,” the forum served as a vital platform for developing innovative solutions to global challenges and addressing delays in the implementation of the SDGs. This is a summarized transcript of Denis Mukwege’s speech.

Denis Mukwege

2018 Nobel Peace Prize Laureate

Denis Mukwege is a Congolese (D.R.C.) gynecologist, born on March 1, 1955 in Bukavu. He studied medicine and specialized in obstetrics and gynecology in France. He holds a doctorate degree (PhD) in medical sciences from the Université Libre de Bruxelles where he is a Professor. For over 20 years, Dr. Mukwege has been treating survivors of sexual violence and women with severe gynecological problems at the Panzi Hospital, which he founded in 1999. Denis Mukwege 2018 Nobel Peace Prize Laureate The Hospital and Panzi Foundation are renowned for their pioneering work in specialized responses to sexual gender based violence, and their work in advocating for the rights and empowerment of Congolese women. Doctor Mukwege is an outspoken advocate for the rights of survivors of sexual violence. He co-presides over the Global Survivors’ Fund, which he co-founded in 2019. His action and dedication have been recognized worldwide with various awards among which the United Nations Human Rights Prize (2008), the Sakharov Prize (2014) and the Nobel Peace Prize (2018) as well as honorary degrees from different Universities.

Jun. 2025, Volume.2 No.2

igee proceedings

pISSN: 3022-5183 eISSN: 3022-5191

IGEE Proc 2025;2(2):58-63
https://doi.org/10.69841/igee.2025.012

Perspective

Sustainability Challenges in Korea

Chang Yong Rhee

Governor of the Bank of Korea

I. Introduction

Over the years, the GEEF has brought together global leaders, international organizations, businesses, and stakeholders to explore solutions for achieving the United Nations' Sustainable Development Goals (SDGs). I hope this forum continues driving practical solutions to today's sustainability challenges.

I am here to share Korea's perspective on these issues. Some people say, "The Governor of the Bank of Korea is overstepping his bounds," because I speak on social issues beyond monetary policy. Discussing the SDGs today may reinforce that perception. While central bankers debate their role in such discussions, sustainability challenges directly impact our economy and daily lives. For this reason, I cannot remain indifferent—not just as a central bank governor, but also as a citizen.

Sustainability takes many forms, but today I will focus on two urgent challenges for Korea's economy. The first is climate change, a global crisis affecting everyone. The second is our declining birth rate and aging population, a challenge that is especially severe in Korea.

II. Climate Change

There is global and domestic consensus that human activities drive global warming and reducing carbon emissions is essential. However, Korea faces significant resistance to accelerating carbon reduction due to its heavily export-oriented economy dominated by high-carbon manufacturing industries. Strengthening emission reduction policies and environmental regulations raises concerns about export companies losing competitiveness. Thus, balancing urgent carbon reduction with sustain-

Received: April 1, 2025 **Revised:** April 8, 2025
Accepted: May 8, 2025

ing industrial competitiveness has become a central issue.

However, climate change should not be viewed solely from the perspective of export industries. It is a crisis directly affecting our daily lives and quality of life. We are already experiencing more extreme heat waves, frequent flooding, and the gradual disappearance of familiar fruits and vegetables. Our summer rainfalls used to be predictable, but not anymore. If Los Angeles can experience massive wildfires, what is stopping Korea from experiencing similar disasters? Climate change is not distant—it is occurring now, and its impacts are unavoidable.

Air quality is a clear example. Last week, I visited Cape Town, South Africa, for a BIS meeting. While it was winter in Korea, it was summer there, with warm weather, a refreshing sea breeze, and remarkably clean air. Within days, I realized, "This is truly clean air." Upon returning to Incheon Airport, I immediately felt a headache—not just from the flood of emails about economic and political concerns, but also from the noticeably poorer air quality. Korea's air quality has improved recently, but after experiencing cleaner air in Washington, D.C., I can clearly sense the difference. As someone sensitive to lung health after experiencing long COVID, this difference is especially noticeable. Although conditions have improved, fine dust remains a serious issue.

Statistically, the cost of deteriorating air quality is undeniable. Over the past 15 years, diagnoses of atopic dermatitis and allergic rhinitis have doubled, and cases of heat exhaustion have quadrupled, now totaling 4,000. Climate change directly threatens our health, making the challenges of protecting public health increasingly severe as temperatures rise and pollution worsens.

Another example is the increased frequency of sudden downpours, repeatedly flooding Seoul's Gangnam Station area, one of Korea's wealthiest neighborhoods, submerging numerous luxury vehicles over the past several years. Beyond property damage, the human toll has been devastating. Just two years ago, 14 people tragically lost their lives when an underpass collapsed after 500mm of rain fell in thirteen days. Observing these intense summer storms reminds me of tropical squalls typically seen in Thailand or South America.

The Korea Meteorological Administration now classifies rainfall exceeding 50mm per hour or 90mm over three hours as "extreme heavy rain," conditions responsible for 80% of flood damage. These extreme events have more than doubled since the 1970s. Given these dramatic changes, it is unclear whether our current flood prevention infrastructure—such as dams, embankments, and drainage systems—can handle the intensifying conditions. About 20% of national river embankments are already rated as "inadequate" or "poor," and projections suggest half of Korea's dams may fail to prevent flooding by 2040. We must proactively strengthen infrastructure now to withstand growing climate challenges.

Third, climate change is disrupting our food supply. Last year, I faced criticism from agricultural stakeholders after suggesting apple imports due to soaring prices (Im et al., 2024). Initially, I anticipated resistance primarily from traditional apple-growing regions like Daegu and North Gyeongsang Province. However, apple production areas are gradually shifting northward. Apple cultivation in Daegu-Gyeongbuk has decreased by nearly half compared to 30 years ago. Once grown nationwide, except for the southern coast and Jeju Island, projections suggest high-quality apples will only be viable in Gangwon Province's mountainous areas by the 2030s, due to rapid climate change (Rural Development Administration, 2022). Within a decade, importing apples will likely become a necessity rather than controversial.

The fishing industry faces similar disruptions. Pollack, once a staple in Korea, has nearly vanished from local waters, with catches below one ton since 2019. Traditional species like croaker and anchovies are declining, while warmer-water species like yellowtail and mackerel are increasing. Korea's fishing industry must rapidly adapt by modernizing vessels, gear, and aquaculture techniques to match the changing marine ecosystem.

While countless examples exist, the core message is clear. Climate change is not just a challenge for export industries—it already deeply impacts our daily lives and various domestic sectors. Thus, addressing climate change and reducing carbon emissions is not a matter of choice—it is an urgent necessity.

Although the government has initiated policy efforts, substantial progress remains necessary. First, Korea's Green Taxonomy (K-Taxonomy) must align with international standards to clearly define "environmentally friendly" activities, signaling strong support for carbon reduction. Second, carbon pricing must be more realistic. Last April, the global average carbon price was approximately $30 per ton, reaching $60 per ton in the EU, compared to only $6 per ton in Korea. At this price, companies find it more economical to buy emission credits than reduce emissions, undermining carbon reduction targets. Third, structural improvements to Korea's

Emissions Trading System (K-ETS) are needed. Gradually reducing the 90% free allocation rate and tightening the emissions cap will create stronger market incentives for effective emissions trading.

The Bank of Korea is also increasing its efforts by conducting financial stress tests on climate-related risks. Financial institutions traditionally manage risks like loan defaults and real estate fluctuations, but climate-driven risks introduce unexpected tail risks not yet fully considered. Events like Los Angeles' wildfires or Australia's six-month wildfire crisis in 2019 are not distant threats. They serve as warnings for Korea. Severe localized climate damage could cause significant financial losses for households and businesses, destabilizing financial institutions and spreading shocks throughout the economy.

Thus, the Bank of Korea actively researches climate risks' impacts on our industries and financial system, conducting stress tests with financial institutions under various scenarios. Next Tuesday, we will present these climate stress test results at a joint conference with the Financial Supervisory Service.

Bank of Korea employees are also committed to reducing carbon emissions through research (Kim et al., 2024) and daily practices. Believing even small actions matter, we have adopted eco-friendly measures such as using recycled-paper business cards, reducing plastic use, turning off unused lights, and implementing license plate-based driving restrictions.

III. Ultra Low Fertility and an Aging Population

Beyond climate change, one of the most pressing sustainability challenges is our demographic crisis—an aging population combined with extremely low fertility rates. Korea's total fertility rate slightly rose to 0.75 in 2024 from 0.72 in 2023. Although this small uptick is welcome, a fertility rate of 0.75 remains a national emergency. If this trend continues, Korea faces an irreversible population crisis that threatens economic stability and social cohesion.

Some people suggest that population decline might have benefits, such as reduced pollution, lower energy consumption, and higher GDP per capita, possibly enhancing quality of life. However, this view dangerously oversimplifies the issue. A fertility rate of 0.75 leads not to gradual decline but rapid demographic collapse, undermining economic and social stability. By contrast, the OECD average fertility rate of 1.4 results in a more manageable and sustainable population decline.

The difference between fertility rates of 0.75 and 1.4 significantly impacts economic growth prospects. At 0.75, Korea's population would shrink from 51.7 million to 30 million in 50 years, just 58% of today's figure, declining annually by 1.1%. In contrast, at a rate of 1.4, the population decline is less severe, reaching 43 million—83% of today's level—with an annual drop of 0.4%. From a purely demographic standpoint, the difference in GDP growth between these two scenarios would amount to 0.4 percentage points annually. But the true cost goes beyond this simple calculation. A declining youth population, crucial for innovation, entrepreneurship, and economic dynamism, would severely undermine Korea's long-term growth potential. According to a recent Bank of Korea study, Korea's potential growth rate, currently around 2%, may approach near 0% by the late 2040s (Lee et al., 2024). If the fertility rate remains at 0.75, Korea will inevitably face prolonged negative economic growth after 2050. Conversely, at 1.4, Korea could maintain positive economic growth well into the future.

Beyond GDP, persistently low fertility will create substantial fiscal strain, increasing the burden on younger generations. As the elderly population surges, spending on pensions, healthcare, and elder care will rise significantly. According to the National Assembly Budget Office (2025), Korea's national debt-to-GDP ratio, currently 46.9%, is projected to reach 182% within 50 years if fertility remains at 0.75. If fertility improves to 1.4, the ratio would increase more slowly, reaching 163%. The burden on young Koreans will become particularly overwhelming. Currently, four working-age individuals support each elderly person. At a fertility rate of 0.75, this ratio will decline to one-to-one within 50 years. At 1.4, however, it remains more manageable, easing strain on future generations.

Moreover, economic instability from demographic shifts increases society's vulnerability to populism. Stagnant growth exacerbates income inequality, deepens generational and class divides, and fuels political polarization. Politicians and governments may resort to populist fiscal policies, such as direct cash handouts and temporary welfare measures, providing short-term relief without addressing underlying issues. Such policies risk creating a cycle of fiscal inefficiency and mounting national debt, exacerbating rather than resolving the core problems.

To preserve economic sustainability, decisive action must be taken urgently. If Korea's fertility rate remains critically low without significant expansion of the workforce through foreign labor, the country risks chronic negative growth, soaring debt, and escalating social tensions. Avoiding this scenario requires raising the fertility rate to a more viable level. Completely reversing population decline may be unrealistic since many advanced economies face similar demographic challenges, but Korea cannot afford to remain passive. At a minimum, we must strive to reach the OECD average fertility rate of 1.4.

Why has Korea's fertility rate fallen so drastically? The answer lies in structural barriers discouraging young people from marriage and parenthood. Bank of Korea studies indicate young Koreans delay or forgo marriage and childbirth due to intense competition and anxieties over employment, housing, and childcare. Young people today face fierce competition for scarce, high-quality jobs, making career stability difficult. Simultaneously, soaring housing prices make homeownership seem unattainable. Under these pressures, raising children is more than challenging—it is an overwhelming financial and emotional burden.

A major driver of this crisis is the extreme concentration of population and economic activity in the Seoul metropolitan area. A recent Bank of Korea study analyzing fertility trends in 35 OECD countries identified Korea's urban concentration as among the highest globally, pinpointing it as a key factor behind the country's ultra-low fertility (Hwang et al., 2023). Over 50% of Korea's GDP, population, and jobs are concentrated in the Seoul metropolitan area—much higher than 5% in the U.S. and Germany, 10-20% in the U.K. and Italy, 20-30% in France, and 30% in Japan. While Korea's rapid economic development—the "Miracle on the Han River"—transformed the country into an economic powerhouse, it also centralized infrastructure, talent, and opportunities in Seoul. Consequently, young people continue migrating to the capital for career prospects, draining vitality from regional economies and pushing many toward demographic extinction.

Korea's highly competitive university entrance system further reinforces the population concentration in the Seoul metropolitan area. Admission to prestigious universities is considered essential—not only for stable employment but also for social status and marriage prospects. This fuels intense competition for limited spots at elite universities, overwhelmingly located in Seoul. Private education has become critical, prompting families to relocate to Seoul's affluent areas like Gangnam-gu, known for high-quality private educational infrastructure. Many parents unable to afford homeownership instead rely on costly rental housing to secure educational advantages. This strategy appears justified, as students from Seoul account for 32% of admissions to Seoul National University (SNU), despite representing only 16% of school-age population. More strikingly, students from Gangnam-gu alone constitute 12% of SNU admissions, three times the district's 4% share of school-age residents (Chung et al., 2024). Relocating to Gangnam-gu is thus seen as essential for top university admission, intensifying Seoul's population density, raising housing prices, and worsening the fertility crisis.

Korea's university admission system is excessively competitive by any standard. Parents sacrifice their quality of life and retirement savings, investing considerable resources to secure their children's admission to elite universities. Paradoxically, this intense pursuit of academic success imposes a heavy cost on both parents and children. From as early as kindergarten, students experience relentless pressure and burnout, depriving them of childhood joys and a healthy adolescence.

Korea's critically low fertility rate (0.75), extreme population concentration in the Seoul metropolitan area, and overheated university competition seem like separate issues but are deeply interconnected. Left unresolved, these challenges—drastic population decline, persistent negative economic growth, escalating social tensions, and diminishing opportunities for youth—will push Korea toward an unsustainable tipping point. Addressing these structural issues simultaneously is challenging, yet the urgency demands bold action. Recognizing this, the Bank of Korea recently proposed two policy suggestions: foster a limited number of regional hub cities and implement a "regional proportional admission system" for universities.

First, to effectively reduce the extreme population concentration in the Seoul metropolitan area, we must strategically develop a small number of regional hub cities. Over the past two decades, regional development policies have been introduced to address this imbalance. However, due to political challenges and efforts to evenly distribute resources nationwide, these initiatives have been too fragmented to meaningfully curb Seoul's dominance. According to Bank of Korea research, the optimal approach—given Korea's land area and population—is to concentrate substantial investments in two to six carefully selected regional hub cities. Targeted,

large-scale investment in critical infrastructure, such as healthcare, education, and cultural amenities, is essential to providing a quality of life comparable to Seoul, thus effectively attracting and retaining residents (Chung et al., 2023, 2024). Pursuing this focused strategy will rebalance population distribution, revitalize regional economies—including surrounding smaller cities—and achieve sustainable national development.

In parallel, bold reforms to Korea's college admissions system are essential. The Bank of Korea has proposed a "regional proportional admission system," where universities voluntarily allocate admissions based on each region's proportion of high school seniors (Chung et al., 2024). Despite multiple revisions to university entrance system, excessive competition in university admissions remains unresolved. BOK's new proposal seeks to enhance universities' autonomy in admissions while strongly requiring balanced regional representation—a crucial step to address extreme competition. Adopting this system offers several benefits. First, it reduces the disproportionate influence of socioeconomic factors such as parental wealth and private education, thus significantly enhancing social mobility. Second, dispersing admissions competition from Seoul would ease demographic pressures, stabilize housing prices, and improve fertility rates. Third, attracting students from diverse regions promotes mutual understanding, social cohesion, and reduces regional disparities.

This proposal does not require government intervention or legal amendments, relying instead on the willingness and initiative of leading universities. In Korea, there remains a strong belief that selecting students based solely on academic scores is the fairest, leading resistance to this proposal. Some universities argue they already implement regional proportional admissions for roughly 15% of their freshmen. However, such limited quotas can stigmatize these students and have insufficient impact on demographic or housing pressures in Seoul. To be effective, regional proportional admissions must be applied to most incoming students' admissions. In many advanced nations, regional diversity in admissions is widely accepted and encouraged. I believe Dr. Jim Yong Kim, joining us today and a former president of Dartmouth College, understands this issue well. He could highlight how Korea's test score-based admissions approach is an exception globally, and how this reform could realistically occur through proactive leadership at major universities.

In my view, allowing universities greater flexibility in evaluating applicants—under regional proportional requirements—would better acknowledge and fairly recognize diverse talents. Human talent is far too diverse to be measured by academic tests alone. Yet, Korea's current admissions system prioritizes a narrow skillset: memorization, quick mathematical calculations, and rapid text summarization under time pressure. These skills, overly rewarded by standardized exams, limit the range of recognized talents. I happen to possess these particular skills and was a major beneficiary of Korea's college admission system. However, if asked to write a creative essay over a week, I might not have excelled. Today, elite university students often share certain defining characteristics such as a personality that diligently follows instructions without rebellion, a willingness to endure 15 years of repetitive study from kindergarten, an IQ high enough to handle the academic workload, but not so high as to question or challenge its purpose.

When Korea's primary goal was catching up with more advanced nations, the current educational system was beneficial in developing individuals who excelled at following orders and carrying out assigned tasks. However, with Korea now at the forefront of global technological competition, we need people unafraid to explore new frontiers, bringing diverse backgrounds and innovative thinking. Additionally, we must foster an environment that encourages collaboration, creativity, and meaningful interaction. It is time for universities to broaden their evaluation criteria and nurture diverse talents by implementing regional proportional admissions.

The challenges highlighted today—climate change and demographic crisis—pose critical threats and require urgent action. Korea has achieved remarkable economic progress, joining the ranks of advanced nations. Now we must focus on enhancing individual well-being, ensuring prosperity and happiness for all citizens. Through bold decisions, we can develop vibrant, youth-friendly, green regional hubs that combat climate change and support marriage and childbirth. The Bank of Korea remains fully committed to securing a sustainable, prosperous future for upcoming generations.

Thank you for your time and attention.

Changyong Rhee[1]
Governor of the Bank of Korea
Chang Yong Rhee currently serves as the Governor of the

[1]This manuscript was prepared with the assistance of Sanghun Park and Joonki Min from the Office of Sustainable Growth, and Inro Lee and Inkyung Yoo from the Economic Research Institute.

Bank of Korea (BOK) and the Chairman of its Monetary Policy Board. He also chairs the Committee on the Global Financial System (CGFS) at the Bank for International Settlements (BIS) and is a member of the BIS Board of Directors. Widely regarded for his expertise in economics and public policy, he has built an extensive career spanning academia, international organizations, and government. Before assuming his role at the BOK in 2022, Rhee held several influential roles in international institutions and public service. From 2014 to 2022, he served as the Director of the Asia and Pacific Department at the International Monetary Fund (IMF), where he led economic surveillance, policy consultation, and efforts to enhance regional cooperation. Prior to that, he was the Chief Economist of the Asian Development Bank (ADB) from 2011 to 2014, leading economic research and contributing to regional development strategies. Rhee has also made significant contributions to the Korean government. From 2009 to 2011, he served as Secretary General and Sherpa of the Presidential Committee for the 2010 G-20 Seoul Summit, playing a key role in shaping the global economic agenda during Korea's G-20 presidency. Earlier, he was Vice Chairman of the Financial Services Commission (FSC) from 2008 to 2009, where he helped navigate financial regulatory policy during a critical period. In addition to his public service, Rhee has enjoyed a distinguished academic career. He was a Professor of Economics at Seoul National University from 1994 to 2008, after serving as an Assistant and Associate Professor. Before returning to Korea, he was an Assistant Professor at the University of Rochester from 1989 to 1994. He earned his Ph.D. in Economics from Harvard University in 1989 and his B.A. in Economics from Seoul National University in 1984.

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Jun. 2025, Volume.2 No.2

igee proceedings

pISSN: 3022-5183 eISSN: 3022-5191

IGEE Proc 2025;2(2):64-67
https://doi.org/10.69841/igee.2025.019

Letter

Introducing the 2024 'Social Engagement Fund' Cohort

Eun Kyoung Rhee, Sarah Soyeon Oh

Institute for Global Engagement & Empowerment (IGEE)
Yonsei University

We are proud to present the finalists of Yonsei University's 2024 Social Engagement Fund (SEF), hosted by the Institute for Global Engagement & Empowerment (IGEE). As an institution committed to advancing the United Nations' Sustainable Development Goals (SDGs), IGEE designs and implements a variety of social contribution programs to address real-world challenges and generate practical solutions for a better future. The SEF program empowers students to transform their awareness and ideas about global social issues into tangible, positive change. In 2024, 25 student teams applied; after a rigorous review by multiple faculty members, 9 teams—five domestic and four international—were selected to receive support.

While this year's projects were classified as exempt from IRB review due to their primarily educational nature, we wish to emphasize that these activities offered invaluable learning experiences for undergraduate students as they engaged with real-world social challenges. Future initiatives will incorporate more comprehensive IRB guidance and oversight to further uphold ethical research standards.

Across all six projects, a total of 11 different Sustainable Development Goals (SDGs) were addressed: SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), SDG 5 (Gender Equality), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 10 (Reduced Inequalities), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 17 (Partnerships for the Goals). The projects demonstrated a broad and integrated approach to sustainable development by targeting multiple goals. For example, the Mongolian Ger District project addressed SDGs 1, 2, 7, 11, and 13 through its focus on poverty reduction, food security, renewable energy, urban sustainability, and climate action. The Seogwipo high school initiative targeted SDGs 4, 8, and 17 by promoting quality education, career-related mentorship, and collaborative partnerships. The web platform for single parent households was aligned with SDGs 3, 5, and 10, aiming to improve health, gender equality, and reduce inequalities. Collectively, these projects not only covered a wide spectrum of the SDGs but also illustrated the interconnectedness of social, economic, and environmental objectives in advancing sustainable development (Figure 1).

The following six articles showcase the exceptional work and dedication of several of these teams in advancing the Sustainable Development Goals (SDGs):

Received: June 17, 2025 **Revised:** June 19, 2025
Accepted: June 20, 2025

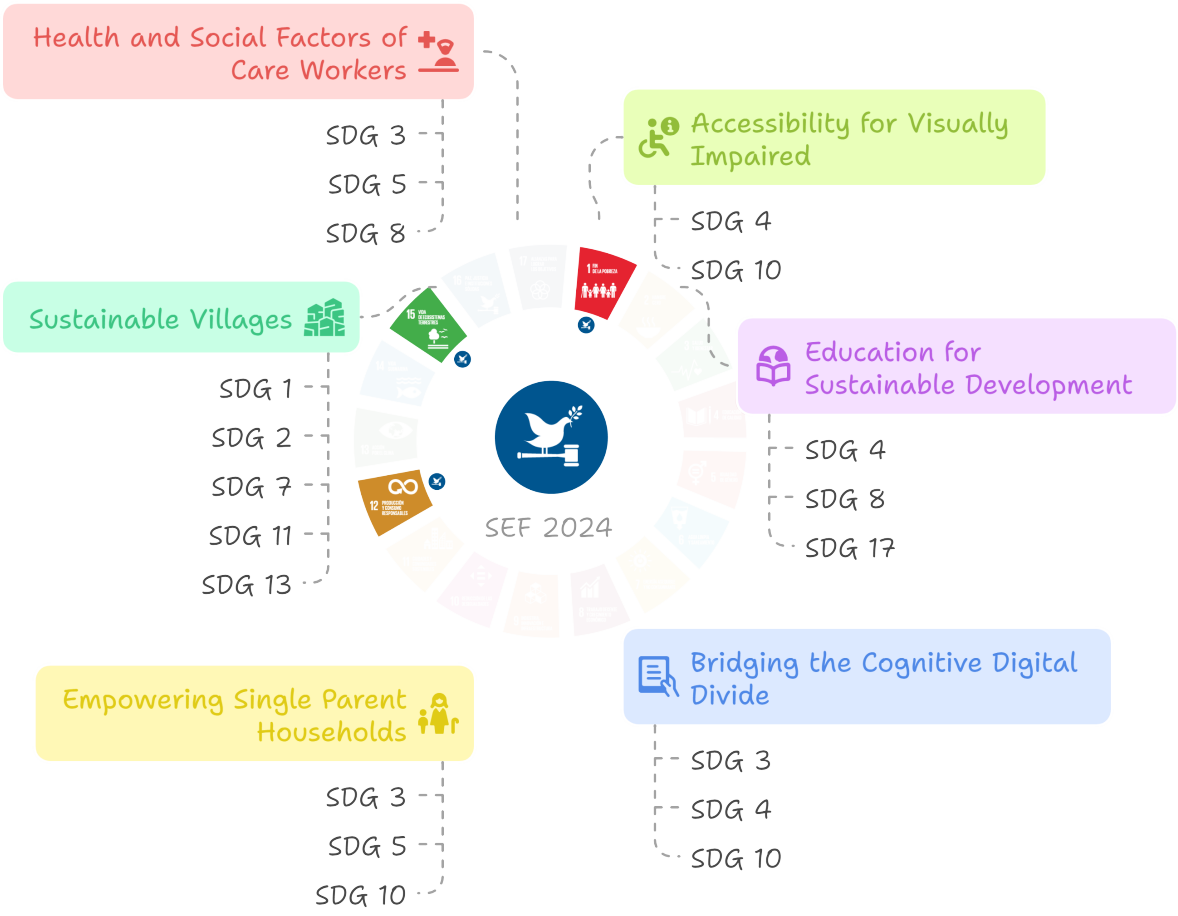


Figure 1. Sustainable Development Goals (SDGs) addressed by SEF 2024

1. Establishment Plan for Sustainable Villages through Resolving Mongolian Ger District Issues

Authors: Eun-hye Song, Khuslen Bazarragchaa, Geon-young Kim, Sung-kwon Lee

Departments: School of Business; School of Chemical and Biomolecular Engineering; School of Electrical and Electronic Engineering

Confronting the intertwined crises of urban migration, environmental degradation, and social inequality in Mongolia's ger districts, this project proposed a replicable sustainable village model. In quote of the authors:

"This study moves beyond the conventional climate refugee framework by analyzing these broader drivers of migration through structured surveys and in-depth interviews with both ger district residents and the general urban population."

The study is commendable for its efforts to assist not only the residents of Mongolia's ger districts and settlement areas but also the general public in Ulaanbaatar and those engaged in afforestation. The project's multifaceted initiatives included infrastructure development, livestock farming, agricultural cooperatives, afforestation, and solar energy. The "Sustainable Village Master Plan" created for Salkhit reflects the team's commitment to commercial, residential, and agricultural sustainability.

2. Education for Sustainable Development and Career for High School Students in Seogwipo

Authors: Younghyun Lee, Yumin Hahn, Gayoon Yang

Department: Underwood International College

This study piloted an integrated Education for Sustainable Development (ESD) and career education program for high school students in Jeju, fostering both student agency and

SDG literacy. The research highlighted the powerful potential of combining ESD with career education. Implemented as a well-structured, student-led initiative at Pyoseon High School, the program led to "statistically significant improvements in overall competency domains" and a notable shift in students' perceptions—from passive, school-based views of sustainability to more active and personalized understandings.

3. Empowering Single Parent Households: A Web Platform to Address Systemic Gaps in Welfare and Care Support

Authors: Mingyu Park, Juhyeong Song, Jiwon Park
Department: College of Nursing

This project addressed the significant barriers single mothers in South Korea face in accessing welfare services, aiming to bridge information gaps and promote self-reliance through a comprehensive web platform. The team's alignment with SDG 3 (Good Health and Well-being), SDG 5 (Gender Equality), and SDG 10 (Reduced Inequalities) was clear in their words:

"Single parent households are placed on a continuum of choices from the moment they recognize their pregnancy. It is common for them to face these choices alone... The development of this platform is closely linked to the achievement of the Sustainable Development Goals (SDGs)... Specifically, SDG 3.7 aims to ensure universal access to family planning, sexual and reproductive health services, and information by 2030... Furthermore, in line with SDG 3.8... the platform was designed to offer user-friendly information on vaccination schedules and health check-ups."

This team was commended for addressing the often-overlooked needs of a population that faces substantial barriers to accessing healthcare and related information. Their innovative use of a web-based platform, enhanced by AI tools, was commended for laying a strong foundation for inclusive digital welfare systems.

4. Bridging the Cognitive Digital Divide: A Prototype-Based Intervention for Elderly Learners in South Korea

Authors: Yeeun Kim, Haeyoon Shin, Soo Yeon Kim
Department: Department of Psychology, Statistics, & Business and Global Leaders College

This research tackled the digital literacy challenges faced by older adults in South Korea. Despite widespread smartphone ownership, digital proficiency remains low. Drawing on global best practices and cognitive aging research, the authors developed and evaluated Ee Eum, a prototype intervention for individuals aged 65 and older.

This project demonstrated that perceptual design elements—such as "high-contrast color combinations" and "enlarged text sizes (25–28pt)"—can significantly enhance legibility and reduce cognitive load. First Click Test accuracy improved from 39.79% to 86.02% after implementation. This study contributed meaningfully to conversations on digital equity and gerontechnology.

5. Analysis of the Correlation Between Health Status and Social Factors Among Korean Care Workers

Authors: YeJin Yun, Yuna Kim, Miyeon Yoon, Sejin Park
Department: College of Medicine & College of Nursing

This study examined the health and labor conditions of care workers in South Korea, highlighting how job satisfaction, compensation, and work environment affect their well-being. Using surveys from 345 care workers and in-depth interviews, the study found a strong link between job satisfaction and health outcomes, while revealing systemic disparities across care work sectors.

The authors stated that despite facing "emotional burden, social invisibility, dissatisfaction with compensation, and the absence of grievance mechanisms," many care workers derive purpose from their roles. The study supported the need for labor rights reform and aligned with SDGs 3, 5, and 8.

6. Bridging the Accessibility Gap: Investigating Challenges and Best Practices for Visually Impaired Individuals in STEM and Finance in North America—Policy Implications for South Korea

Authors: Juwon Cheong, Yunsung Chae, Jaeyoon Lee
Department: Underwood International College & College of Commerce and Economics

This research explored the lived experiences of visually impaired individuals in STEM and finance fields, using North American policy frameworks to inform Korean reforms.

Drawing on laws like the European Accessibility Act and the Americans with Disabilities Act, the team investigated real-world accessibility barriers and solutions.

Interviews with blind professionals and students in South Korea provided critical insights into institutional gaps. The project contributed especially to SDG 4 (inclusive education) and SDG 10 (reduced inequalities) by proposing actionable steps to improve digital and educational accessibility.

These projects were a testament to the creativity, rigor, and empathy of Yonsei's student community. SEF 2024 reminded us that the SDGs are not abstract targets but lived commitments—shaped by our community's commitment to foster a more sustainable world.

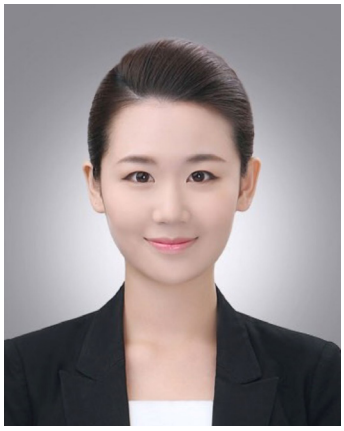
We extend our deepest congratulations to all SEF 2024 finalists and look forward to the continued impact of their work.

Warm regards,

Eun Kyoung Rhee & Sarah Soyeon Oh

Institute for Global Engagement & Empowerment (IGEE)

Yonsei University



Sarah Soyeon Oh *is a research professor at the Institute for Global Engagement & Empowerment (IGEE) at Yonsei University, where she helps coordinate the Social Engagement Fund and leads a range of research projects focused on sustainable development and student empowerment. With a background in public health, Oh's primary interests include applying machine learning and statistical analyses techniques to maternal and child epidemiological research to build inclusive support systems for underrepresented communities.*

Eun Kyoung Rhee *is a visiting professor at Yonsei University's Institute for Global Engagement & Empowerment (IGEE), where she supports the Social Engagement Fund and conducts research on sustainable development. With a background in Political Science, her work focuses on balanced regional development as a core strategy for achieving sustainable development, exploring policy approaches and practical solutions to address social challenges such as regional decline.*

Jun. 2025, Volume.2 No.2

igee proceedings

pISSN: 3022-5183 eISSN: 3022-5191

IGEE Proc 2025;2(2):68-82
https://doi.org/10.69841/igee.2025.014

Article

Establishment Plan for Sustainable Villages through Resolving Mongolian Ger District Issues†

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In recent years, Mongolia has witnessed a steady influx of migrants into the ger districts on the outskirts of Ulaanbaatar. While some have been displaced by climate change-induced zud and desertification, which have devastated traditional livestock-based livelihoods, a larger share of the migration stems from structural inequalities—namely, the concentration of employment opportunities, education, and essential infrastructure in the capital. This surge in population has intensified urban overcrowding and deepened various environmental and social challenges. The ger districts stand out as areas facing particularly acute challenges such as high unemployment, poverty, air pollution, soil contamination, energy poverty, and a critical lack of educational and healthcare services.This study moves beyond the conventional climate refugee framework by analyzing these broader drivers of migration through structured surveys and in-depth interviews with both ger district residents and the general urban population. Based on the findings, a sustainable village model is proposed for the Salkhit area, integrating agriculture, settled livestock farming, agricultural cooperatives, solar power generation, and tourism infrastructure. These systems are designed to operate autonomously and scale to other regions of Mongolia.By offering both policy and practical guidelines, this model aims to relieve metropolitan congestion and promote balanced regional development. However, due to limitations such as insufficient climatic, geographic, and agricultural baseline data and constraints in technical infrastructure, continuous feedback through test-bed operations and phased revisions are essential to ensure long-term viability and effectiveness.

Keywords Mongolia, Ger District, Sustainable Village, Sustainable Development Goals

Received: May 18, 2025 **Revised:** May 30, 2025 **Accepted:** June 10, 2025
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†This research is supported by the Social Engagement Fund (SEF) 2024.

1. Introduction

In recent years, Mongolia has faced escalating challenges related to climate change, prompting continuous migration to ger districts on the outskirts of the capital, Ulaanbaatar. According to UN-Habitat (2016), 47% of Mongolia's population currently resides in Ulaanbaatar. In addition, the 2022 Mongolian Housing Census indicates that 50.1% of households in Ulaanbaatar live in ger districts with insufficient infrastructure (Zindaa, 2024).

These areas are currently grappling with a wide range of social issues, including unemployment, poverty, poor health conditions, and inadequate educational infrastructure. In particular, high population density has caused severe traffic congestion, while the widespread use of heating fuels such as coal and waste tires has significantly worsened air pollution. The World Health Organization (WHO) reports that 80% of Ulaanbaatar's air pollutants during the period from November to April originate from ger heating (World Health Organization [WHO], 2018). Additionally, the use of traditional outdoor toilets has contributed to serious soil contamination. These complex and interlinked issues are becoming increasingly severe and call for practical, long-term solutions.

This study initially hypothesized that ger district residents were primarily climate refugees. However, fieldwork conducted in Mongolia revealed broader socio-economic motivations behind migration, including the pursuit of better education for children, access to healthcare, and job opportunities. As a result, the research scope was expanded to encompass the entire ger district population rather than focusing solely on those displaced by environmental factors.

Policy responses to challenges in Ulaanbaatar's ger districts have often been limited to short-term relief or environmental remediation. For example, the provision of free nighttime electricity during winter months temporarily reduced energy costs but did not lead to substantial improvements in living conditions. A UNICEF (2018) report similarly notes that such measures—including the distribution of clean stoves and face masks—failed to address the underlying structural vulnerabilities faced by ger district residents.

In contrast, this study focuses on the actual needs of residents and aims to develop a sustainable and practical alternative model grounded in their lived experiences. Accordingly, it seeks to identify the key drivers behind the population increase in ger districts, examine the major challenges faced by residents, and derive essential elements for sustainable community development. Ultimately, the study aims to contribute to the planning and establishment of long-term sustainable village models for ger district communities. These models are intended not only to alleviate poverty and improve living environments but also to support inclusive urban resilience and climate-responsive development, thereby reflecting the broader objectives of global sustainability initiatives.

2. Materials and Methods

Literature Review

To assess the current conditions, key issues, and policy responses related to ger districts, we reviewed a range of domestic and international academic publications, policy documents, and non-governmental organization (NGO) reports. Particular attention was paid to previous studies on the core components of sustainable village development, such as settlement-based agriculture and livestock farming, as well as solar energy systems. This theoretical review provided a foundation for evaluating both the feasibility and justification of establishing sustainable villages in the Mongolian context.

Resident Interview

Semi-structured interviews were conducted with ger district residents, target settlement areas, and the general public in Ulaanbaatar. These interviews offered qualitative insights into local challenges—including heating practices, education, and water quality—and helped identify residents' needs and expectations for sustainable villages. In addition, interviews were held with households that had already installed solar equipment, in order to assess the practical feasibility of solar energy adoption. The diversity of interviewees, including their roles and locations, is reflected in Table 1, which outlines the composition of participants across different resident groups.

1) Resident Interviewee Selection

- Ger District Residents: Due to access limitations, participants were recruited through a local church within the ger district, rather than random sampling.
- Target Settlement Residents: Random interviews were conducted on-site, including a targeted interview with the Governor of Salkhit for contextual insights.

Table 1. Resident Interview Participants

Separation	Interviewee ID	Roles	Places
Residents of Ger Districts	P1	Residents	Church in Ger district
	P2		
	P3		
Residents of Target Settlement Areas	P4	Residents	Interviewee's residence
	P5		
	P6	Governor of Salkhit	Local administration office of Salkhit
General Public in Ulaanbaatar	P7	Citizen	Ulaanbaatar square
	P8		
	P9		
	P10		
	P11		
Residents with Solar Equipment	P12	Residents	Interviewee's residence
	P13		
	P14		
Afforestation Inhabitants	P15	Representative	Afforestation A
	P16	Workers	Afforestation A
	P17	Representative	Afforestation B
	P18	Representative	Afforestation C
	P19	Representative	Afforestation C

- General Public: Citizens were randomly approached at Ulaanbaatar Square for street interviews.
- Residents with Solar Equipment: Participants were identified through referrals during afforestation fieldwork, focusing on households using solar panels.
- Afforestation Inhabitants: Interviewees were selected from sites managed by an environmental NGO, including field workers and site representatives.

Expert/Organization Interview

In-depth interviews were conducted with a range of experts and practitioners from the Mongolian University of Life Sciences, the Han-Mongolian Urban Cooperation Center at Seoul National University, Mongolian agricultural cooperatives, non-governmental organizations (NGOs), and a large-scale farm located in Baruunkharaa, Selenge Province, Mongolia. The interviews focused on the current status and challenges associated with implementing agricultural cooperatives, afforestation initiatives, and settlement-based agriculture and livestock projects. Drawing on the institutional experiences of each organization, the interviews explored both the practical possibilities and limitations of introducing these models. As summarized in Table 2, the interviewees represented a diverse set of institutions and roles across academia, NGOs, cooperatives, and the private sector.

1) Expert and Organizational Interviewee Selection

- International Food-related NGO: To explore solutions for sustainable village food systems, interviews were conducted with the foundation's chairman and the Mongolia-based representative after contacting relevant departments.
- Environmental NGO: To understand reforestation support, interviews were held with Mongolia-focused personnel from both the Korea and Mongolia offices.
- Farm: The owner of Mongolia's largest settlement-based farm was interviewed to assess the viability of large-scale agriculture.
- Agricultural Cooperatives: To investigate the status of agricultural cooperatives, interviews were conducted with both headquarters staff and a local branch representative. A cooperative member was also interviewed to gain practical, grassroots insights.
- Livestock Cooperatives: A representative from a major livestock cooperative was interviewed to assess current operations and relevance to sustainable village planning.
- Mongolian University of Life Sciences: Professors from relevant departments were contacted to provide academic advice on the feasibility of settlement-based agriculture in Mongolia.
- Seoul National University: Interviews were arranged with researchers involved in Mongolia-related urban planning

Table 2. Organization Interview Participants

Separation	Affiliation	Interviewee ID	Roles	Places
Non-Governmental Organization (NGO)	International food-related NGO	P20	Chairman	Offices in Gyeongsangnam-do
	International food-related NGO	P21	Mongolia representative	Online
	Environmental NGO	P22	Head of department	Seoul office
	Environmental NGO	P23	Manager	Seoul office
	Environmental NGO	P24	Mongolia representative	Ulaanbaatar office
Private	Farm	P25	Farmer	Large-scale farm in Baruunkharaa, Selenge province, Mongolia.
Mongolian Cooperatives	Agricultural cooperatives	P26	Headquarters	Ulaanbaatar office
	Agricultural cooperatives	P27	Headquarters	Ulaanbaatar office
	Agricultural cooperatives	P28	Branch representative	Ulaanbaatar office
	Agricultural cooperatives	P29	Member	Interviewee's residence
	Livestock cooperatives	P30	Representative	Ulaanbaatar office
University	Mongolian University of Life Sciences	P31	Professors	Mongolian University of Life Sciences
	Mongolian University of Life Sciences	P32	Professors	Mongolian University of Life Sciences
	Mongolian University of Life Sciences	P33	Professors	Online
	Mongolian University of Life Sciences	P34	Professors	Mongolia Smart Farm Operations
	Seoul National University	P35	Researchers	Seoul National University
	Yonsei University	P36	Researchers	Yonsei University

projects.

- Yonsei University: Contact was made to receive expert consultation on urban development and sustainable settlement models.

Surveys

Surveys were conducted with 14 ger district residents and 27 Mongolian university students. The questionnaire for ger district residents focused on everyday challenges and their intentions to migrate. For university students, the survey aimed to assess their social perceptions of ger districts, their awareness of urban issues, and their understanding of sustainability. The collected responses were used as foundational statistical data for the study.

1) Survey Participant Selection

- 14 Ger District Residents: The survey was distributed with the assistance of a local church previously involved in resident interviews.
- 27 Mongolian University Students: Participants were recruited online through random outreach by a Mongolian team member's contacts within local universities.

Fieldworks

Fieldwork was carried out at potential sites for the establishment of sustainable villages. The investigation focused on assessing land availability, accessibility, resident acceptability, and existing infrastructure to evaluate the suitability and feasibility of village development. In addition, site visits were conducted to the ger districts themselves in order to directly observe and assess the limitations of current living conditions.

Methodological Limitations

While this study employed a multi-method approach to gain a comprehensive understanding of the issues facing the ger districts and the feasibility of sustainable village development, it is not without limitations. The sample size for both interviews and surveys was relatively small due to time and resource constraints, which may limit the generalizability of the findings. Additionally, the qualitative data, while rich in context, are based on subjective perspectives that may not fully represent the broader population.

1) Research Design

The study was conducted in three phases. First, an analysis of the current conditions in ger districts was carried out to identify the key challenges that a sustainable village model must address. Second, based on these findings, a vision and set of objectives were established, and a preliminary master plan was developed. Feasible implementation strategies were derived through reference studies in specific domains, including land use, agricultural and livestock systems, solar energy deployment, and tourism resource utilization. Third, a needs assessment and field survey of the target site were conducted to evaluate local acceptability and specific demands, which informed the formulation of a final village establishment plan. The overall research process—including its phases, data sources, and analytical framework—is illustrated in Figure 1, based on the "Basic Plan for Village Development in Seongbuk-gu" by the Korea Urban Research Institute (2013).

3. Results

Analyzing the state of Ger District to identify District Challenges

1) Face-to-Face Interviews with Ger District Residents (n=2)

Face-to-face interviews with two residents of the ger districts revealed a range of challenges related to living condi-

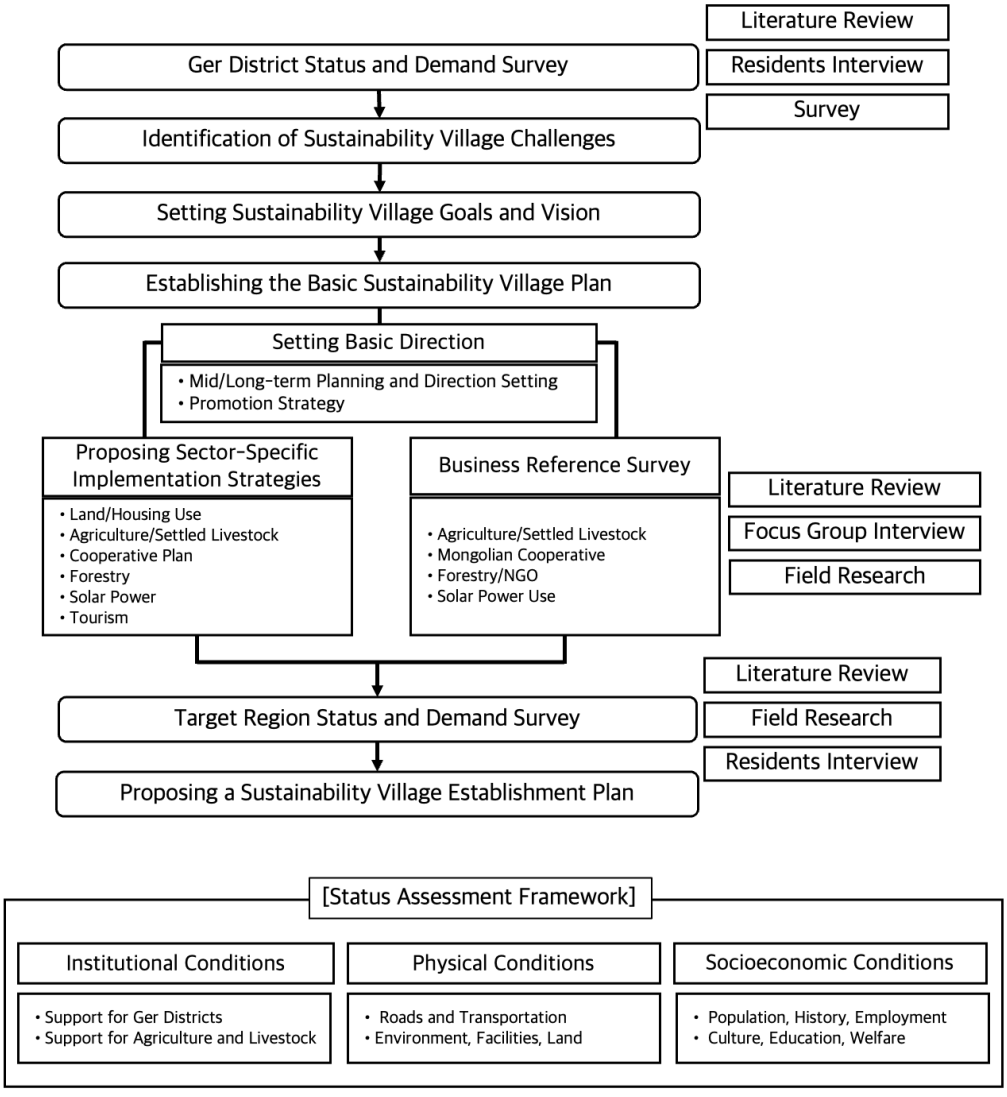

Figure 1. Research Framework.

tions, including heating, sanitation, education, and transportation. Although coal is more affordable than wood as a heating fuel, it causes severe particulate pollution and contributes to headaches and respiratory illnesses. Water and sewage systems are outdated, and conventional outdoor toilets are still in use, leading to soil and water contamination. The lack of educational infrastructure has resulted in infringements on children's right to education. It was also noted that many residents prefer apartment-style or house-type residences over traditional gers, valuing their cleanliness and warmth.

2) Survey of Ger District Residents (n=14)

A remote survey was conducted with 14 ger district residents. The main issues identified were unemployment (17.5%), heating problems (17.5%), health-related concerns (12.5%), and the lack of water and sewage systems (10%). Other frequently mentioned challenges included inadequate educational facilities, limited access to healthcare, and unstable electricity supply. Notably, 83.3% of respondents indicated a willingness to relocate to a sustainable village if these problems were resolved. While this points to a potentially strong preference, the limited sample size warrants caution in interpretation. Still, the result may reflect a broader intention to resettle, provided that basic infrastructure and a stable living environment are ensured.

3) Face-to-Face Interviews with Ulaanbaatar Citizens (n=5)

Five Ulaanbaatar citizens participated in face-to-face interviews and expressed a clear awareness of the challenges facing ger districts. They noted that air pollution—particularly from heating fuel—was negatively affecting public health. Ulaanbaatar is currently overpopulated, with two to three times the ideal urban population, and interviewees showed a preference for population dispersion to suburban areas equipped with infrastructure such as schools and hospitals. Key urban elements highlighted by respondents included paved roads, green spaces, and educational facilities.

4) Online Survey of Ulaanbaatar University Students (n=27)

An online survey was conducted with 27 university students in Ulaanbaatar to assess their perception of ger district issues. The most critical problems identified were soil contamination from traditional outdoor toilets (33.9%), air pollution from unregulated fuel use (32.2%), and urban overcrowding (27.1%). Notably, 85% of respondents stated they would be willing to relocate to a sustainable village if it provided essential urban infrastructure. While this indicates a high level of interest among university students, the relatively small and specific sample limits the extent to which these findings can be generalized. Nevertheless, the result may suggest emerging demand among younger generations for alternative, sustainable forms of settlement outside the capital.

5) Identified Challenges

Based on the findings, the following key challenges were identified for the development of sustainable villages:

First, the issues faced by ger district residents are not limited to climate-induced displacement; rather, they affect the entire ger population regardless of migration background.

Second, although traditional ger housing was expected to be preferred, residents expressed a clear preference for apartment-style or house-type dwellings, indicating substantial demand for improved living environments.

Third, the creation of stable employment opportunities is a critical factor in encouraging voluntary resettlement and long-term settlement.

Fourth, both ger district residents and urban citizens in Ulaanbaatar demonstrated a shared awareness of the severity of environmental pollution.

Accordingly, sustainable villages should not be viewed merely as relocation destinations, but as comprehensive settlements designed to fundamentally improve living conditions and support residents' self-reliance and autonomy.

Reference Analysis of Sustainable Village Development Elements

As summarized in Table 3, this study identified the essential components for building a sustainable village through interviews with practitioners and experts, as well as by analyzing domestic and international case studies in agriculture, settled livestock farming, cooperatives, afforestation, and solar energy. These findings provided the basis for detailed planning in each sector and were used to evaluate both feasibility and long-term sustainability.

1) Agriculture

Mongolia's agricultural conditions are limited, with only about 1% of the country's land suitable for cultivation (Jeong,

Table 3. Identification of Key Issues and Corresponding Solutions

Issue Classification	Detailed issue	Solution	Plan
Infrastructure	- Water and sewer utilities	Residential	Offer apartment-style housing instead of Ger
	- Heating and cooling issues		
	- Conventional restrooms		
	- Coal fuel		
Jobs and Economics	- Lack of jobs	Agriculture	Creating jobs through agriculture
	- Lack of village economic development	Settled livestock farming	Creating jobs through settlement farming
	- Lack of winter jobs	Cooperatives	Improve distribution and sales efficiency
		Tourism	Boost local economies
Environment	- Environmental pollution	Solar energy	Reduce greenhouse gas emissions and provide sustainable energy
	- Desertification		
	- Poorer health due to coal fuel use	Afforestation	Desertification prevention

2014, p. 192). While the self-sufficiency rates for wheat (96%) and potatoes (99%) are relatively high, vegetables are at 54%, indicating a heavy reliance on imports for essential crops (Ministry of Food, Agriculture and Light Industry, 2023). Due to Mongolia's industrial dependence on mining and pastoralism, expanding agricultural productivity is considered a national development priority.

This study conducted interviews with professors and researchers at the Mongolian University of Life Sciences to assess agricultural potential. Two promising regions were identified: the Central Agricultural Zone and the Steppe Agricultural Zone, where high-value crops such as corn, buckwheat, and soybeans can be cultivated. These results helped define criteria for crop selection in future village planning.

Expert consultation at a large-scale farm in Baruunkharaa, Selenge Province, Mongolia, confirmed the feasibility of cultivating watermelon, melon, and grapes. Small-scale farming in afforested areas also demonstrated the ability to produce eco-friendly vegetables like cucumbers, Chinese cabbage, carrots, and onions in response to local demand.

The study also examined the possibility of introducing smart farming. According to the Smart Farm R&D Center at the Mongolian University of Life Sciences, smart farming remains in the experimental stage—focusing on variables such as greenhouse wall thickness and water control systems. However, the high cost of winter heating significantly hinders profitability. Therefore, the model excluded smart farms and instead focused on a simpler, more practical agricultural structure.

2) Settled Livestock Farming

Mongolia's livestock industry accounts for approximately 10.2% of the national GDP and 6.4% of foreign trade. However, its sustainability is increasingly threatened by climate change and poor resource management—exemplified by the loss of about 4.9 million animals (7.6% of the herd) earlier in the same year (Ministry of Food, Agriculture and Light Industry, 2023).

To address the limitations of traditional nomadic herding, this study examined the feasibility of transitioning to settled livestock farming. Interviews with the grassland organization Green Mongolia confirmed the structural vulnerabilities of nomadic livestock systems and emphasized the need for more stable, settlement-based alternatives.

The potential for producing 48-hour aged meat through settled livestock farming was noted as a promising route to access premium food markets and enhance the long-term viability of local economies. Interviews with domestic and international staff from the International Corn Foundation further revealed that corn is primarily used for animal feed in Mongolia and can be processed into silage. These findings suggest that a partially self-sufficient livestock system is achievable through settled livestock models.

3) National Agricultural Cooperatives

Interviews with the headquarters and regional branches of NAMAC, Mongolia's national agricultural cooperative, revealed that cooperatives operate in a member-driven and autonomous manner. The headquarters do not collect membership fees and instead focuses on support functions such as training, financing, and promotional activities.

However, considering that agriculture and livestock projects in the proposed sustainable village model must start from a zero base, the study concluded that a more struc-

tured support framework and a viable membership fee model are necessary to ensure business stabilization and growth.

In addition, interviews with smallholder farmers operating within afforested areas underscored the need to strengthen storage and distribution infrastructure. Thus, cooperatives should evolve beyond the role of production-based communities and incorporate revenue diversification strategies such as securing storage facilities, leasing agricultural equipment, and developing distribution networks.

4) Afforestation Project

Mongolia is facing severe consequences of climate change, with average temperatures rising by 2.25°C and precipitation decreasing by 8% over the past 80 years. As of 2020, 76.9% of the national territory had become desertified. These environmental changes have not only undermined the agricultural base but have also deteriorated overall living conditions, contributing to transboundary air pollution such as yellow dust affecting neighboring countries like South Korea and China.

Consequently, afforestation projects in Mongolia serve a strategic purpose: beyond securing green space, they play a crucial role in creating favorable agricultural environments and mitigating desertification through windbreak forests. Interviews with both local and international forestry practitioners confirmed that windbreaks improve crop growth conditions by buffering strong Mongolian winds, thereby highlighting the complementary role of forestry in sustainable agriculture.

However, field investigations also identified significant challenges in revenue generation, due to the absence of efficient systems for price negotiation, product distribution, and storage. Therefore, afforestation efforts must be designed to simultaneously improve ecological resilience and ensure economic viability.

5) Solar Energy

Solar energy was identified as an appropriate renewable energy solution for sustainable village development in Mongolia, owing to the country's abundant solar irradiation and vast land area. As indicated in Table 4, both literature and interviews with local residents suggest that Mongolia receives more than 2,900 hours of sunshine per year, making it highly suitable for solar power generation. In fact, some households are already using solar panels and battery storage systems to meet basic electricity needs such as watching television and charging electronic devices.

Furthermore, global trends in the lifecycle of solar panels and electric vehicle batteries indicate a growing demand for recycling end-of-life components. Projections suggest that by 2040, China alone will account for 252 GW of retired battery capacity. Worldwide, approximately 1.56 million tons of recyclable battery materials are expected by 2030, increasing to 6.2 million tons by 2040. These figures suggest that recycling waste solar panels and batteries could help lower the initial installation costs of solar infrastructure in Mongolia.

Based on this sector-specific reference analysis, the study identifies solar energy not only as a technically viable solution but also as a financially strategic component in the development of sustainable villages.

Site Selection for a Sustainable Village

To address the previously identified challenges and implement appropriate solutions, a suitable site for a sustainable village in Mongolia was selected. Table 5 outlines the selection criteria and the corresponding scope of candidate sites.

Based on these criteria, the settlement of Salkhit (Салхит), located in Khongor Sum of Darkhan-Uul Aimag in northern Mongolia, was selected as the most appropriate site for implementation. Figure 2 shows the locations of the capital, Ulaanbaatar, and Salkhit on the map of Mongolia, and Table 6 presents key information about Salkhit.

Table 4. Regional Climate and Weather Statistics in Mongolia (WorldData, 2025)

Region	Temperature Max per Day	Temperature Max per Night	Sunshine Hours	Rainy Days	Precipitation	Humidity
Central	8.7°C	-4.8°C	2,920 h	32	204	58.0%
Eastern	8.2°C	-5.7°C	2,811 h	42	277	61.0%
Northern	7.8°C	-5.9°C	2,665 h	48	314	
Southern (Gobi Desert)	11.2°C	-2.1°C	3,030 h	23	186	47.0%
Western (Altai Mountains)	6.8°C	-6.7°C	2,665 h	32	197	59.0%

Table 5. Site Selection Criteria and Corresponding Conditions

Criterion	Details and Scope
Agricultural suitability	Central and steppe agricultural zones, which have the highest agricultural potential among Mongolia's five major agricultural zones (Central, Steppe, Gobi, High Mountain, Great Lakes Basin and the Altai Mountains)
Proximity to the capital	Central agricultural zone near the capital or industrial cities to support relocation of ger district residents
Transportation and logistics accessibility	Villages located along Mongolia's central railway line
Suitability for establishing a sustainable village	Villages with populations under 2,000 and basic infrastructure to support expansion and settlement

Table 6. General Status Information of Salkhit (Source: Data obtained from NSDI Mongolia, 2024, https://nsdi.gov.mn/)

Location	223 km northwest of Ulaanbaatar 33 km south of Darkhan 13 km south of Khongor	
Topography and Elevation	Urban district	Around 750m gently hilly terrain
	Periphery	Around 800m hillside meadow
	Mountain	Up to 950 m / Southeast
	River	West of urban district
Climate	Annual daylight hours	2,800 ~ 2.900h
	Average annual relative humidity	45 ~ 50%
	Average temperature (January / July)	Below -24°C / Above 18°C
	Wind direction	South wind
	Precipitation	Sufficient for agriculture

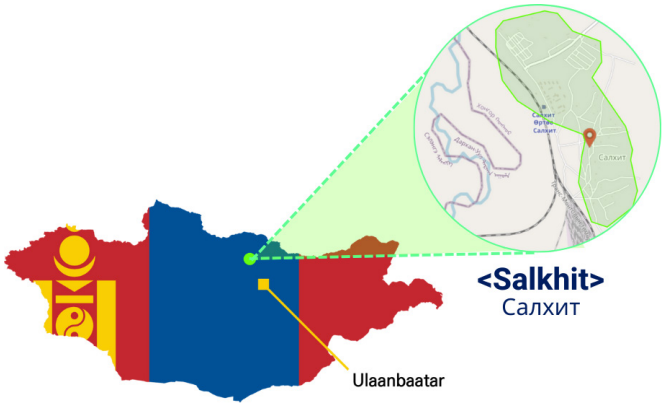

Figure 2. Location of the Salkhit in Mongolia (Source: Drawn by the authors, based on data from NSDI Mongolia, 2024, https://nsdi.gov.mn/).

The settlement of Salkhit can be broadly divided into one central commercial area and three residential neighborhoods. The commercial area, located in the center of the town, includes the railway headquarters, public facilities, schools, and apartment complexes, while the residential area consists mainly of privately owned homes. Table 7 shows physical status information of Salkhit, including apartments, roads, transportation, and water resources.

The town also hosts a Bag - The smallest administrative division in Mongolia, comparable to a village or subdistrict - Administrative Office and one local office of a Mongolian political party. Educational infrastructure includes School No. 11 and two kindergartens. Healthcare facilities consist of two hospitals and one pharmacy. Commercial infrastructure includes two banks and eight supermarkets. In addition, the town contains a railway station, a railway headquarters, and a thermal power plant that provides district heating. Cultural and recreational facilities include one cultural center, one sports center, and one basketball court.

As shown in Table 8, as of the end of 2024, Salkhit had a total population of 1,543 residents across 513 households. Assuming the working-age population to be between 19 and 59 years old, this group accounts for 49.7% of the total population. Among this working-age group, more than 70% are employed in the railway industry, with the remainder working in wholesale and retail, education, seasonal agriculture (mainly in summer), and service sectors.

In Salkhit, School No. 11 of Mongolia is located, accommodating a total of 337 students, 20 teachers, and 21 staff

Table 7. Physical Status Information of Salkhit

Apartment	15 (12 households each) + 1 (24 households) = 16 in total	
Road	Primary paved arterial road	Connects to Khongor sum (13 km)
	Paved internal ring road	Main road between village center and railway station
	Unpaved internal road	Connect alleys and inner areas of the village
Transportation (Train)	International	Twice a week
	Domestic (to Ulaanbaatar)	Twice daily
	Regional (to Erdenet)	Once daily
Water resource	Urban water infrastructure and 3 wells	

Table 8. Population of Salkhit (Source: Data obtained from Salkhit administration office, 2024)

Age (years)	Population (persons)
1~18	519
19~49	502
50~59	265
60 +	257
Total	1,543

members. Additionally, there is one kindergarten operated by the railway company and another managed by Salkhit Bag.

Sustainable Village

Figure 3 summarizes the master plan for a sustainable village by applying key elements of a sustainable village to Salkhit.

Salkhit's sustainable village plan is structured around eight key domains: land use, residential, agriculture, settled livestock farming, cooperatives, afforestation, solar energy, and tourism. The details related to land use were completed with the review of an urban engineering expert, and the specifics regarding cooperatives and afforestation were supplemented based on findings from prior reference analysis of sustainable village.

1) Land Use

Figure 4 shows a bird's-eye view of the central area, where the overall development is envisioned as a model of urban regeneration. The plan seeks to introduce a new commercial area centered on agriculture and livestock industries, while maintaining the integrity of the existing zones, including Commercial Zone A and Residential Zones 1, 2, and 3.

Peripheral zones will accommodate agricultural fields, livestock barns, afforested areas, solar power facilities, and a tourism complex. In the central area, public institutions such as police and fire stations, as well as agricultural cooperative facilities, will be located to serve both Commercial Zones A and B and support the development of the commercial district.

Furthermore, the installation of public housing complexes, parks, and pedestrian pathways will enhance the spatial connectivity between all functional zones within the village.

2) Residential

Based on interviews with residents of Salkhit, which confirmed increasing demand from both railroad industry employees and migrating populations from ger districts, a public rental housing program will be introduced to accommodate this rising demand. A total of sixteen four-story buildings will be constructed, with the capacity to house an additional 1,100 ger district migrants and 500 residents of Salkhit. These units will be allocated to new industrial workers on a priority basis, and for migrants who are unable to afford homeownership, the housing will be offered under a monthly rental system to facilitate stable settlement.

3) Agriculture

To establish a sustainable agricultural system, the target rural population for the village was set at 250 individuals. Based on this figure, total farmland was calculated by allocating 0.6 ha per person, resulting in 150 ha of arable land. This allocation is grounded in a comparative analysis with South Korea's agricultural structure. As of 2023, the agricultural population in South Korea was approximately 2,089,000 (National Statistical Office of Korea, 2024, February 27), and the total cultivated area was 1,512,145 ha, equating to about 72 acres per capita on average (National Statistical Office of Korea, 2024, April 18). Given Mongolia's comparatively underdeveloped agricultural infrastructure and the pilot nature of the project, a conservative figure of 60 acres per person was deemed realistic. This also aligns with the actual landholding size (~50 acres) reported by coopera-

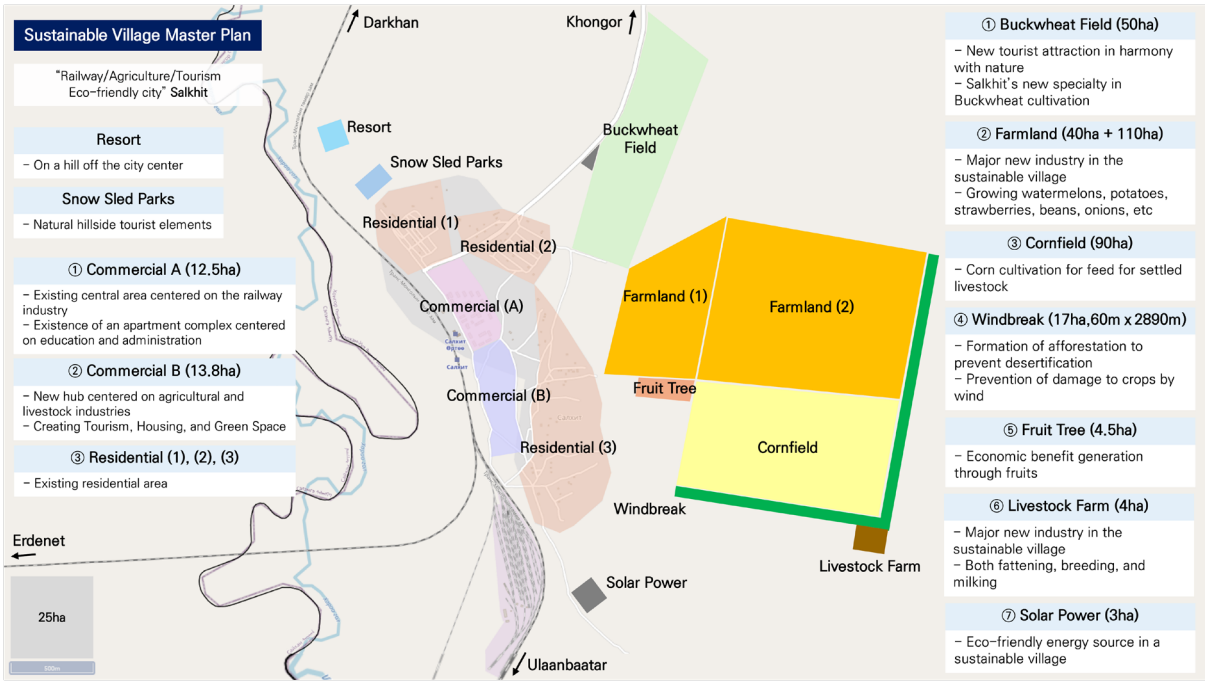

Figure 3. Sustainable Village Master Plan for Salkhit (Source: Drawn by the authors, based on data from NSDI Mongolia, 2024, https://nsdi.gov.mn/).

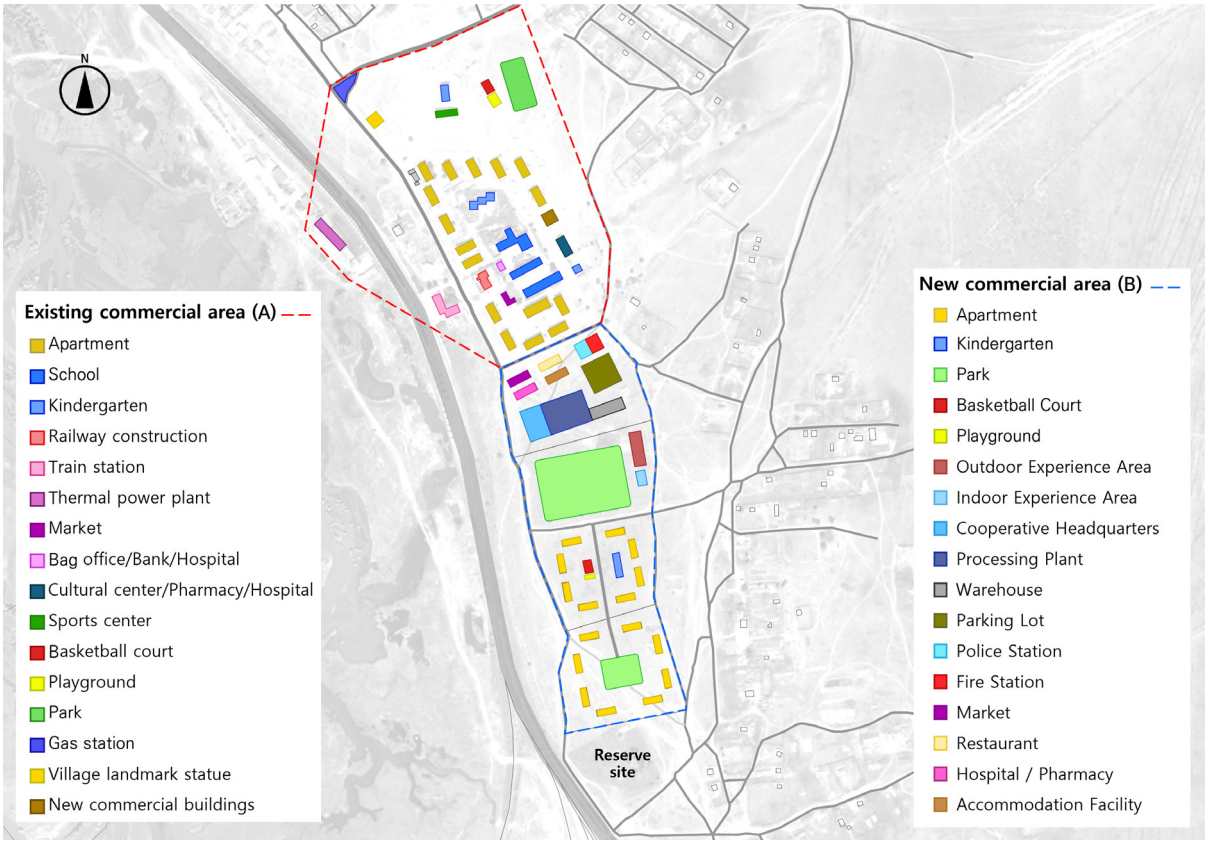

Figure 4. Bird's-eye view of the central area (Source: Drawn by the authors, based on map data ©2025 Google, https://maps.google.com).

tive farmers interviewed during field research in Mongolia.

The total 150 ha of farmland is divided into 25 sectors, operated under a collaborative farming model. This system is designed to encourage community participation while ensuring efficiency through structured group management. The operational process consists of the following steps:

1. Basic agricultural education is provided to all residents, including instruction on crop characteristics and cultivation methods.
2. A survey on crop preferences and educational comprehension is conducted to inform group formation.
3. Residents are then organized into teams of ten, balancing skill levels and educational outcomes. Individuals who demonstrate higher levels of understanding and leadership are appointed as team leaders.
4. Each team is assigned 6 ha of farmland and, through internal discussions, selects a main crop and supplementary crops. For instance, one team may designate wheat (3 ha) as the main crop and allocate the remaining land to potatoes (1 ha), strawberries (1 ha), and watermelons (1 ha). This approach promotes crop diversification, which stabilizes income and mitigates risks associated with climate variability.
5. The farming cooperative reviews each team's crop plan and land allocation. Upon approval, teams receive agricultural machinery, seed supplies, and technical support to initiate production.

In addition, to address potential losses from extreme weather events, a rental and loan reduction policy is implemented. In case of severe crop damage, the agricultural cooperative assesses the extent of the damage and applies graduated relief measures. Inspired by South Korea's Farmland Bank program, the system includes progressive rent and interest relief depending on the extent of damage, from 45% to 100% (Korea Rural Community Corporation, 2020).

4) Settled Livestock Farming

The proposed settled livestock farm is designed to integrate both beef cattle fattening and breeding systems, complemented by a small-scale dairy operation with four dairy cows. The fattening component involves purchasing calves from external sources, raising them over a fixed period, and eventually shipping them as finished beef cattle. In contrast, the breeding operation focuses on inseminating cows to produce calves, which are then sold to generate revenue. This integrated model was selected to enhance both productivity and profitability. The livestock management system employs a free-range method within open barn areas, allowing multiple animals to roam together. This approach supports adequate physical activity, reduces stress, and promotes overall animal welfare. The farm is intended to operate on a small scale. Daily operations require one to two full-time workers responsible for general livestock care, health monitoring, feeding, manure management, and reproductive tasks. Feed is tailored to the species and age of the animals, typically consisting of a mixed ration of hay and corn silage in a 40–50% proportion. This feeding strategy supports steady growth and helps maintain consistent meat quality. From an operational standpoint, systematic support and collaboration with the local livestock cooperative are critical. Prospective farmers are required to complete training programs provided by the cooperative prior to receiving livestock. Initial operating capital and feed cost assistance are also provided. As the operation stabilizes, farmers have the option to expand their herd size. Five years after the initial settlement, low-interest loan repayments begin at an annual rate of 1%, with dairy cows and heifer-related costs exempt from repayment. For dairy operations, milk is delivered monthly to the cooperative, and income is distributed based on the quantity supplied, enabling farmers to meet living expenses. This introductory model aims to offer a practical foundation for initial settlement while supporting long-term self-sufficiency and sustainable growth of the farm.

5) Cooperative

(1) The Necessity and Roles of Cooperatives

The first field study in Mongolia revealed that the most pressing challenges for local farmers were not limited to crop cultivation but extended to sales and distribution. For example, the Bayannuur farm was unable to harvest seabuckthorn berries due to the lack of storage facilities, while income dropped significantly after their only transportation truck broke down. In the case of the Erden farm, negotiating with wholesalers proved difficult, limiting their profitability. These observations led to the identification of three structural problems:

1. Lack of storage facilities
2. Weak distribution infrastructure
3. Absence of wholesale expertise

Given the limitations of individual farmers in addressing these challenges, the need for agricultural cooperatives

equipped with collective storage and distribution capabilities becomes clear. While existing cooperatives in Mongolia are typically composed of independent and experienced farmers or livestock producers, this study proposes a new type of cooperative aimed at supporting first-time agricultural participants through an integrated support system.

(2) Cooperative Membership Fees

The operating costs of the cooperatives, including the maintenance of wells, storage facilities, and village markets, are covered by membership fees contributed by participating farmers and herders.

(3) Roles of the Integrated Agricultural and Livestock Cooperative

- Market Operation: Operates a village-level market that sells agricultural and livestock products, ensuring income for producers and access to fresh food for residents.
- Water Resource Management: Oversees the installation and operation of wells and irrigation systems to provide a stable farming environment.
- Regional Branding: Develops and promotes local specialty products, especially those made from regional crops and seabuckthorn, to strengthen internal and external sales channels.
- Microloans: Provides low-interest microloans to farmers and herders to cover initial production and living costs.

(4) Roles of the Agricultural Cooperative

- Short-Term Equipment Rental: Offers short-term rentals of farming equipment, typically one set per five zones, with rental fees applied.
- Storage Facility Management: Manages storage for seasonal inventory adjustment and year-round supply to local processing plants.
- Wholesale and Distribution: Purchases crops at wholesale prices, supplies the village market, and handles external sales through contracted distributors, also managing price negotiations on behalf of farmers.
- Agricultural Education: Provides training on crop selection, cultivation, fertilizer usage, machinery operation, and agricultural business planning, supplemented by onsite expert guidance.
- Buckwheat Management: Oversees buckwheat planting and harvesting in the summer, and product development and tourism initiatives in the winter.

(5) Roles of the Livestock Cooperative

- Equipment Rental and Management: Offers short-term rental of livestock-related tools such as milking machines, calving devices, and tractors used for silage production.
- Storage Facility Use: Ensures proper storage of feed, hay, and processed dairy and meat products to maintain freshness and quality.
- Wholesale and Distribution: Purchases livestock at wholesale prices, manages day-of-slaughter sales and aged meat offerings for quality assurance, and handles contracts and distribution for external markets.
- Livestock Education: Provides technical training on topics such as artificial insemination, disease prevention, feed production, and efficiency improvements, supported by expert guidance.
- Feed and Breed Management: Covers up to 40% of livestock feed needs through silage, supports hay production via buckwheat field linkages, and conducts regular health checkups for quality assurance.

6) Afforestation

According to the National Agency of Meteorology and Environment (2020), approximately 120.3 million hectares, or about 76.9% of Mongolia's total land area, have been affected by desertification. The affected area is continuously expanding, leading to intensifying desertification. This process is accelerated not only by climate change but also by anthropogenic factors such as excessive livestock grazing and mining activities. Furthermore, desertification contributes to yellow dust storms impacting neighboring countries, including South Korea and China. According to reference analysis, afforestation projects are planned within sustainable villages to mitigate desertification and climate change and to preserve Mongolia’s ecosystem.

Wind induces dehydration in crops, resulting in shorter growth compared to areas without wind. Continuous exposure to wind causes plants to bend. Consequently, crops and fruit trees may suffer mechanical damage and inhibited growth due to wind stress (Woo, 2017). In the case of Salkhit, winds originating from the southern mountain range significantly influence crop growth; therefore, afforestation acting as a windbreak forest is established primarily along the southern side. The windbreaks are installed perpendicular to the prevailing wind direction. To enhance wind protection effectiveness, a three-layered structure is composed by mixing tree species of varying heights, including tall trees such as

Siberian elm (Ulmus pumila) and poplar (Populus spp.), as well as shrubs like willows (Salix spp.) and sea buckthorn (Hippophae rhamnoides). Considering the wide expanse of farmland, the windbreak forest is designed with a width of 60 meters—wider than the typical 20 to 40 meters—covering a total area of 17 ha.

At the 76th United Nations General Assembly, the Mongolian government pledged to plant one billion trees by 2030 to combat desertification (KOTRA, 2022). Afforestation projects are being implemented across various regions of Mongolia through collaboration with the South Korean government, private enterprises, international NGOs, and other stakeholders. Given that the demand for seedlings exceeds production capacity, a seedling production and supply initiative is underway to support afforestation efforts and to market surplus seedlings. This initiative follows the established framework of existing afforestation programs.

In addition, fruit trees such as seabuckthorn (Hippophae rhamnoides) and blackcurrant (Ribes nigrum) are cultivated locally. However, due to the absence of cold storage facilities and difficulties in securing markets, tens of tons of seabuckthorn berries are wasted annually. The introduction of cold storage facilities through cooperatives is planned to enable processing into food products and oils, thereby generating additional income.

7) Solar Energy

A sustainable energy source will be introduced by utilizing Mongolia's favorable solar environment. To reduce initial installation costs, pre-used solar panels with an efficiency rating above 75% will be repurposed. Since solar panel manufacturers typically guarantee a lifespan of 20–25 years with a performance standard of 80%, secondhand panels with sufficient remaining life and performance will be sourced, particularly from neighboring countries like China, where a large volume of decommissioned panels is available (Energy Economics Institute, 2023). The scale and configuration of solar power systems will be determined based on assessments of local sunshine duration and the village's estimated electricity demand. Any surplus energy generated will either be stored in energy storage systems (ESS) utilizing recycled batteries or sold to the Mongolian government to generate additional income.

8) Tourism

According to Reuters (2019), due to severe winter air pollution in Ulaanbaatar, there is a growing demand among citizens for rural places. Meanwhile, sustainable villages face challenges in generating stable year-round income due to the country's short agricultural season and the lack of distinctive crop identity. In response, it seeks to secure year-round income generation by developing a tourism complex that can complement the agriculture-based economy.

A 50 ha buckwheat field will be established as a tourist attraction, and locally grown specialty crops such as buckwheat and watermelon will be used to operate farm-based experience programs. In addition, traditional Mongolian cultural camps and seasonal events such as winter festivals will be organized to attract external visitors and enhance the village's visibility as a cultural destination.

4. Discussion and Conclusions

The field investigation confirmed that migration to ger districts is not driven solely by climate displacement but is influenced by a broader set of socio-economic factors, including access to education, healthcare, and employment. Residents face interconnected challenges such as air pollution from coal-based heating, soil contamination due to inadequate sanitation, limited income opportunities, and weak infrastructure.

To address these issues, this study developed a sustainable village model integrating agriculture, settled livestock farming, cooperatives, afforestation, and solar energy. The proposed model demonstrated potential for reducing environmental degradation, diversifying income, and fostering community-based self-sufficiency. Expert consultations further validated the technical feasibility of crop selection, cooperative operations, renewable energy use, and tourism development tailored to the Salkhit region.

Nevertheless, several critical limitations were identified, including a lack of baseline data on the region's environment and economy, underdeveloped local infrastructure, and potential gaps in resident engagement. In particular, the absence of reliable data on agricultural productivity and energy demand patterns constrained the ability to formulate detailed implementation plans.

In response, this study underscores the importance of operating the model village as a flexible test bed that can incorporate continuous empirical validation and resident-centered feedback. Through this test bed, future research should first assess the economic viability and operational stability of

each core sector—agriculture, livestock, and tourism—while continuously refining and adjusting strategies based on real-time outcomes. For instance, designing a reliable self-sufficient energy system will require quantitative modeling of solar generation, seasonal demand, ESS capacity, and projected revenues from surplus energy sales. Equally important is the financial foundation of the model. To ensure that residents can afford the costs associated with initial settlement and early operations, it is necessary to develop a balanced financial strategy that integrates both an internal circular economy and time-bound external support mechanisms. Establishing this well-prepared and adaptive framework will allow the model village to evolve beyond a short-term pilot, ultimately contributing to the stable livelihoods of residents and the long-term sustainability of the community.

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Jun. 2025, Volume.2 No.2

igee proceedings

pISSN: 3022-5183 eISSN: 3022-5191

IGEE Proc 2025;2(2):83-93
https://doi.org/10.69841/igee.2025.015

Article

Education for Sustainable Development and Career for High School Students in Seogwipo†

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This study examines the effectiveness of an Education for Sustainable Development (ESD) program conducted at Pyoseon High School in Jeju, Korea. Integrating career education, the program aimed at enhancing students' awareness of sustainable development and key competencies. Conducted with 124 first-year students during school hours, the program consisted of three phases: an introduction to sustainable development, student-led projects addressing local issues, and final presentations. A mixed-methods approach was employed to measure the effectiveness, combining pre- and post-program surveys with focus group interviews. Paired t-test analysis on survey responses showed statistically significant improvements in overall competency domains. Qualitative analysis of focus group interviews indicated a shift from passive, school-based perceptions of sustainability toward more active and individualized understandings, particularly in connecting sustainable development to diverse career pathways. In conclusion, this program demonstrates the effectiveness of bridging ESD with career education, showing that student-led learning can enhance core competencies for sustainable development. It offers a promising direction for the future advancement of ESD in Korea.

Keywords Education for Sustainable Development, Career Education, Sustainable Development Goals, Student-Led Learning

1. Introduction

Background and Objectives

In 2015, the United Nations (UN) General Assembly adopted the 'Sustainable Development Agenda' surrounding 17 Sustainable Development Goals (SDGs), which emphasized the need for Education for Sustainable Development (ESD) as its main content and means of achievement (United Nations General Assembly, 2015). Education on global

Received: May 18, 2025 **Revised:** May 30, 2025
Accepted: June 9, 2025
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†This research is supported by the Social Engagement Fund (SEF) 2024.

agendas such as sustainable development, sustainable lifestyles, and human rights are the foci of the 7th target of SDG 4, while the operating system of the United Nations Educational, Scientific and Cultural Organization (UNESCO) has since announced guidelines and programs such as 'ESD for 2030' in its *Roadmap* (United Nations Educational, Scientific and Cultural Organization, 2020). Accordingly, various stakeholders in South Korea, including the government and educational institutions, have worked to expand domestic educational opportunities for sustainable development.

This study aims to propose a new ESD program linked with career education, taking into account the limitations of existing approaches. By designing a short-term educational program supporting career planning based on sustainable development and verifying its effectiveness with high school students, the study seeks to promote career design rooted in social responsibility and suggest future directions for the advancement of ESD in Korea.

The program was implemented for first-grade students at Pyoseon High School in Seogwipo City, Jeju. This location was selected due to its relatively limited occupational diversity, making it an ideal setting to address regional disparities in career development competencies. Pyoseon High School introduced the International Baccalaureate (IB) program for all its students in 2021, creating an educational environment that emphasizes student autonomy and social engagement. This pedagogical context was carefully considered throughout the program's development.

The follow-up study employed a mixed-methods approach to assess the change in students' perceptions and understanding of sustainable development. This methodology combined quantitative measures through pre- and post-program surveys with qualitative insights gathered from focus group interviews.

Literature Review

Recent domestic ESD trends lean toward structural improvements, including the amendment of the 'Framework Act on Education' in 2021 and the enactment of the 'Framework Act on Sustainable Development' in 2022, integrating ESD into the national curriculum (Korean National Commission for UNESCO, 2023). However, these efforts focus excessively on environmental education, neglecting broader sustainable development agendas in an otherwise comprehensive spectrum. Sustainable development emphasizes balanced growth across various sectors, requiring individuals and organizations to play active roles, but current domestic ESD faces limitations in helping learners understand global agendas and define their roles in future society (Jeong et al., 2024).

Another core area of focus is the reality of regional disparities in career development competencies, which are essential for individual and societal growth. Such competencies are important as they involve skills for self-directed career selection and growth, but vary significantly by region, such as school location, due to disparities in community infrastructure, population composition, and educational resources (Jeong, 2021). Existing research highlights gaps in such competencies based on regional size, prompting policies to address inequalities (Kim, 2006; Jang, 2018). Thus, programs tailored to regions with limited resources are necessary for strengthening students' career development capabilities.

Drawing from such limitations, Korea's ESD program should expand beyond environmental topics to help students understand sustainable development in line with their futures. This study proposes a possible approach to addressing these issues by integrating ESD and career education, which can be expected to enhance career competencies while fostering roles in sustainable societies. In addition, the program aims to bridge regional gaps, support diverse age groups, and ensure scalability across regions.

2. Materials and Methods

Participants

The program was conducted with 124 first-year students at Pyoseon High School, located in Seogwipo City, Jeju. As the program took place during regular school hours, all first-grade students participated regardless of their prior interest in sustainable development. Five undergraduate mentors from Yonsei University facilitated the program by moderating discussions, providing support, and guiding student learning. These mentors had backgrounds in sustainable development, youth engagement, and project facilitation.

Program Structure

The program focused on raising awareness of sustainable development while incorporating the three dimensions of learning emphasized by UNESCO in ESD and Global Citi-

zenship Education (GCED); cognitive, social and emotional, and behavioral dimensions, as stated in its report *Educational Content Up Close* (UNESCO, 2020). The program was structured into three phases: introduction to sustainable development, student-led project, and final presentation. Phase 1 focused on introducing the concept of sustainable development to build foundational understanding. Phase 2 involved a student-led project, in which students explored a local community issue, applied knowledge, and collaborated with peers. In Phase 3, students delivered a final presentation, where they shared their project outcomes and reflected on their experiences.

1) Phase 1: Introduction to Sustainable Development

During the first phase, students were introduced to sustainable development through two 3-hour sessions on December 23 and 24. These sessions explored the concept of the SDGs, beginning with the official UN definition and leading students to identify their goals of interest. They were then encouraged to find connections between the SDGs and their everyday surroundings.

The 'I am - I will be' activity was developed with reference to UNESCO's Teacher's Guide, specifically drawing on the 'Identity-Outline' activity (UNESCO, 2016). This activity aims to help students reflect on their sense of self, self-esteem, and feelings of belonging while encouraging a deeper understanding of their roles within the broader world. Through guided questions, students are encouraged to consider how they define themselves, what matters to them, and how their choices impact others and the planet. With the same objective, the 'I am - I will be' activity utilized a worksheet featuring two concentric circles as shown in Figure 1. Students wrote their names in the center, surrounded by roles they currently identify with and aspire to in the future. Each role was accompanied by a brief explanation of its connection to specific SDGs. They had a chance to answer questions such as *"What is my current role in society?"*, *"What role do I see myself playing 10 years from now?"*, and *"Which SDGs might be connected to that future role?"*

In the 'A Desirable Society' activity, students engaged in collaborative dialogue supported by a cloud-based audience response platform. Such a platform was considered to promote inclusive participation by allowing all voices to be heard without fear of judgment and to support a more interactive exchange between students and instructors (Mayhew et al., 2020). During this activity, students first shared their visions of a desirable society in small groups and selected five keywords. These were submitted via the platform, generating a collective word cloud that served as the starting point for a class-wide discussion around the question: *"What kind of society do we envision as a class?"* Detailed guidance provided to students is presented in Figure 2.

The SDG Impact Assessment Tool was introduced to help evaluate the potential impacts a societal change may have

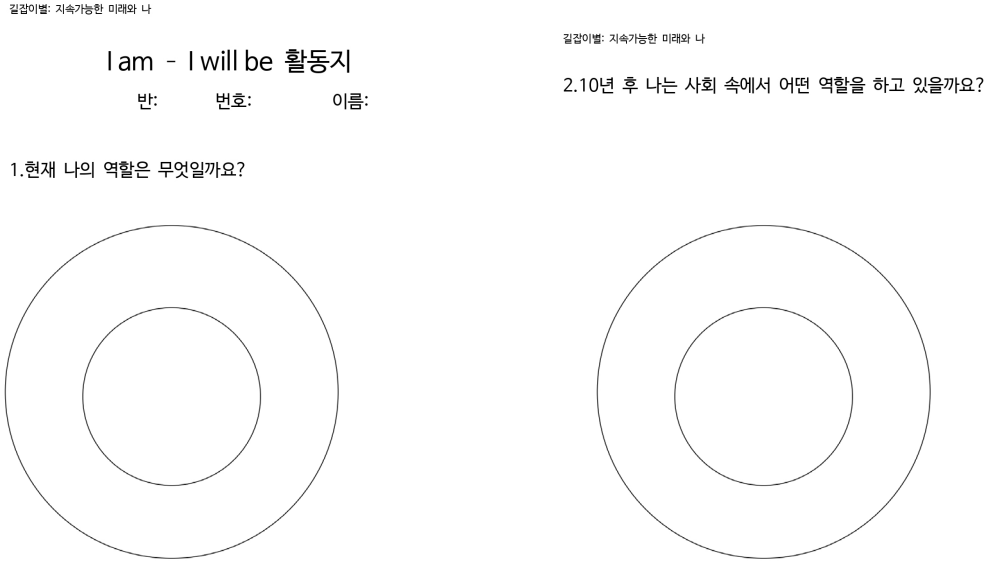

Figure 1. 'I Am-I Will Be' Worksheet.

on the SDGs (Eriksson, 2019). Developed by Wexsus, this tool enables users to conduct a qualitative self-assessment of how a specific change influences each of the 17 goals (Sustainable Development Solutions Network [SDSN] Northern Europe, 2024). Students assessed the introduction of free public transportation in Seogwipo with each SDG by evaluating with the following categories: direct positive, indirect positive, no impact, indirect negative, direct negative, or don't know - more knowledge needed (Eriksson, 2019). For each choice, they provided a brief written explanation for their choice. This exercise encouraged critical thinking about local decisions and interconnectedness with global agendas. After completing their assessments, students shared their results on a classroom board as shown in Figure 3, facilitating open discussion on differing perspectives.

2) Phase 2: Student-led Project

Building on their understanding of the SDGs, students developed projects in line with UNESCO's recommendation to employ interactive, project-based, learner-centered pedagogy as stated in its *Roadmap* (UNESCO, 2020). Students were encouraged to lead a team project to solve a local community issue, as students began analyzing community issues using the Five Ps of Sustainable Development: People, Planet, Prosperity, Peace, and Partnership. After conducting individual research on local issues, students discussed their findings with peers and formed project teams based on shared interests. Each team then developed a detailed action plan to address a chosen issue.

Between December 25 and January 1, teams carried out self-directed projects addressing a range of local challenges. Topics included elderly isolation in rural communities, youth delinquency, and waste accumulation on Jeju's coastlines.

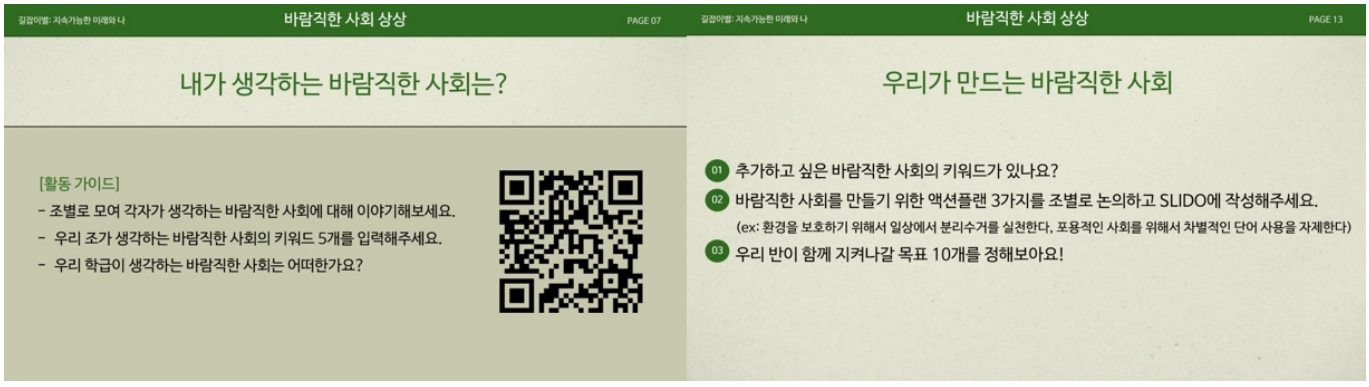

Figure 2. 'A Desirable Society' Activity Slides.

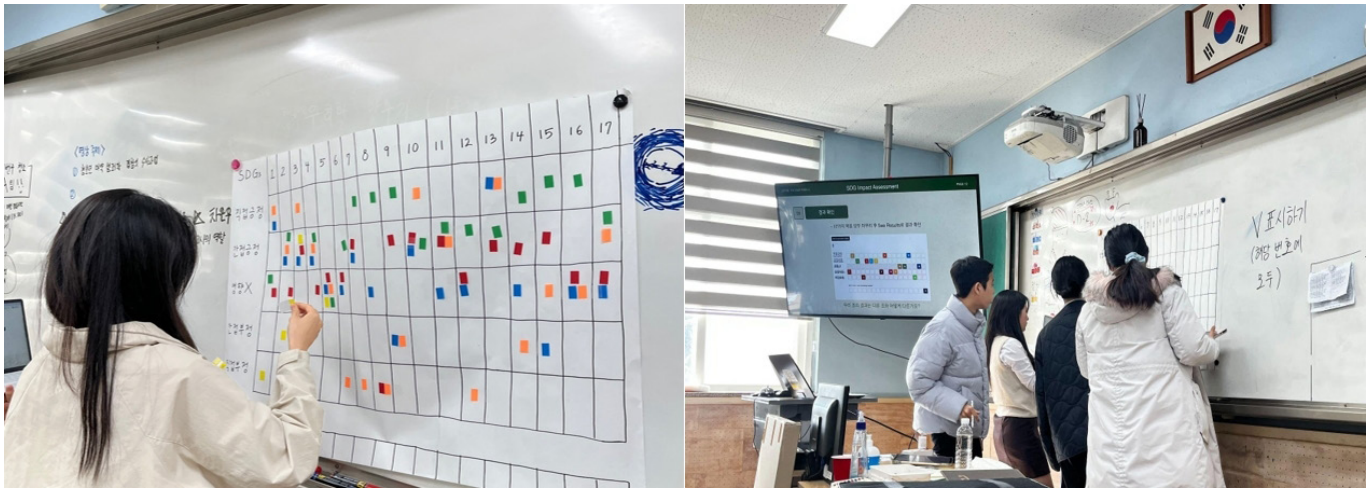

Figure 3. The 'SDG Impact Assessment' Activity.

At the end of this phase, five outstanding teams were selected according to creativity and innovation, feasibility and impact, and alignment with sustainable development. An exemplary outstanding project is presented in Figure 4.

3) Phase 3: Final Presentation

On January 2, the selected teams delivered final presentations to an audience of all first-year students and mentors. Each team shared their project outcomes, key insights, and reflections on how their efforts related to sustainable development and future career paths. Projects addressed elderly isolation, gaps in intergenerational communication, youth delinquency, community healthcare, and ethical dilemmas in technological development, as detailed in Table 1. Figure 5 presents photographs from the final presentation session.

Research Design

The program's effectiveness in the four domains, awareness of sustainable development, cognitive competence, social and emotional competence, and behavioral competence, was evaluated using both quantitative and qualitative methods.

For the quantitative analysis, pre- and post-surveys consisting of 18 questions were administered to 124 participating students to assess changes across the four categories. The full set of survey questions is listed in Table 2. Survey responses were recorded on a 5-point Likert scale, and paired sample t-tests were conducted to determine statistically significant differences.

Focus group interviews were conducted to explore changes in 'awareness of sustainable development' in greater depth. Two students from each class were randomly selected to form a group of ten, and pre-program and post-program interviews were conducted to identify shifts in responses. The interviews were conducted by three researchers of the program, with the pre-program interview lasting approximately 15 minutes and the post-program interview around 50 minutes. The interview questions explored two key areas: understanding of sustainable development and interest in linking careers with sustainable development as detailed in Table 3.

3. Results

T-Test Analysis

Among the students who responded to the pre-program and post-program surveys (111 and 101, respectively), those who didn't participate in both surveys, submitted multiple responses, or did not submit the student project outcomes were excluded. Thus, a total of 86 valid responses were retained for analysis. Responses to each question were converted to a five-point Likert scale and analyzed using paired sample t-tests. All statistical analyses were performed using Microsoft Excel Data Analysis Toolpak.

1) Awareness of Sustainable Development

Paired sample t-test results, as detailed in Table 4, indicate that both questions measuring awareness of sustainable development show statistically significant improvements. Notably, question 2, which assesses the perceived connection between sustainable development and students' career choices or future goals, exhibits the greatest change with a mean increase of 0.94 points.

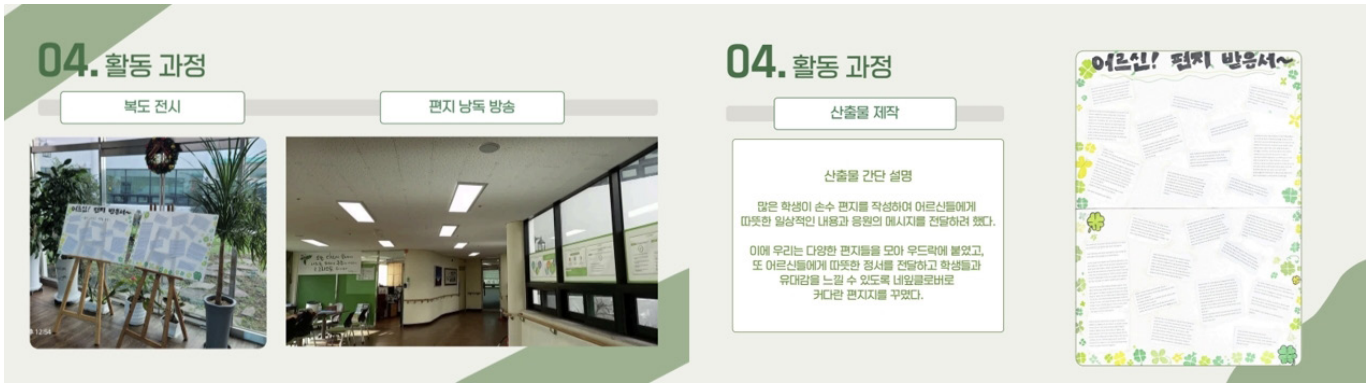

Figure 4. Student-Led Project (Elderly Isolation in Seogwipo City).

Table 1. Details of Outstanding Self-Directed Projects

Project Topic	Objective	Details	Related SDG
Elderly isolation in Seogwipo City	- Connect with elderly members of the local community - Raise awareness among students	- Collected letters from 1st-grade students using Google Forms - Visited a local nursing home to share the letters	- SDG 10 (Reduced Inequalities) - SDG 11 (Sustainable Cities and Communities)
Lack of intergenerational communication - focusing on family	- Bridge socio-cultural gaps between parent and child generations - Encourage intergenerational communication within households	- Created an informational social media account to share content about food, fashion, slang, etc. from the 1990s	- SDG 17 (Partnerships for the Goals)
Promoting the advancement of healthcare and cultural life in the Pyoseon community	- Propose solutions to support cultural development within the Pyoseon community - Explore ways to improve the local healthcare system	- Created a magazine to propose the idea of transforming a closed school into a cultural complex - Wrote articles to raise awareness about the lack of medical facilities in Pyoseon	- SDG 3 (Good Health and Well-Being) - SDG 11 (Sustainable Cities and Communities)
Misperceptions about youth delinquency	- Raise awareness of youth delinquency issues - Promote solidarity, reduce social stigma, and suggest institutional improvements	- Produced a documentary exploring public perceptions, causes, and solutions to youth delinquency	- SDG 4 (Quality Education) - SDG 10 (Reduced Inequalities) - SDG 16 (Peace, Justice and Strong Institutions)
Ethical dilemmas in scientific and technological development	- Discuss the impact of technological change on human identity - Create a space for dialogue on the sustainable direction of economic and technological development	- Organized a debate on the topic and shared both perspectives by creating a website and social media content	- SDG 9 (Industry, Innovation and Infrastructure)

Figure 5. Final Presentation.

2) Cognitive Competence

The paired sample t-test results, as detailed in Table 5, reveal statistically significant improvements across all four questions related to cognitive competence. These findings suggest that the program had a meaningful impact on students' development of competencies associated with understanding and analyzing issues related to sustainable development.

Table 2. Survey Questionnaire

Awareness of Sustainable Development
1. I can explain what sustainable development is.
2. I have thought about how sustainable development relates to my career choices or future goals.
Cognitive Competence
3. I can analyze societal issues.
4. I can compare various data to draw rational conclusions.
5. I can compare different perspectives to make a judgment.
6. I can critically evaluate the validity and reliability of information.
Social and Emotional Competence
7. I can clearly express the values that are important to me.
8. I can recognize and regulate my emotions in conflict situations.
9. I try to understand the emotions or perspectives of others.
10. I believe diverse perspectives should be respected during group discussions.
11. I think about the role I can play in solving societal issues.
12. I reflect on how my actions affect others and society.
13. I respect and accept others' opinions during group activities.
14. I can lead a team and coordinate opinions to solve a shared task.
Behavioral Competence
15. I can set specific goals and detailed implementation plans.
16. I can steadily follow through with plans to achieve my goals.
17. I can find specific and actionable solutions.
18. I can flexibly adjust plans when unexpected challenges arise.

3) Social and Emotional Competence

The results regarding social and emotional competence, as shown in Table 6, are more nuanced. Of the items analyzed, questions 7, 8, 9, 11, 13, and 14 demonstrate statistically significant improvement. However, no significant difference is observed for questions 10 and 12 between the pre- and post-surveys.

Yet it is notable that the pre-program mean for question 10 - respect for diverse perspectives during discussions - is already relatively high at 4.23, which may have limited the room for notable improvement. As for question 12, which addressed students' consideration of the impact of their actions, no clear reason can be identified for the lack of significant change. This suggests a need to reinforce this aspect in future iterations of the program.

4) Behavioral Competence

All four questions related to behavioral competence exhibit statistically significant improvements as detailed in Table 7. This indicates the program's effectiveness in enhancing students' capacity for action-oriented behavior in the context of sustainable development.

Focus Group Interviews

Students' answers in pre- and post-program interviews were compared to identify changes in their understanding of sustainable development and their interest in linking it to future careers.

1) Pre-Program Interviews

When asked whether they had previously encountered the

Table 3. Focus Group Interview Questionnaire

Pre-Program Interview	Post-Program Interview
1. Sharing Reflections	
-	1-1. What was the most enjoyable or memorable activity during the program? 1-2. Did you face any difficulties, feel a sense of accomplishment, or have any regrets?
2. Understanding of Sustainable Development	
2-1. Have you heard of sustainable development before? If so, in what context did you hear about it, and what comes to mind?	2-1. How has your understanding of sustainable development changed before and after the program?
3. Interest in Linking Careers with Sustainable Development	
3-1. What career path are you currently considering? 3-2. Have you ever considered the connection between your career and sustainable development?	3-1. How has the program influenced your career planning?

Table 4. Results of Paired Sample T-test on Awareness of Sustainable Development

Question No.	Descriptive Statistics				T-Statistic (P-Value)
	N	Pre-test M (SD)	Post-test M (SD)	Mean Difference	
1	86	3.44 (0.90)	4.07 (1.01)	0.63	-4.8586 (0.0000)***
2	86	3.15 (0.99)	4.09 (0.97)	0.94	-6.8374 (0.0000)***

* p < .05, ** p < .01, *** p < .001

Table 5. Results of Paired Sample T-test on Cognitive Competence

Question No.	Descriptive Statistics				T-Statistic (P-Value)
	N	Pre-test M (SD)	Post-test M (SD)	Mean Difference	
3	86	3.72 (0.90)	4.21 (0.88)	0.49	-4.2730 (0.0001)***
4	86	3.77 (0.83)	4.24 (0.86)	0.48	-4.7560 (0.0000)***
5	86	3.83 (0.87)	4.27 (0.84)	0.44	-4.2448 (0.0001)***
6	86	3.71 (0.96)	4.14 (0.90)	0.43	-3.9418 (0.0002)***

* p < .05, ** p < .01, *** p < .001

Table 6. Results of Paired Sample T-test on Social and Emotional Competence

Question No.	Descriptive Statistics				T-Statistic (P-Value)
	N	Pre-test M (SD)	Post-test M (SD)	Mean Difference	
7	86	3.78 (0.99)	4.27 (0.85)	0.49	-4.1862 (0.0001)***
8	86	3.59 (0.88)	4.00 (0.86)	0.41	-3.7358 (0.0003)***
9	86	3.98 (0.95)	4.30 (0.79)	0.33	-3.1747 (0.0021)**
10	86	4.23 (0.94)	4.35 (0.86)	0.12	-1.0548 (0.2945)
11	86	3.74 (0.92)	4.16 (0.86)	0.42	-3.5625 (0.0006)***
12	86	3.99 (1.01)	4.20 (0.86)	0.21	-1.8633 (0.0659)
13	86	4.13 (0.93)	4.40 (0.80)	0.27	-2.5430 (0.0128)*
14	86	3.87 (1.02)	4.23 (0.96)	0.36	-2.9959 (0.0036)**

* p < .05, ** p < .01, *** p < .001

Table 7. Results of Paired Sample T-test on Behavioral Competence

Question No.	Descriptive Statistics				T-Statistic (P-Value)
	N	Pre-test M (SD)	Post-test M (SD)	Mean Difference	
15	86	3.48 (0.96)	4.14 (0.93)	0.66	-5.3733 (0.0000)***
16	86	3.45 (1.06)	3.99 (0.96)	0.53	-4.0517 (0.0001)***
17	86	3.69 (0.94)	4.13 (0.89)	0.44	-3.8717 (0.0002)***
18	86	3.65 (0.97)	4.14 (0.93)	0.49	-4.2730 (0.0001)***

* p < .05, ** p < .01, *** p < .001

concept of sustainable development, all participants responded affirmatively. Students commonly cited engagement in school-based experiences, such as mandatory participation in Pyoseon High School's global citizenship project. Some students also referenced poster-making activities related to Environmental, Social, and Governance (ESG) management, social studies classes, and extracurricular school activities.

When prompted to explain the concept of sustainable development, most students referred to keywords such as “environment” and “ecosystem.” One student demonstrated a high level of understanding by accurately citing the UN definition - “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” These responses reflect a relatively strong familiarity and conceptual grasp of sustainable development, which may be attributed to the school’s IB curriculum. However, students’ understanding appeared to be predominantly shaped by school-based activities and focused largely on environmental issues. The frequent use of similar

terminology among participants suggests that prior learning experiences were largely passive and repetitive.

When asked about their intended career paths, students expressed a range of aspirations across disciplines including marine biology, philosophy, and visual design. Their responses on the motives of such interests often reflected personal experiences or media influence. We categorized students' career paths based on three domains — natural sciences, humanities, and arts. Among these groups, students pursuing careers in the natural sciences demonstrated a clearer awareness of its relevance to sustainability, as reflected in specific references to "infrastructure development in developing countries through modular architecture." In contrast, students in the humanities and arts tracks generally expressed weaker or no explicit connections between their career goals and sustainable development. The details of the responses are presented in Table 8.

2) Post-Program Interviews

When asked about the most impactful activities in the program, many students highlighted the student-led group projects, while two students mentioned the classroom discussions conducted during the SDG Impact Assessment activity. Overall, participants expressed a high level of satisfaction with the participatory components of the program. Some students also noted areas for improvement, such as the limited duration of the program, which "restricted their ability to develop more in-depth projects and to implement and analyze their ideas." One student remarked on "the frustration of being unable to propose actionable solutions as a student," reflecting a broader desire among participants to further develop and refine their student-led initiatives.

In response to questions regarding changes in their understanding of sustainable development, students reported a broadened awareness of the scope of sustainability and a stronger sense of its relevance to their personal lives. Specifically, they indicated an expanded understanding of the SDGs in social and economic dimensions, as well as an appreciation for systematic and stepwise approaches to problem-solving. Several students also noted that "the SDGs are not limited to distant or complex societal challenges but are directly related to daily life and individual career paths."

When asked about the program's influence on their career planning, many students articulated a clearer sense of connection between sustainability and their professional goals. Most students either explained newly found connections between their intended careers and sustainability or showed reinforcement of previously noted links. However, students in the humanities - particularly one aspiring philosophy major - reported "difficulty in identifying meaningful connections between their career interests and sustainable development." The details of the responses are illustrated in Table 9.

3) Interview Analysis

A comparative analysis of the pre-program and post-program focus group interviews reveals substantial changes in both understanding of sustainable development and interest in linking careers to sustainable development.

Specifically, students demonstrated an expanded comprehension of the SDGs, including their application beyond the environmental domain to encompass social and economic issues. Additionally, students began to relate these concepts to everyday life. Many participants remarked that "the program provided a more comprehensive and integrated opportunity for reflection on sustainability compared to previous school activities." Several students also reported "gaining a stronger sense of personal responsibility and agency in contributing to sustainable development."

Moreover, a significant number of students articulated new or strengthened connections between sustainability and their

Table 8. Summary of Key Responses from Pre-Program Interviews

Career Track	Number of Students	Response Characteristics
Natural Sciences	4	- Interests included marine biology (2 students), architecture, and pharmacy - Emphasized contributing to health and societal progress through science - Noted connections to sustainability in themes such as ecosystem preservation, infrastructure development, and public health
Humanities	3	- Interests included philosophy, economics, and business - Expressed intellectual curiosity and practical interest
Arts	3	- Interests included visual design, culinary arts, and performing arts - Responses emphasized personal passion and self-expression over social engagement

Table 9. Summary of Key Responses from Post-Program Interviews

Career Track	Number of Students	Response Details
Natural Sciences	4	- (Marine Biology) Explained sustainable fishing and its relevance to career plans as a marine biologist - (Marine Biology) Noted an understanding of wastewater treatment processes from a biological perspective - (Architecture) Expressed being proud of the possibility of contributing to society through infrastructure development in underdeveloped regions - (Pharmacy) Expressed determination to develop pharmaceutical solutions that address both healthcare inequality and environmental issues
Humanities	2*	- (Philosophy) Expressed trouble finding direct connections with career plans - (Economics) Noted that seeing diverse views with SDG Impact Assessment activity was interesting
Arts	3	- (Visual Design) Explored ethical issues in design while researching tools for marginalized groups - (Culinary Arts) Learned about alternative meat produced using 3D printers and began thinking about zero-waste practices in cooking - (Performing Arts) Gained a new perspective on acting as a means of raising awareness of social issues

*One student who participated in the pre-program interview did not attend the post-program session.

career goals by referencing concrete themes such as 'sustainable fisheries', 'healthcare inequality', 'ethical issues in design', and 'alternative meat'. While students in the humanities showed little change in their responses between the interviews, those in the natural sciences and arts demonstrated a markedly increased recognition of sustainability's relevance to their fields. Overall, students appeared to engage more actively with the concept of sustainable development by connecting it to their personal lives and career aspirations, with some expressing a clear intention to contribute to sustainability through their future professions.

4. Discussion and Conclusions

Program Significance

The program is significant in that it adopted self-directed educational methods into ESD by integrating career education. The inclusion of self-reflection and discussion in classroom activities encouraged student participation and engagement. In addition, student-led projects empowered students to engage in self-directed learning by analyzing community issues and creating feasible solutions. Through these approaches, the program offered students an opportunity to actively reflect on the SDGs and develop their career aspirations based on an understanding of a sustainable society. In addition, it allowed students to exert their influence as subjects leading positive change and to confirm the role of future generations in community development.

Research results support these positive impacts on students. T-test results reveal significant improvement in students' awareness of sustainable development, cognitive competence, behavioral competence, and most aspects of social and emotional competence. Focus group interviews reveal that the program encouraged students to incorporate sustainability into their career planning and heightened their social responsibility. These findings align with existing research demonstrating the effectiveness of ESD with emancipatory approaches in helping students integrate sustainable development principles into their personal lives and value systems. This approach promotes appreciation for diversity while equipping learners with essential competencies for lifelong application (Wals & Benavot, 2017). The significant improvements observed in students' competencies, along with their increased integration of sustainability into career planning, reinforce these benefits of the emancipatory model for ESD.

Implications for Society

This study holds significant implications for Korean society, suggesting a possible direction for the development of domestic ESD. The proven effectiveness of integrating career education into ESD, as well as the implementation of self-directed approaches, suggests the need to transform the traditional environment-oriented model and diversify programs to

include more student-led activities. By encouraging students to expand their understanding of sustainable development and actively engage in discussions, schools can become incubators for social innovation and cultivate the youth to become agents of sustainable change.

Conclusion and Limitations

In conclusion, this study highlights the potential of developing ESD beyond traditional environment-oriented, conceptual learning models. The program presented in this study reveals significant effectiveness in enhancing students' understanding of sustainable development and the key competencies of active engagement. The self-directed nature of the program enabled students to integrate sustainable development into their personal values and lives, with the potential to foster long-term engagement. In this regard, the program serves as a successful case of ESD targeted at high school students, which may suggest new directions for domestic ESD programs.

However, the study faces some limitations. The program's short duration limited the ability to observe long-term impacts, while students themselves expressed deeper interest in extended activities. Furthermore, as the sample of the study were first-year IB students with relatively higher exposure to ESD, the applicability of research results to students from other backgrounds and interests can be limited. This highlights the need for follow-up studies with extended programs and students with little exposure to ESD. Analysis of program effectiveness on different sample groups and extension of its duration to observe long-term changes are necessary to ensure the program's scalability.

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Jun. 2025, Volume.2 No.2

igee proceedings

pISSN: 3022-5183 eISSN: 3022-5191

IGEE Proc 2025;2(2):94-102
https://doi.org/10.69841/igee.2025.016

Article

Empowering Single Parent Households: A Web Platform to Address Systematic Gaps in Welfare and Care Support†

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Single parent households in South Korea face significant barriers in accessing welfare support due to fragmented information systems, persistent social stigma, and limited policy utilization. Despite the existence of various support programs, gaps in practical accessibility and reliability remain. This study aimed to develop a web-based platform that improves access to parenting, welfare, and emotional support information for single parent households, thereby promoting self-reliance and social inclusion.A full-stack web platform was developed using React.js, Next.js, Node.js, MongoDB, AWS S3, and the OpenAI GPT-4 API. The platform includes key functions such as an AI-powered chatbot, parenting diaries, health management tools, and structured access to verified welfare information. Domain-specific prompt engi-neering was applied to improve chatbot accuracy and empathy. The study did not involve human participants but relied on literature-based needs analysis and system design methodologies.The developed platform successfully integrated reliable information delivery, real-time AI-based guidance, and tools for tracking child health and caregiving. It addressed challenges such as low information reliability, limited support networks, and emotional isolation. Preliminary implementation confirmed the platform's usability and relevance, although features like automated policy updates and geolocation services remain in development.The platform demonstrates the potential of digital solutions to mitigate systemic gaps in welfare information and caregiving support for single parent households. By aligning with key Sustainable Development Goals (SDGs), the platform not only alleviates parenting burdens in the short term but also contributes to long-term goals of gender equity, health access, and social inclusion. Further iterations will focus on improving mobile accessi-bility, scaling user engagement, and enhancing AI accuracy.

Keywords Single parent households, Web development, SDGS, Health and Welfare, Information accessibility, Social in-clusion

Received: May 18, 2025 **Revised:** May 30, 2025
Accepted: June 10, 2025
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†This research is supported by the Social Engagement Fund (SEF) 2024.

1. Introduction

In modern society, family structures are becoming increasingly diverse. Despite changing perceptions of marriage and family forms, single parent households are still not fully accepted as a legitimate family type in South Korea. As of 2023, under the Single-Parent Family Support Act, 214,537 low-income single-parent families and 517,853 individuals were registered as recipients of government support (Statistics Korea, 2024). The number of single parent households raising children has been steadily increasing, driven by various sociocultural factors: growing acceptance of diverse family forms, changing social attitudes toward single parent households, greater complexity in the causes of single motherhood, evolving values regarding the acceptance of single-mother identities, amendments to family law, and expanded economic support for single-parent families (Park & Ko, 2017).

Since the mid-2000s, policy directions have shifted from prioritizing adoption to supporting childrearing by single parent households. Consequently, support for prenatal and postnatal care through basic residential facilities has expanded, along-side the establishment of additional welfare facilities aimed at supporting single parent households. The major types of facilities available include single-mother and child residential centers, shared homes for single-mother families, and shelters for single-parent families (Ministry of Gender Equality and Family, 2025).

However, according to statistics from the Seoul Metropolitan Government, there are currently only 23 residential facilities and 4 counseling centers operating in the city (Seoul Metropolitan Government, 2025), which is insufficient considering there are 3,384 single parent households and 860 single fathers residing in Seoul (Seoul Metropolitan Government, 2024). Furthermore, single parent households living in facilities, separated from their families of origin, face increased vulnerabilities, as they must independently manage all aspects of childcare and daily life without fa-milial support (Gwon et al., 2019).

Meanwhile, the Single-Parent Family Support Act provides childcare allowances to single-parent households, including single parent households, but the level of support remains significantly lower than the actual costs of raising a child (Lee, 2013). Moreover, the eligibility threshold is set at only 52% of the median income, leaving many single parent households—particularly those engaged in precarious, low-wage employment—in a difficult position where they are forced to choose between re-maining among the working poor or depending entirely on public assistance (Lee, 2013).

Addressing these challenges is essential not only for the welfare of individual families but also for the broader goal of achieving greater social sustainability. En-suring the health, well-being, and social inclusion of single parent households and their children is directly aligned with several Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being), SDG 5 (Gender Equality), and SDG 10 (Reduced Inequalities).

The primary objective of this study is to design and develop a web-based plat-form to bridge the information accessibility gap faced by single parent households. In particular, the Korea Population, Health and Welfare Association's 2022 report, 'The Third Survey on the Status and Needs of Child-Rearing Single parent households', highlighted critical issues in information accessibility and reliability, and emphasized the need for a personalized "push service" linked to national support systems (KoPHWA, 2018). Accordingly, this study aims to identify key unmet needs through a review of existing literature and propose a practical digital intervention. By de-veloping an AI-powered web service, the project seeks to enhance single parent households' access to reliable childcare information, welfare policies, and commu-nity support systems.

Although the project does not establish or test explicit hypotheses due to its developmental nature, it proceeds under the fundamental assumption that providing customized information through digital technology will contribute to improving the social inclusion and well-being of single parent households.

2. Literature Review

Research on single parent households during the 1990s shifted from a traditional focus on adoption to studies centered on pregnancy and childbirth among those who chose to raise their children (Shin, 2017). In the 2000s, research further expanded to explore the relationships between single parent households and their families, as well as their emotional well-being (Shin, 2017). As the number of single parent house-holds raising children increased, studies began to address issues such as the right to parental custody and educational rights for adolescent single parent households, along with investigations into the status of policy support (Shin, 2017). Given the rapid changes in the social environment surrounding single parent households, this review focuses primarily on studies conducted after 2010. The following sections summarize the key findings from previous research on

single parent households.

Life Cycle of Single parent households

Single parent households are placed on a continuum of choices from the moment they recognize their pregnancy. It is common for them to face these choices alone. According to research, single parent households experience various temptations and considerable fear and difficulty during the decision-making processes regarding abortion and adoption (Seong et al., 2018). Even after deciding to give birth, they face further challenges such as financial difficulties, housing instability, and social stigma, often compounded by a lack of accessible information (Seong et al., 2018). Research comparing parenting efficacy between married mothers and single parent households has also shown that single parent households exhibit greater anxiety about their parental roles and lower levels of parenting efficacy (Shin & Lee, 2016).

Throughout the processes of pregnancy, childbirth, and childrearing, single parent households must independently resolve complex issues, including redefining relationships with their families and the child's biological father, resolving legal registration of their child, overcoming social stigma, achieving financial independ-ence, securing stable housing, and addressing economic hardships (Lee & Um, 2013). Given that single parent households frequently encounter discrimination and various negative experiences across these life stages—economically, psychologically, and socially (Kim et al., 2012; Lee & Um, 2013; Seong et al., 2018; Shin & Lee, 2016)—comprehensive support is necessary to promote their independence, improve childrearing environments, change societal perceptions, and reform social welfare systems.

Economic Conditions, Self-Reliance, and Policy Support for Single parent households

Economic hardship is one of the most significant challenges faced by families headed by single parent households. Financial conditions are closely linked to the ability of single parent households to achieve self-reliance and to adequately raise their children (Seong et al., 2018). Even when employment is secured, low wage levels and the lack of flexible working conditions to accommodate childcare re-sponsibilities make stable participation in the workforce difficult, often leading di-rectly to poverty (Seong et al., 2018). According to previous studies, early-stage single-mother families often lack surrounding support networks, highlighting the need for long-term, structured support plans that facilitate gradual labor market in-tegration (Seong et al., 2018). In addition, establishing accessible support networks and creating an environment conducive to information utilization are critical elements for promoting self-sufficiency (Seong et al., 2018; Lee, Jeong, & You, 2023).

Meanwhile, although various programs and policies have been implemented to assist single parent households and low-income single-parent families, several studies have pointed out that these initiatives often fail to adequately reflect the specific needs of single-mother families (Kim et al., 2012; Yi, 2012; Kim, 2013). Although a wide range of formal services exists (Ministry of Gender Equality and Family & Korea Lottery Commission, 2024), they frequently do not translate into practical support for single parent households, and difficulties in accessing relevant infor-mation remain widespread (KoPHWA, 2018; Lee et al., 2023).

Qualitative research on the experiences of single parent households receiving support shows that, in many cases, single parent households have proactively sought out public and private support resources independently, without assistance from the child's father, their families of origin, or extended relatives (Lee et al., 2023). However, challenges persist, including a lack of sufficient, accurate information available online and disparities in individual information utilization capabilities, which hinder access to additional resources (Lee et al., 2023).

In the Korean context, child support payments following divorce are primarily determined through mutual agreement between parents rather than through strong legal enforcement (Kang et al., 2022). This can place greater financial pressure on single mothers, reinforcing the importance of structured welfare policies and in-formation access in promoting economic self-reliance.

In summary, single parent households are simultaneously faced with economic vulnerabilities and barriers to accessing essential information, creating a dual burden in pursuing self-reliance and raising their children. Addressing these challenges ne-cessitates the establishment of tailored support systems and the strengthening of information delivery infrastructure.

Relationships with Family and Surrounding Communities

In Korean society, where the ideology of the "traditional family" remains dominant, choosing to live as a single parent

household remains a difficult path (Lee & Um, 2013; Seong et al., 2018). Single parent households are often estranged from their families of origin (Lee & Um, 2013; Seong et al., 2018). Even basic emotional support from family members during pregnancy and childbirth cannot be taken for granted for these women, and societal support tends to be even more limited. Alt-hough societal acceptance of diverse family forms has increased in recent years (Park & Ko, 2017), prejudices and negative perceptions toward single-mother families persist (Kim et al., 2012; Kim, 2013; Lee & Um, 2013). According to studies based on interviews with single parent households, many continue to experience discrim-inatory attitudes and negative perceptions from staff at hospitals, local government offices, and childcare centers (Kim et al., 2012; Kim 2013; Seong et al., 2018).

Based on the findings of the literature review, single-mother families face a complex set of challenges, including difficulties in achieving economic self-reliance, limited access to essential information, and a lack of robust social support systems. Although a variety of welfare services have been established, numerous studies consistently highlight the significant barriers that single parent households encounter in recognizing and utilizing these services effectively (Kim et al., 2012; Yi, 2012; Kim, 2013; KoPHWA, 2018; Lee et al., 2023). Moreover, single parent households continue to navigate the demanding reality of balancing parenting and daily life while confronting persistent social stigma and discriminatory attitudes (Kim et al., 2012; Kim, 2013; Lee & Um, 2013; Park & Ko, 2017; Seong et al., 2018).

In response to these challenges, this study aims to develop a web-based platform designed to enhance information accessibility and promote more effective support linkages for single parent households. The platform is structured around three core development goals: providing reliable welfare and childcare information, offering personalized information access, and strengthening record-keeping functions nec-essary for childrearing. The ultimate objective is to offer practical support that em-powers single parent households to build independent and sustainable lives.

Table 1 summarizes the gaps identified through the literature review and the corresponding strategies proposed for the web development project.

3. Methods

To develop a practical and accessible digital solution for single parent households, we utilized a modern full-stack web development architecture composed of React.js, Next.js, Node.js, MongoDB, AWS S3, and OpenAI GPT-4 API. These technologies were selected for their scalability, performance, and suitability for delivering both static and dynamic content in a user-friendly interface.

Frontend Development

The user interface was built using React.js, a widely-used JavaScript library for building responsive and interactive web applications. React allows for component-based design, making the user experience modular, maintainable, and adaptable to future updates. To enhance server-side rendering and optimize performance for both users and search engines, we integrated Next.js, a React framework that supports hybrid static and dynamic content generation.

Table 1. Challenges Identified and Web Development Strategies

Challenges Identified in Literature Review	Web Development Strategy
Existence of various policies and systems but limited practical utilization	Strengthening integration and accessibility of welfare/support information; providing information via Chatbot AI
Lack of reliability and fragmentation of available information	Establishing a system based on verified and reliable data; providing information via Chatbot AI
Difficulties in childrearing amidst economic and social hardships	Implementing childcare diaries and health record features; providing hospital information and related services; Utilizing AI to offer personalized childcare and health feedback;
Insufficient social support networks	Strengthening psychological and social support through tailored information delivery; considering features for peer group formation and community building

Note. AI = Artificial Intelligence.

Backend and Server-Side Architecture

The server-side logic and API endpoints were implemented using Node.js, a JavaScript runtime known for its non-blocking, event-driven architecture. Node.js was chosen for its efficiency in handling asynchronous tasks and real-time user interactions.

Database and Data Storage

For data storage and user-generated content management (e.g., childcare diaries, health records), we employed MongoDB, a flexible NoSQL database that stores data in JSON-like documents. This structure allows for fast and scalable development, particularly useful for storing diverse and evolving data formats. Additionally, Amazon Web Services (AWS) S3 was used to store and manage static assets and uploaded files. AWS S3 provides secure, scalable storage and integrates well with other services.

AI-Powered Information Support

To implement the AI chatbot feature and provide personalized information, we utilized the GPT-4 language model via the OpenAI API. Initially, a persona-based system message format in JSON was used to guide the chatbot's behavior, but its performance in terms of contextual depth and response quality was limited. To enhance the chatbot's effectiveness, we adopted a two-fold strategy: first, a curated dataset of sample user inquiries and expert-guided responses was constructed to inform prompt design; second, a domain-specific prompt engineering method was implemented, enabling the system to dynamically tailor prompts based on categorized user inputs (e.g., emotional support or policy guidance). This hybrid approach allowed for more context-aware, empathetic, and accurate interactions with users, aligning the chatbot more closely with the platform's support objectives.

Rationale for Technology Selection

These technologies were chosen based on their open-source availability, community support, and proven effectiveness in delivering secure, scalable, and user-friendly web services. React and Next.js streamline frontend development, while Node.js and MongoDB enable rapid backend implementation. AWS S3 ensures reliable file handling, and GPT-4 allows for intelligent, adaptive dialogue. Together, this stack facilitates the creation of a web platform that not only meets the immediate informational needs of single parent households but is also extensible for future enhancements such as peer-support communities and mobile accessibility.

4. Results

The web-based platform developed in this study successfully implemented a set of core functions designed to address the multifaceted needs of single parent households. Drawing upon verified data from government and public institutions, the platform was structured to improve information accessibility, provide personalized guidance, support parenting activities, and offer preliminary emotional support.

Centralized Access to Welfare Resources

The platform features an integrated information system that consolidates reliable welfare and support resources from official institutions. By organizing scattered policy information into a cohesive and user-friendly structure, the platform mitigates the issue of information fragmentation. This allows users to efficiently navigate and understand available government programs based on their individual circumstances and needs.

Enhanced Chatbot with Context-Aware AI Response Strategies

An AI-powered chatbot was incorporated to enhance user engagement and en-sure quick, accurate responses to user queries. The chatbot leverages the GPT-4 model to deliver personalized, natural-language guidance in real time. In addition to delivering factual information about welfare programs, the chatbot is designed to offer basic emotional support and suggest relevant services for users experiencing psychological or emotional distress. This function addresses the isolation and stigma often experienced by single parent households and promotes greater autonomy in accessing support services.

While initial attempts to fine-tune the chatbot using persona-based prompts via OpenAI's system message in JSON format offered limited results in terms of depth and contextual accuracy, alternative methods were explored to improve the quality of responses.

First, a curated conversation dataset was constructed by collecting realistic example dialogues representing common user concerns and matching them with expert-informed responses. These pairs were then used to design prompt templates that reflect how actual support professionals might respond in various scenarios.

Second, a domain-specific prompt engineering approach was implemented. The system first classifies the user's input into categories such as emotional support, policy inquiry, or technical help. Based on this classification, the chatbot dynami-cally selects a tailored system prompt, optimized for each category. This allowed the AI to respond in a more context-aware and purpose-appropriate manner.

Together, these methods contributed to significantly more relevant, empathetic, and practical interactions, improving the chatbot's effectiveness and perceived re-liability.

Parenting Diary and Child Health Management Tools

A parenting diary and health record system was introduced, enabling users to document and monitor their children's developmental milestones and health condi-tions. The system includes features such as vaccination scheduling, health check-up reminders, and customizable logs for daily childcare activities. These tools support consistent caregiving and help users maintain a structured overview of their child's well-being.

In addition, the recorded data is analyzed by the AI system to provide person-alized feedback on the child's developmental progress and health status. By identi-fying potential concerns early or offering age-appropriate parenting suggestions, the platform helps caregivers make more informed decisions. This feedback function expands the role of the platform from a simple record-keeping tool to a practical aid in child development and health management.

Features for Location-Based Services and Automated Policy Updates

A map-based search function for nearby hospitals, counseling centers, and welfare institutions was conceptualized during the development phase, but it has not yet been implemented. This feature remains part of the future development roadmap. Its aim is to improve accessibility to local services through a geolocation-based in-terface. While its practical implementation is pending, the inclusion of such a func-tion reflects the broader goal of building a comprehensive and location-sensitive support system for single parent households. Further research and testing will be required to ensure its effectiveness and relevance.

Additionally, the development team initially intended to implement a system capable of automatically detecting and updating changes in official welfare policies or government programs—an especially important feature given the frequent modi-fications in public support schemes.

However, due to technical limitations and resource constraints, such automation has not yet been realized. Specifically, the absence of standardized, ma-chine-readable formats for government policy data, combined with the complexity of parsing unstructured web-based information, posed significant challenges. Although AI-driven parsing techniques were explored as a potential solution, the accuracy and reliability of the extracted data were insufficient for dependable implementation, ultimately leading the team to forgo automation at this stage. As it stands, information updates must still be conducted manually, which could affect the timeliness and completeness of the provided data. Future iterations of the platform will need to address this gap to maintain the reliability and currency of its informational content.

Collectively, these features reflect a user-centered approach to web development aimed at addressing not only the practical needs of single parent households but also the social and emotional challenges they face. By aligning technical functionality with evidence-based needs, the platform offers a holistic tool for improving par-enting support, emotional well-being, and access to welfare services.

Contribution to the Sustainable Development Goals (SDGs)

The development of this platform is also closely linked to the achievement of the Sustainable Development Goals (SDGs) advocated by the international community (Table 2). Specifically, SDG 3.7 aims to ensure universal access to family planning, sexual and reproductive health services, and information by 2030 (United Nations, 2025), and the platform contributes to this goal by providing parenting and health-related information. Furthermore, in line with SDG 3.8, which promotes universal health coverage and access to essential health services (United Nations, 2025), the platform is designed to offer user-friendly information on vaccination sched-

Table 2. Platform Linkage & Contribution with SDGs

SDG	Target	*Linkage & Contribution*
SDG 3.7	Ensure universal access to sexual and reproductive healthcare services	*Provides accessible information on parenting, health management, and reproductive healthcare for single parent households.*
SDG 3.8	Achieve universal health coverage and access to essential healthcare services	*Offers vaccination schedules and health checkup reminders to improve access to essential healthcare services.*
SDG 5.1	End all forms of discrimination against women and girls	*Promotes equitable access to welfare information without discrimination against socially vulnerable groups.*
SDG 5.b	Enhance the use of ICT to empower women	*Strengthens women's information-seeking capacity through AI chatbot services and personalized information provision.*
SDG 10.2	Promote the social and economic inclusion of all	*Ensures access to comprehensive welfare information regardless of economic status or background.*
SDG 10.3	*Ensure equal opportunity and reduce inequalities of outcome*	*Reduces disparities in information access related to income and region through a universal access platform.*

Note. ICT = Information and Communication Technology; AI = Artificial Intelligence.

ules and health check-ups.

In support of SDG 5.1, which seeks to eliminate discrimination against women and girls (United Nations, 2025), the platform focuses on providing non-discriminatory access and empowerment for single parent households, who are a socially margin-alized group. It also aligns with SDG 5.b, which emphasizes the use of information and communications technology (ICT) to promote women's empowerment (United Nations, 2025), embedding this principle at the core of its design.

Moreover, to fulfill SDG 10.2 and SDG 10.3, which call for social and economic inclusion and the reduction of inequalities (United Nations, 2025), the platform emphasizes equitable access to high-quality welfare and support information for all single parent households, regardless of their economic status or background. Beyond simply offering information, the platform seeks to expand life opportunities for single parent households. It is expected to address existing disparities in information accessibility based on income or social standing and contribute to building a more inclusive social structure.

5. Discussion and Conclusions

This study developed a web-based platform to address the multidimensional challenges faced by single parent households in South Korea. Building upon prior research, the platform was designed to respond to persistent gaps such as the frag-mentation of welfare information, limited access to emotional support, and practical difficulties in navigating existing support systems. Previous studies have shown that despite the formal existence of various welfare programs, these services are often inaccessible or underutilized due to insufficient information delivery, weak social support, and low reliability (Kim et al., 2012; Yi, 2012; Kim, 2013; KoPHWA, 2018; Lee et al., 2023). These issues are compounded by experiences of social stigma and discrimination (Kim et al., 2012; Kim, 2013; Lee & Um, 2013; Park & Ko, 2017; Seong et al., 2018).

To mitigate these issues, the platform was developed around three core objec-tives: (1) providing reliable and verified welfare information from official sources, (2) supporting caregiving tasks through tools such as parenting diaries and health records, and (3) enhancing access to guidance via an AI-powered chatbot. This integration of functional tools reflects a user-centered design that acknowledges the complexity of daily life for single parent households and aims to empower them in both practical and emotional dimensions.

A particularly critical challenge encountered during development involved the attempt to implement an automated system for detecting and updating changes in welfare-related policies. This functionality is especially significant for single parent households, who are highly dependent on timely and accurate information to access essential services. However, the lack of standardized, machine-readable government data formats, along with the difficulty of parsing unstructured policy text from of-ficial websites, posed substantial technical obstacles. Although AI-powered text ex-traction and parsing techniques were explored, they proved insufficiently accurate and consistent for practical deployment.

These limitations reveal broader structural problems in the digital architecture of public policy communication. For vulnerable populations such as single parent households, delays or errors in accessing updated information can directly

affect eligibility, benefits received, and daily decision-making. Therefore, future research should not only focus on technical refinement but also advocate for systemic im-provements in public data accessibility. These may include establishing open, structured, and interoperable data standards, mandating machine-readable formats for welfare policies, and fostering collaboration between government agencies and civic tech developers. Such initiatives are essential to build digital tools that are both scalable and socially responsive.

In addition to addressing immediate user needs, the platform was intentionally designed to contribute to broader social development goals. Its features support progress toward gender equity, health access, and the reduction of social inequali-ties—areas directly aligned with the Sustainable Development Goals (SDGs). Rather than functioning solely as a service portal, the platform positions itself as a model for inclusive digital welfare infrastructures that prioritize equity and empowerment through intentional technical design.

Nonetheless, the platform has several limitations. While the AI chatbot showed improved performance through domain-specific prompt engineering, it still lacks the depth and nuance of human counselors. As users begin to rely more heavily on AI-generated information, ensuring accuracy, relevance, and emotional appropri-ateness will require the implementation of robust monitoring and feedback mecha-nisms. Furthermore, the platform has yet to be tested with a large and diverse user base. Future iterations must incorporate real-world usage feedback to refine its functions and improve usability across demographic and regional contexts.

Enhancing mobile accessibility remains a critical area for further development. For many single parent households, mobile devices represent the primary point of access to digital resources. Thus, optimizing the user interface for mobile use—particularly in low-connectivity or resource-constrained environments—will be essential for ensuring equitable access.

In conclusion, this study presents a practical and socially responsive digital so-lution to systemic welfare information gaps. By integrating AI tools, verified re-sources, and user-friendly caregiving functions, the platform addresses not only the technical challenges of information delivery but also the social realities of single parent households. It offers a promising foundation for future civic technologies and digital welfare systems designed to reduce inequality and promote inclusive well-being.

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Jun. 2025, Volume.2 No.2

igee proceedings

pISSN: 3022-5183 eISSN: 3022-5191

IGEE Proc 2025;2(2):103-113
https://doi.org/10.69841/igee.2025.017

Article

Bridging the Cognitive Digital Divide: A Prototype-Based Interven-tion for Elderly Learners in South Korea†

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The acceleration of digital transformation across public and private sectors has exacerbated disparities in digital literacy, particularly among older adults who face cognitive, sensory, and technological barriers to effective engagement. In South Korea—despite widespread smartphone ownership among the elderly—digital proficiency remains disproportionately low, underscoring the inadequacy of current accessibility-focused interventions and the pressing need for cognitively and perceptually attuned digital education frameworks. This study examines the effectiveness of *Ee Eum*, a prototype digital literacy intervention specifically designed for adults aged 65 and older, integrating user-centered interface design principles with tiered educational scaffolding. A sequential mixed-methods design was employed. Initial qualitative inquiry through focus group and individual interviews (n = 30) identified key usability obstacles and content needs. This was followed by a series of controlled usability experiments (n = 31), including A/B testing of visual variables (e.g., contrast ratio, font size) and First Click Tests to evaluate interface navigability and perceptual clarity. Results demonstrated that high-contrast color combinations (e.g., yellow text on blue backgrounds) and enlarged text sizes (25–28pt) significantly improved legibility and reduced cognitive load. The inclusion of visual affordances in user interface elements led to substantial gains in navigational accuracy, with First Click Test performance increasing from 39.79% to 86.02% when target areas were visually emphasized. These findings provide empirical support for the role of perceptually optimized interface design in enhancing digital accessibility for older adults. The *Ee Eum* prototype offers a replicable framework for inclusive UI/UX development and contributes to ongoing discourse in gerontechnology, digital equity, and human-centered aging policy.

Keywords Digital Literacy, Older Adults, Human-Centered Design, UI/UX Optimization, Gerontechnology, Mixed-methods evaluation

Received: May 18, 2025 **Revised:** May 30, 2025
Accepted: June 9, 2025
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†This research is supported by the Social Engagement Fund (SEF) 2024.

1. Introduction

The pervasive digitalization of essential services—including healthcare, transportation, finance, and government—has amplified the urgency of addressing digital inequality, particularly among older adults. Although South Korea is recognized as one of the world's most technologically advanced societies, digital literacy among its elderly population remains markedly low (Kim, 2024). While 87.1% of Korean adults aged 65 and older own smartphones, approximately 63.2% are unable to independently install or use applications (Kim, 2024; Hwang, 2024), suggesting a profound gap between device access and functional usage capacity, suggesting a profound gap between device access and functional usage capacity (Ministry of Science and ICT, 2022, p. 57). This disparity underscores the limitations of infrastructure-centric policies and reflects a broader global trend in which the digital divide is no longer defined by access alone, but increasingly by the capacity for meaningful and autonomousengagement (Hwang, 2020).

The disparity is further visualized in Figure 1, which compares digital informatization levels across marginalized groups in Korea—namely the disabled, low-income individuals, agricultural and fishery populations (Agri-Fishery Population), and the elderly. While all groups exhibit relatively high scores in access to devices and networks, stark deficits appear in areas requiring digital competence and full utilization, with the elderly demonstrating the most significant drop-off across all categories (Ministry of Science and ICT, 2022, p. 57).

Scholarly and policy discourses have shifted accordingly, framing digital literacy as a composite of operational, navigational, and critical competencies. OECD data reveal stark generational differences in digital problem-solving abilities, with fewer than 5% of older adults demonstrating proficiency, compared to over 60% of young adults. OECD data reveal stark generational differences in digital problem-solving abilities: fewer than 5% of older adults demonstrate proficiency, compared to over 60% of young adults. These disparities are clearly reflected in Figure 2, which displays Internet usage rates by age and educational attainment across OECD countries. While usage among younger individuals remains consistently high, the gap becomes more pronounced among adults aged 55–74 with low or no formal education, indicating that digital exclusion intersects with both age and education level (OECD, 2019, p. 191). This gap has been further exacerbated by the COVID-19 pandemic, during which many core public services transitioned to online-only platforms, leaving technologically unprepared seniors increasingly isolated and excluded (Kim, 2023; MSV Insight, 2023). In response, nations such as the United States, Japan, and Australia have initiated long-term, community-based interventions—such as CYBER-SENIORS (CYBER-SENIORS, 2021), BeConnected (Be Connected – Ev-

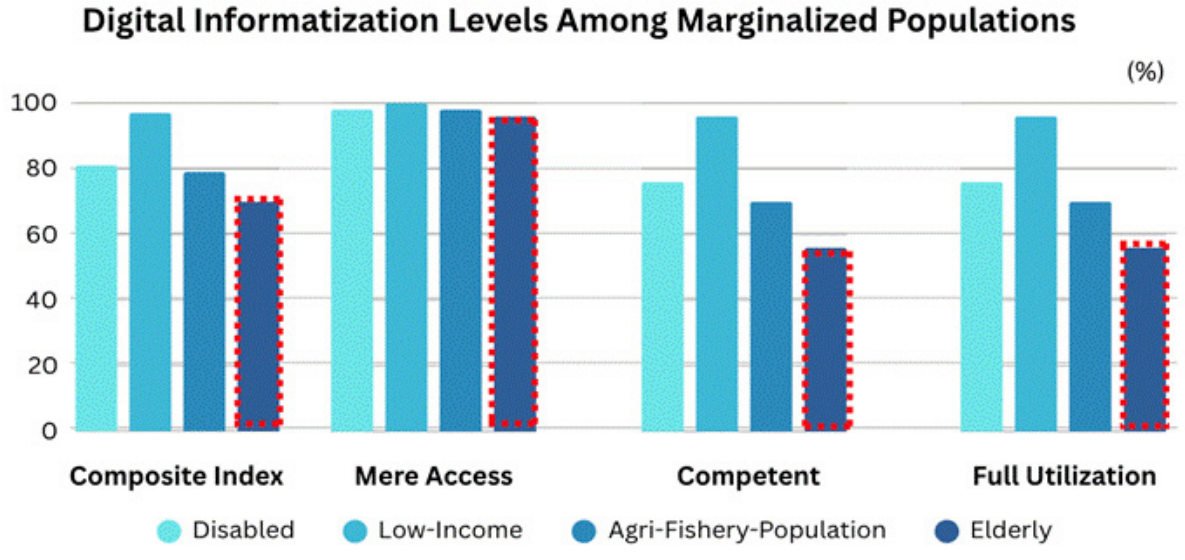

Figure 1. The Level of Digital Informatization by Information Vulnerable Groups (disabled, low-income, farmers and fishermen, and the elderly) in Korea 2022 Source: Ministry of Science and ICT (2022). 2022 Digital Divide Report, p. 57.

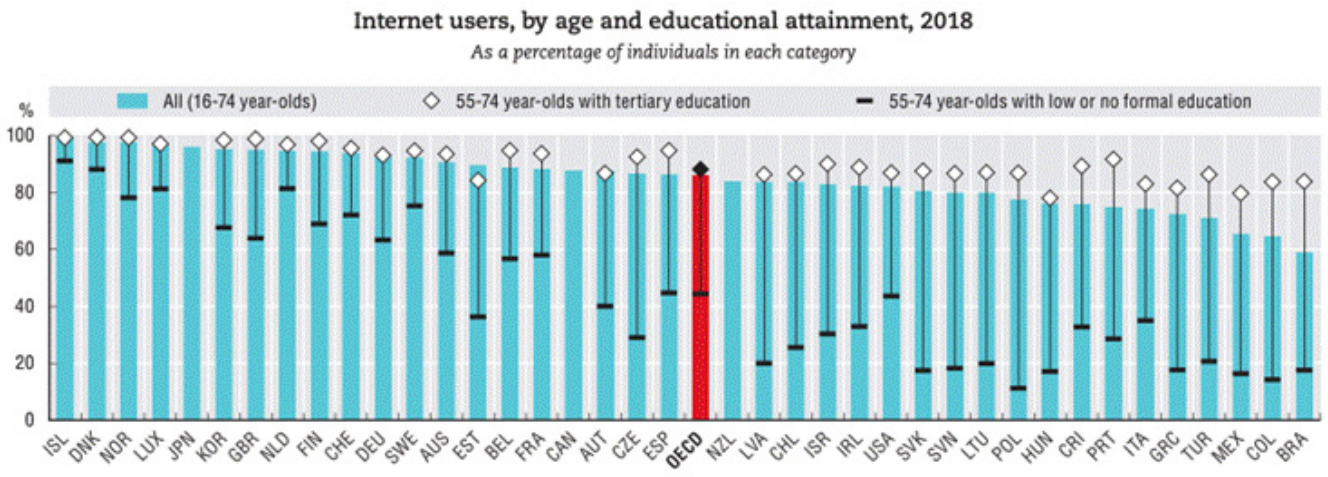

Figure 2. Percentage of Internet users by age and education level in major OECD member countries Source: OECD(2019). Measuring the Digital Transformation: A Roadmap for the Future, p. 191.

ery Australian Online, 2018), and Smart Silver Project (Kim & Park, 2021)—focused on digital mentoring, skill-building, and inclusive design.

By contrast, digital inclusion initiatives in South Korea remain predominantly supply-driven, emphasizing hardware distribution and network access. Few initiatives incorporate cognitive aging principles, or user interface and experience (UI/UX) adaptations tailored to perceptual and processing limitations commonly observed in older populations. Existing digital literacy programs are often confined to didactic instruction and static video tutorials, which fail to support active, experiential learning or provide intuitive navigation. Moreover, the widespread use of English in interface elements further compounds barriers to adoption and comprehension among monolingual Korean-speaking elders (Kim, 2021).

This study addresses these gaps through the development and evaluation of *Ee Eum*, a digital literacy intervention specifically designed for older adults. The program integrates a user-centered interface, high-contrast visual elements, scalable typography, and Korean-language microcopy—brief, task-oriented text elements embedded in digital interfaces that provide contextual guidance to users—to support perceptual clarity and task comprehension. It further incorporates interactive, tiered content allowing for self-paced learning and immediate feedback. The theoretical foundation of the intervention draws upon cognitive load theory, visual perception research in aging, and best practices in gerontechnology design.

The primary objective of this research is to evaluate whether UI/UX-optimized digital learning tools can significantly improve digital task performance among elderly users and use the data to create the Minimum Viable Product (MVP). Accordingly, the study evaluates the following hypotheses:

1. H1: High-contrast color schemes and enlarged font sizes will improve task accuracy and reduce response time relative to conventional interface configurations.

2. H2: Visual affordances (e.g., highlighted UI elements) will enhance interface navigability and First Click accuracy—a usability evaluation method that measures the location of a user's initial click when attempting to complete a predefined task— (Experiment A- with visual assistance, Experiment B- without visual assistance)

Through a mixed-methods research design incorporating usability testing and interface experiments, this study aims to contribute empirically grounded insights into inclusive digital design and inform future public policy on digital aging and equity.

The project promotes active digital participation and contributes to the UN Sustainable Development Goals (SDGs). For SDG 4 (quality education), it offers flexible, hands-on learning unconstrained by time or location. Unlike traditional digital training, this model emphasizes practical interaction and iterative improvement through user data. It also addresses SDG 10 (reduced inequalities) by narrowing the digital divide and SDG 11 (sustainable cities) by improving access to public services. Broader impacts include SDG 3

(health and well-being) and SDG 9 (innovation and infrastructure), as digital literacy strengthens access to healthcare and financial tools.

2. Materials and Methods

Materials

The digital literacy intervention evaluated in this study, titled *Ee Eum*, was developed as a web-based mobile application tailored for elderly users (aged 65 and above). The application incorporated design features based on established cognitive and perceptual principles in aging, including high-contrast color schemes, scalable font sizes, simplified navigation structures, and Korean-language microcopy. All interface components were designed and prototyped using Figma (Figma Inc., Version 119.7.6), a collaborative web-based UI/UX design tool.

The preliminary survey employed a qualitative method in the form of in-depth interviews (IDIs), facilitated through a structured online survey hosted on Google Forms. Usability testing was conducted using the Lyssna platform (formerly UsabilityHub), a web-based user testing suite that enabled A/B testing —an experimental method used to compare two versions of a design element (Version A and Version B) by measuring user responses to each —and First Click Test (FCT) implementation. All content within the test was standardized across experimental and control conditions with textual material matched for length, lexical complexity, and topical familiarity.

The A/B testing experiments were conducted using digital prototypes displayed on standardized desktop or laptop screens. All test materials were created using the same font ("Malgun Gothic"), layout structure, and content. Controlled environmental factors included screen resolution, brightness, and contrast. The textual stimuli and UI interfaces were presented using consistent screen dimensions and lighting conditions. Each experimental condition was counterbalanced to mitigate order effects. A total of 31 participants were recruited, representing information-vulnerable groups.

Methods

Two groups of participants were recruited for this study: (1) a group of people aged 65 or older (n = 30) to answer a preliminary survey to understand the pain points of the target group, (2) a broader group (n = 31) engaged in usability testing and interface experiments (Maze, 2023). All participants were South Korean residents aged 65 or older, recruited through local community centers and senior welfare organizations. Inclusion criteria included smartphone ownership and self-reported low to moderate digital proficiency. Exclusion criteria included significant uncorrected visual impairments, cognitive disorders, or previous participation in formal digital literacy training within the past six months.

Three A/B tests were designed to assess specific aspects of usability:

1) A/B Test: Background vs. Text Color Contrast

This test evaluated the effect of color contrast on readability and cognitive efficiency. Participants were randomly assigned to one of three contrast condi-tions—high, medium, or low. The high-contrast condition featured combinations such as yellow text on a blue background; the medium and low contrast groups where utilized as comparative baselines. The specific color codes are mentioned below in Table 1. A binary cognitive task was administered to assess performance under each visual condition. The design followed a double-blind, randomized, and fully counter-balanced structure.

In accordance with the Web Content Accessibility Guidelines (WCAG), luminance contrast is categorized based on specific ratio thresholds: high contrast is defined as a luminance ratio of ≥ 7.5:1, moderate contrast ranges from 4.5:1 to 7.0:1, and low contrast is characterized by ratios below 4.5:1 (W3C, 2018). These standardized thresholds were adopted in the present study to systematically classify and manipulate color contrast conditions during experimental design.

Table 1. Color Combinations Used in Contrast Conditions (HEX Values)[1]

Contrast Level	Foreground (Color)	Background (Color)
High	Yellow (#FFD3CC)	Blue (#0000FF)
High	White (#FFFFFF)	Black (#000000)
High	Black (#000000)	White (#FFFFFF)
High	Yellow (#FFD3CC)	Red (#FF0000)
High	Blue(#0000FF)	Yellow (#FFD3CC)
Medium	Light Orange (#FFA07A)	White (#FFFFFF)
Medium	Light Gray (#D3D3D3)	Pale Blue (#E6F0FA)
Low	Green (#008000)	Black (#000000)
Low	Gray (#808080)	White (#FFFFFF)

[1]Color codes were specified in hexadecimal format to ensure consistent rendering across digital devices.

2) A/B Test: Text Size

This test examined the relationship between text size and user performance on reading comprehension tasks. Participants were exposed to sentences in varying font sizes ranging from 16 pt to 28 pt. Previous studies have identified an optimal font size range (18–24pt) for readability among older users, as font sizes below 18pt tends to hinder legibility whereas excessively large fonts (abov 24pt) disrupt screen structure due to increased scrolling demand (Hou et al., 2022; Kennedy, 2024). Each sentence was followed by a comprehension question with two possible answers and a "pass" option. To prevent carryover effects, each condition featured different sentences addressing similar topics, maintaining an equal word count and comparable sentence structures. Texts were displayed for 500 milliseconds each. Two practice trials were conducted before the main experiment.

3) A/B Test: First Click Test

This test investigated the impact of interface design on intuitive navigation behavior. Participants were asked to locate specific functions within a taxi application interface(Kakao Taxi., Version 6.33.1), both with and without visual emphasis (i.e., bounding boxes). All participants received identical experimental instructions to minimize interpretation differences. Each condition involved four tasks, and screen elements remained consistent in position, visibility (device used to display the screen , and size. A double-blind procedure was employed to prevent feedback bias, and participants were not time-restricted to mimic real-world interaction patterns.

In the first condition (Experiment A), participants were presented with the main screen of the app and the following question: "*You have discovered that a taxi ride was accidentally double charged. Where would you go to check your ride history?*" Participants were instructed to click on the button they believed to be correct. This task was repeated across three different screens, each maintaining consistent position, visibility, and size of screen elements.

In the second condition (Experiment B), the same interface and question were presented; however, the correct button was highlighted with a bright yellow bounding box (#FFD33C) to enhance visual salience. Participants repeated the process across three screens under this condition as well. To maintain experimental validity, participants were not informed whether they had selected the correct answer in the first condition.

Measures

Quantitative outcome variables included:

1. Task Performance Accuracy: Measured via First Click Test accuracy (% correct click) and comprehension questions during A/B text trials.
2. Response Time: Time (in seconds) taken to complete digital tasks under different UI conditions.
3. Readability Metrics: User preferences and reading accuracy across font sizes (16–28pt) and background/text contrast levels (e.g., yellow-on-blue vs. gray-on-white).
4. Engagement Metrics: Captured via app analytics (lesson completion rate, time on task, frequency of use).

All testing environments maintained constant device parameters (screen size, brightness, resolution) and minimized external distractions to ensure ecological validity.

This study adopted a sequential mixed-methods design comprising three phases:

1. Literature and Policy Review: A systematic review of existing academic literature and policy documents was conducted to establish a baseline understanding of digital inclusivity trends and frameworks in both domestic and international contexts.
2. Exploratory Phase (Qualitative): Focus group and individual interviews (n = 30) were conducted to identify perceived barriers, digital usage behaviors, and instructional preferences among older adults. Insights informed the instructional design and UI/UX framework of the *Ee Eum* prototype.
3. Interface Testing Phase (Experimental Design):

- o A/B Testing I (Color Contrast): Tested combinations of high, medium, and low contrast backgrounds and text colors to determine optimal visual clarity. Five high-contrast and four control color schemes were evaluated.
- o A/B Testing II (Text Size): Tested five font sizes ranging from 16pt to 28pt. Accuracy and completion times were recorded.
- o First Click Test: Evaluated interface navigability with and without visual emphasis on clickable targets (Experiment A-with visual aid, Experiment B-without visual aid)

Analysis

All quantitative data were analyzed using IBM SPSS Statistics (Version 27.0; IBM Corp., Armonk, NY, USA). Descriptive statistics were computed to summarize participant char-

acteristics and overall task performance.

For the Background vs. Text Color Contrast test, outcomes included user selection rate (%) and response time (measured in milliseconds) under each contrast condition (high, medium, low). This allowed for comparative analysis of readability preferences and cognitive efficiency. In the Text Size test, performance was evaluated by calculating the accuracy rate (%) for comprehension questions associated with font sizes. Correlation analyses were conducted to assess the relationship between font size and user accuracy. For the First Click Test, the key outcome measure was the error rate (%), defined as the proportion of incorrect selections across trials. Click behavior was compared between conditions with and without visual affordances (e.g., bounding boxes), and additional data on time-to-first-click (in seconds) were recorded to assess navigational efficiency.

3. Results

A/B Test: Color Contrast

The effect of background-text color contrast on readability and user preference was significant. High-contrast combinations (e.g., yellow text on blue background) were significantly favored over low-contrast combinations (e.g., gray on white) as indicated in Figure 3.

Participants demonstrated the highest accuracy and fastest response times with yellow-on-blue contrast (M = 45.2%, mean response time = 6 seconds), while black-on-white and green-on-black combinations were associated with lower accuracy and longer response times as presented in Figure 4.

A/B Test: Text Size

Text sizes ranging from 16pt to 28pt were evaluated for readability and accuracy. The 24–28pt range resulted in significantly higher task accuracy (M = 77.4%) compared to smaller sizes (16–20pt, M = 61.3%). Optimal balance between legibility and layout efficiency was observed at 21–24pt, suggesting a preferred design compromise for interface text.

First Click Test (FCT): Interface Navigability

First Click Test results demonstrated a significant improvement in click accuracy when visual emphasis (e.g., colored boxes) was applied to key UI elements. Mean click accuracy improved from 39.8% (not emphasized) to 86.0% (emphasized) as shown in Figure 5. The spatial distribution of participants' initial click responses is illustrated in Figure 6.

Digital Assistant: Ee Eum (MVP)

As a direct outcome of the empirical usability evaluation—including A/B testing on color contrast and text size, and First Click Tests on interface navigability—the *Ee Eum* prototype was systematically developed to embody the validated principles of age-inclusive interface design. Design decisions were not speculative but grounded in measurable improvements observed during testing: high-contrast visual pairings (e.g., yellow-on-blue) and enlarged font sizes (25–28pt) significantly enhanced readability and reduced response time, while the application of visual affordances more than doubled First Click accuracy, confirming the importance of perceptual salience for interface clarity.

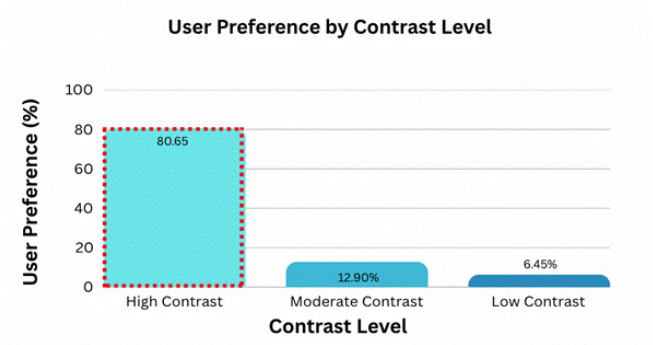

Figure 3. User Preference by Contrast Level.

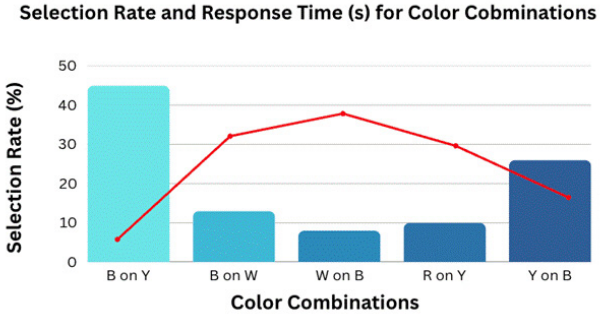

Figure 4. Selection Rate and Response Time Graph for High Contrast (Ratio ≥ 7.5 :1).

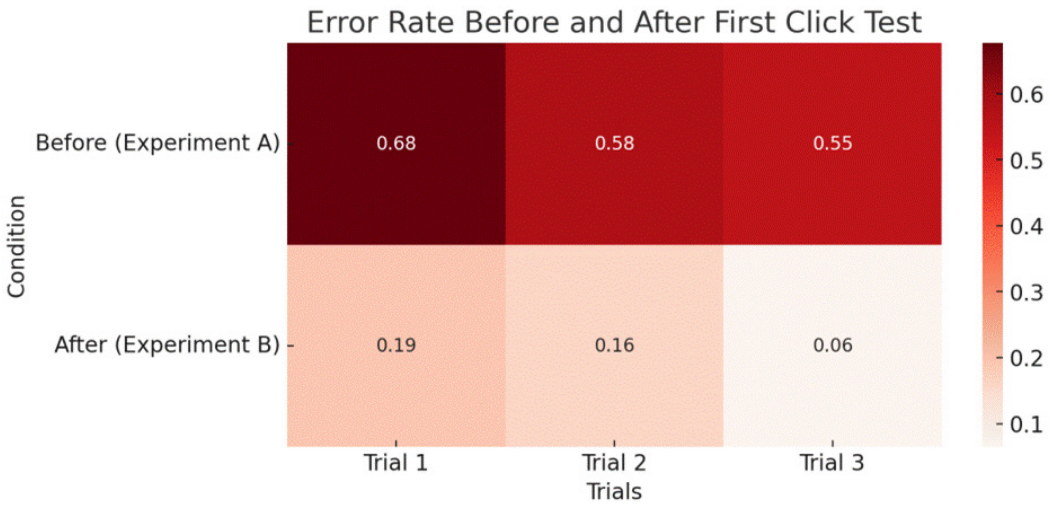

Figure 5. Heatmap of Trial-by-Trial Error Analysis for Experiment A and Experiment B.

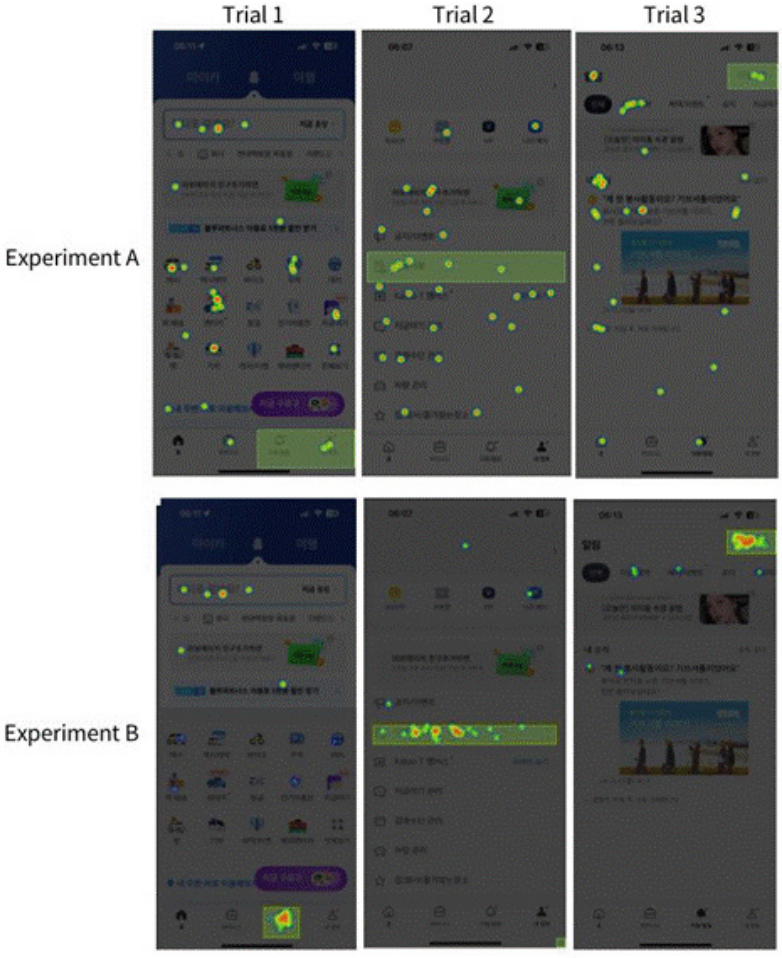

Figure 6. Trial-by-Trial Heatmap Comparison of Experiment A and Experiment B.

To further contextualize user expectations and interface architecture, a comprehensive wireframe audit of representative Korean mobile applications was conducted across four service domains—Health, Finance, Transportation, and Communication— and the core smartphone functions across Android and iOS platforms as shown in Figure 7. These wireframes, captured and organized using Figma, served as a reference for aligning the *Ee Eum* prototype with familiar UI flows, minimizing disorientation among older users. Full list of digital literacy modules used in the intervention is summarized in Table 2.

Additionally, to support first-time users with limited digital experience, the prototype incorporated personalized instructional overlays. These dynamic onboarding elements included visual cues, Korean-language speech bubbles, and auditory prompts that offered step-by-step guidance throughout common tasks (see Figure 8 and Figure 9). Designed to reduce cognitive load and foster autonomous navigation, these features exemplify the application of human-centered design principles for cognitively accessible interaction.

4. Discussion

The study demonstrates how a user-centered digital platform can drive progress toward multiple SDGs by fostering inclusive, sustainable digital engagement for the elderly. In advancing SDG 4, it enables lifelong learning through accessible, practical interaction. Continuous feedback integration supports high-quality, adaptive education. The project reduces digital inequalities (SDG 10), expands access to public services (SDG 11), and enhances well-being (SDG 3) through digital healthcare and connectivity. It further supports SDG 9 by integrating elderly users into digital infrastructure.

This study examined the effectiveness of an age-inclusive digital literacy intervention (*Ee Eum*) by evaluating interface design features and their impact on cognitive performance and learning outcomes among older adults. The findings align with a growing body of literature emphasizing that perceptual and cognitive barriers—not mere lack of access—are primary contributors to digital exclusion in elderly populations. By incorporating high-contrast visual schemes, scalable typography, and intuitive navigational elements, the intervention demonstrated measurable improvements in both usability (First Click accuracy, readability) and educational performance (learning gains and retention).

The strong user preference for high-contrast pairings, particularly yellow-on-blue, and larger font sizes (25–28pt) supports previous research in gerontechnology and visual ergonomics, which emphasizes the diminished sensitivity to low-contrast stimuli with age. Likewise, the significant in-

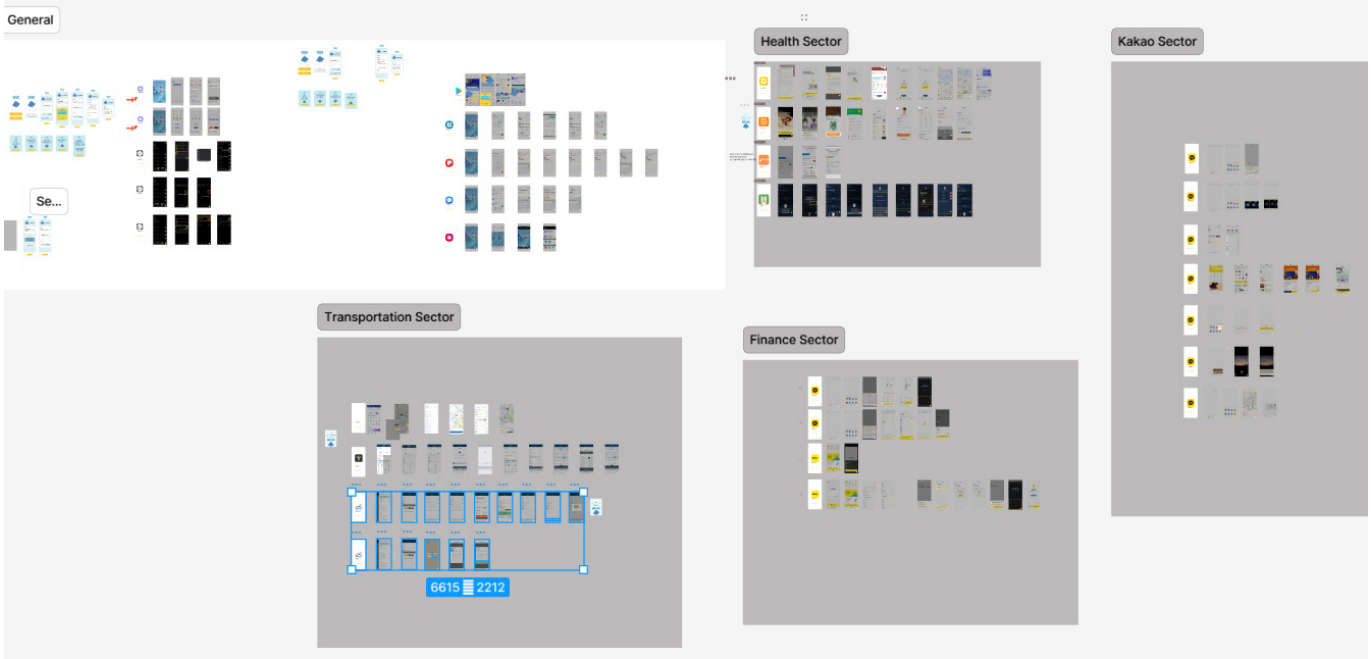

Figure 7. Wireframe of the Digital Literacy Program *Ee Eum*.

Table 2. Digital Literacy Training Modules by Functional Domain[1]

Module Code	Function	Description
App_Basic_000	App Installation	Installing apps (Kakao Talk)
App_Basic_001	Calendar	Managing schedules and setting reminders
App_Basic_002	Memo	Creating and editing personal notes
App_Basic_003	Messaging Apps	Sending messages with and without saved contact
App_Basic_004	Alarm Setting	Setting and adjusting alarms
App_Basic_005	Timer	Setting and adjusting timers
Transportation_000	Kakao Taxi	Requesting a taxi via a mobile application
Transportation_001	KorailTalk App	Accessing and using the KorailTalk train booking app
Transportation_002	KorailTalk Registration (PASS)	Registering with phone number and PASS verification
Transportation_003	KorailTalk Registration (Kakao)	Registering using KakaoTalk authentication
Kakao_000	Video Calling	Making video calls via KakaoTalk
Kakao_001	Sending Photos	Sending photos in KakaoTalk chats
Kakao_002	Add Friends	Adding friends from the recommendation list
Kakao_003	Kakao Pay Integration	Linking a bank account to Kakao Pay
Kakao_004	Kakao Gift	Sending gifts via the KakaoTalk gift feature
Kakao_005	Voice Messaging	Recording and sending voice messages
Kakao_006	Save Photos/Videos	Downloading and saving media from chat
Kakao_007	Location Sharing	Sharing real-time location via KakaoTalk
Finance_000	Kakao Transfer	Sending money through KakaoTalk
Finance_001	Payment Settlement via Kakao	Requesting or settling payments with Kakao
Finance_002	Payment via Kakao Pay	Completing transactions using Kakao Pay
Finance_003	Account Linking	Registering a bank account with Kakao for payment use
Health_000	Ddokdoc Appointment	Booking health checkups via Ddokdoc
Health_001	DoctorNow Telehealth	Accessing remote medical consultations via *DoctorNow*
Health_002	E-Gen Locator	Finding nearby hospitals and pharmacies using E-Gen
Health_003	Medication Reminder (*Tae-Yang-I*)	Managing medication schedules and reminders

[1]All modules were tailored for older adult users with limited digital experience and delivered in simplified Korean across Android and iOS platforms.
2 App_Basic_000 to App_Basic_005 contains wireframes for both android and apple devices.

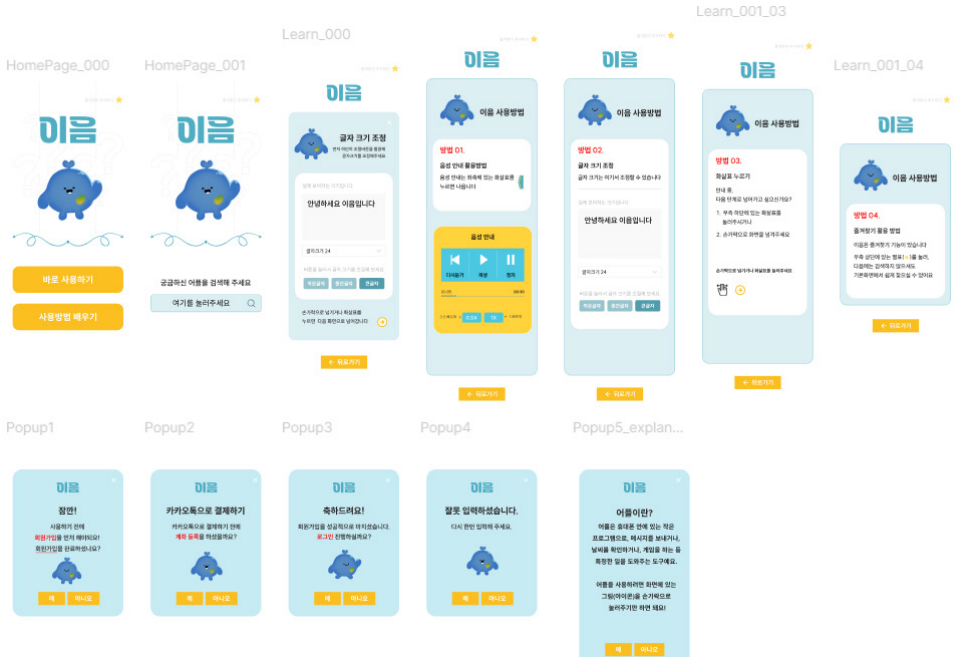

Figure 8. Wireframe of Guide within Digital Literacy Program *Ee Eum.*

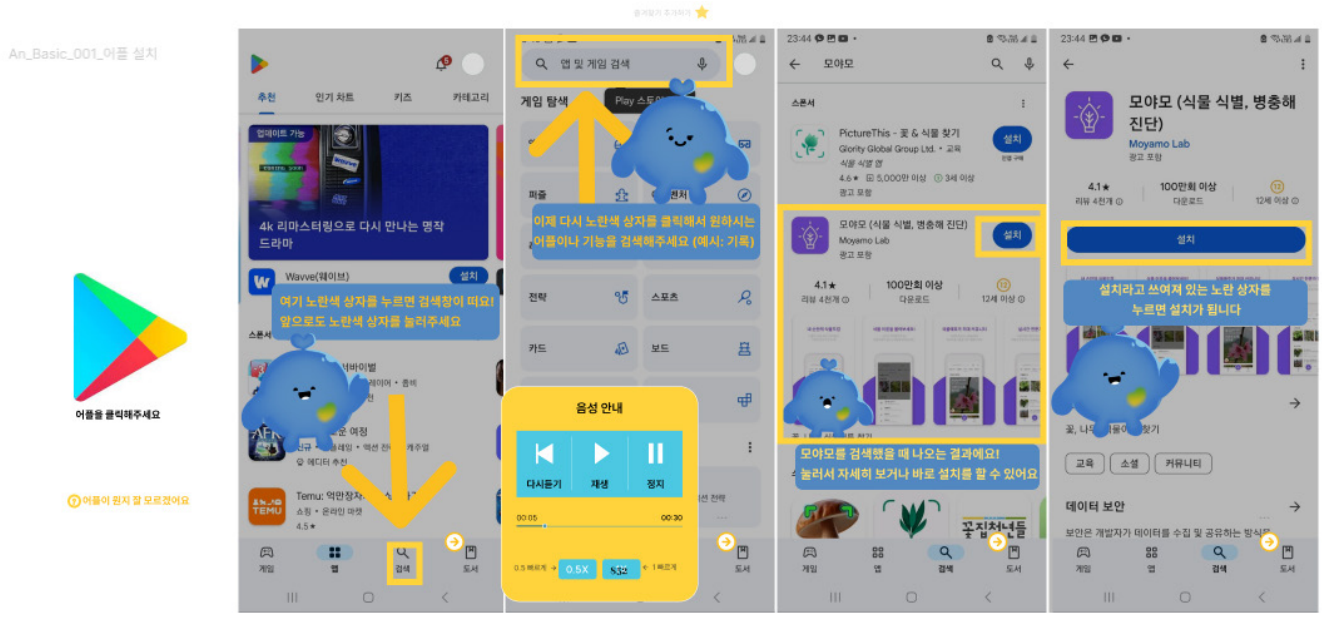

Figure 9. Implementation Stage of User-Customized Features: Direct Guidance by Joints on First Use (MVP).

crease in First Click accuracy following UI emphasis reflects prior work showing that perceptual salience and guided visual hierarchy are essential for older users' interface navigation. These results reinforce the theoretical framework underpinning the design—cognitive load theory, age-related visual processing, and interaction design principles.

The outcomes of this study reinforce the theoretical foundation upon which Ee Eum was designed—namely, cognitive load theory, age-related perceptual processing research, and principles of human-centered interaction design. Together, the results suggest that relatively modest, yet targeted UI/UX modifications can significantly reduce cognitive load and improve interface usability for elderly users, thereby supporting more autonomous and confident engagement with digital content.

However, these findings must be interpreted in light of several methodological limitations. Most notably, although the sample size (n = 31) was sufficient for usability testing, the findings may not be generalizable to all segments of the elderly population, particularly those with significant cognitive impairment, low literacy levels, or no prior exposure to smartphones. Second, usability testing was conducted under controlled conditions, including standardized screen size, lighting, and minimal distractions. While this control enhances internal validity, it limits ecological validity, as real-world usage environments are more variable. Third, the initial needs assessment relied on self-reported data from older adults with limited digital fluency, raising the possibility of response bias or misunderstanding. These constraints underscore the need for cautious interpretation and replication through larger, more rigorous studies.

5. Conclusions

The study contributes to the evidence base on digital literacy interventions by demonstrating that user-centered interface design, grounded in the cognitive and perceptual characteristics of older adults, can significantly enhance digital usability and learning outcomes. The *Ee Eum* application prototype, through high-contrast visual cues, readable typography, and intuitive interaction flows, enabled elderly users to navigate digital content more accurately, learn more effectively, and remain more engaged than those in a traditional learning condition.

Despite certain limitations—including reliance on self-reported data, a modest sample size, and the artificiality of controlled environments—the results underscore the importance of moving beyond hardware access to address cognitive and perceptual accessibility in digital literacy efforts. The findings highlight the value of participatory usability testing and perceptually informed UI/UX design in closing the digital gap for aging populations.

Future research should expand this line of inquiry through larger, demographically diverse samples and real-world usage contexts. Incorporating biometric or behavioral analytics could enhance the objectivity of usability assessments, while longitudinal designs would help evaluate the durability of interface familiarity and digital confidence. Ultimately, aligning digital interfaces with the sensory and cognitive profiles of older adults offers a promising pathway toward inclusive technology design and more equitable digital participation.

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Jun. 2025, Volume.2 No.2

igee proceedings

pISSN: 3022-5183 eISSN: 3022-5191

IGEE Proc 2025;2(2):114-132
https://doi.org/10.69841/igee.2025.018

Article

Analysis of the Correlation Between Health Status and Social Factors Among Korean Care Workers†

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Amid South Korea's demographic crisis of a declining birth rate and a rapidly aging population, care work has become an essential yet undervalued sector. This study investigates the physical and mental health conditions of domestic care workers and explores how social and structural factors shape their labor experiences.Using a mixed-methods approach, the research integrates survey data from care workers (n=345) with in-depth interviews of nine individuals working in various care roles, including certified caregivers, disability support workers, childcare teachers, and domestic workers. Quantitative findings reveal strong correlations between job satisfaction and health outcomes. Higher job satisfaction was associated with lower scores on the Oswestry Disability Index (ODI), Patient Health Questionnaire-9 (PHQ-9), and Generalized Anxiety Disorder-7 (GAD-7), indicating better physical and mental health. Significant disparities were found between care worker subcategories. Qualitative analysis further uncovered recurring themes such as emotional burden, social invisibility, dissatisfaction with compensation, and the absence of grievance mechanisms. Despite these challenges, many workers found meaning in their roles and relied on informal coping strategies such as peer support. This study underscores the urgency of addressing systemic issues in the care sector. The results call for policies that improve working conditions, recognize the social value of care work, and promote health equity. The findings contribute to advancing Sustainable Development Goals (SDGs) 3(Good Health), 5 (Gender Equality), and 8 (Decent Work and Economic Growth).

Keywords SDG 3, Care worker, mixed-methods, South Korea, Health, Job satisfaction

Received: May 18, 2025 **Revised:** May 30, 2025
Accepted: June 9, 2025
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†This research is supported by the Social Engagement Fund (SEF) 2024.

1. Introduction

Purpose and significance

Korean society has been experiencing a population crisis as it faces a low birth rate and an aging population. The reversal of the proportion between the 0-14 age group and age 65 or older group is expected to be worse, and by 2050, the population who is aged 65 or older is expected to account for 40.1% of the total population (Statistics Korea, 2025).

Changes in the demographic structure due to low birth rate and population aging require a conversion in the care work paradigm. First, care work includes activities such as housework, health care, childcare, and elderly care, and focuses on providing physical, emotional, and psychological support to maintain and promote individual health and well-being (Lee, 2012). As socio-economic conditions change rapidly, the demand for care work has become visible and the importance has emerged. However, compared to changes in demand, supply is not keeping up with it. There are a few policies and services for continuous supply of care workers, though. Care work differs fundamentally from general forms of labor. Distinctive characteristics of care work include the prevalence of late-night shifts, rotating schedules, and extended working hours. The harsh reality has made the current situation worse.

Recognizing these problems, Korea has made efforts to increase the number of support targets for care services, such as expanding child allowances and childcare services, preparing care leave systems, and guaranteeing the time spent on care work. In 2021, the Care Workers Support Act was proposed. Nevertheless, the fact that the frequency of emotional problems and depressive symptoms among care workers is remarkably high.

Considering that more than 60% have musculoskeletal diseases and 25% have sleep disorders still present health problems (Park. et al., 2013), it is also suggested that there is a long way to go to improve the treatment of care workers. With this problematic situation unsolved, on March 5, 2024, the Bank of Korea decided to allow foreigners to work in care work system and announced a plan to ease the labor shortage and cost burden of care services.

The government's policy about foreign care workers seems reasonable. However, it is just seen as a temporary measure to the current situation, considering that there were insufficient attempts to solve why the care work market is always incomplete.

As mentioned above, the demand for care work continues to increase as the social structure has been changed. However, there is a gap between supply and demand of care workers, as the supply is delayed due to inappropriate working conditions. Although various attempts have been made at the government level, the government's attempts have not been effective as it has not identified the underlying causes and the experiences of care workers and has not reflected their opinions in the discourse. Therefore, the study using in-depth interviews and surveys on care workers must be conducted in terms of analyzing their work experiences in detail and finding specific meaning in their experiences.

Objective of the study

Through this study, we intend to explore the job experience related to physical / mental health and find important implications quantitively and qualitatively. Identifying the correlation between the health factors of the care workers through a survey and statistical analysis, we will investigate the work experiences of care workers through in-depth interviews and trace their work status microscopically.

SDGs

Having established the demographic and policy context, it is now important to consider how these challenges intersect with global development priorities, particularly the Sustainable Development Goals.

The Sustainable Development Goals (SDGs), adopted by the United Nations in 2015, represent a global commitment to advancing progress across various areas—such as health, gender equality, economic growth, and the reduction of inequality—by the year 2030 (Griggs. Et al, 2017). In response, many countries have developed and implemented national strategies tailored to their specific circumstances. This study aims to contribute to the achievement of SDGs 1 (No Poverty), 3 (Good Health and Well-being), 5 (Gender Equality), 8 (Decent Work and Economic Growth), and 10 (Reduced Inequalities) by analyzing the correlations between the health status of care workers in Korea and relevant social factors.

Focusing primarily on SDG 3, this research explores the health and well-being of care workers, while also addressing the growing importance of care work in the context of Korea's low birth rate and aging population. Given the high proportion of older women and migrant workers in the care workforce, the

study further aligns with SDG 5 by addressing gender-based disparities and the economic empowerment of women. Additionally, it reflects the goals of SDG 8 and SDG 10 by highlighting challenges related to wage inequality and structural disparities. Through this analysis, the study seeks to provide policy implications that can contribute to improving the livelihoods and social recognition of care workers.

2. Literature review

With the study's alignment to the SDGs clarified, the following section reviews existing literature to contextualize care work in Korea and highlight key issues faced by workers in this sector.

Definition and Characteristics of Care Work

Care work is divided into the public and private areas. In the case of the private area, it includes nursing, housework management, postpartum care services, and childcare services. Especially, the majority of care workers employed in the private sector are classified as informal workers, lacking formal labor contracts and guaranteed terms of employment (Yoon, 2013).

As a result, various legal and institutional attempts have been made to improve the treatment of care workers, but there are several legal issues - for example, The status of care workers Whether self-supporting workers are recognized as employees -, so a clear conclusion has not been derived (Yoon, 2013).

It is also explained that care services have some differences in service systems, unlike general services or manufacturing industries. Therefore, it is found that care workers' mental and physical burden about their work is very high (Park et al., 2013).

Working as Domestic Workers

It is found that there are several cases of depression (35.5%) due to mental stress caused by emotional labor and sexual harassment (23.4%) while working as domestic workers. According to an in-depth interview conducted later, even if such emotional and mental damage is big, it is often aggravated by the absence of a grievance system or attempts to resolve it. Although laws such as the Seoul Labor Safety and Health Support Ordinance and the Seoul Metropolitan Government Emotional Workers Protection Ordinance are in place currently, the details are still insufficient and vague (Lee et al., 2024).

Working as Patient Caregivers

It is stated that patient caregivers are introduced through intermediaries or platforms (company) to work. It was also explained that the patient caregiver brokerage company performs tasks only for simple employer-employee matching, without considering working conditions. In addition, it is mentioned that patient caregivers often perform not only 'official care work' described by the National Statistical Office but also some medical works such as aspiration or wound dressing (Hwang & Jung, 2023).

Working as Childcare Teachers

It is emphasized that working as childcare teachers needs considerable physical and mental health, and the teachers are required to perform childcare activities as well as infant protection, various tasks for a long time, for example, textbook teaching management and facility management. They experience a lot of stress due to fatigue and work burdens caused by job characteristics that require a high level of emotional interaction. Eventually, these stresses have a great impact on the teacher's mental health (Koo & Park, 2013).

Working as Child-care Providers

It is found that 60.5% of participants answered 'No' for whether their musculoskeletal diseases have been treated during the past 6 months. 53.7% of participants answered 'Yes' for whether they have visited hospitals due to their diseases. 60.8% of participants answered 'Yes' for whether they have diagnosed diseases, which included herniated disc, hypertension, arthritis and so on. In addition, 74.5% answered that they have pain, which occurs at their back, shoulder, hand/arm, feet/leg (Lee et al., 2014).

Working as Certified Caregivers

According to a study about the physical burden of certified caregivers working in long-term care nursing facilities, the rate of experience with their musculoskeletal diseases was 15.9% over the entire period and 11.3% over the past year.

In addition, musculoskeletal diseases are one of the representative work-related diseases of certified caregivers, often caused by repetitive movements, inappropriate working posture, and excessive use of force. It was also confirmed that chronic pain or sensory abnormalities may appear in the neck, shoulder, waist, upper/lower muscle, and surrounding body tissues (An, 2023).

Working as Disability Support Workers

It is revealed that the prevalence of musculoskeletal diseases in the back, shoulder, neck, and wrist during the job performance was highly reported by disability support workers (Lee & Kim, 2023). It is explained that disability support workers are hourly wage workers, and their pay is close to the minimum wage (Kim, 2022). The wide range of job responsibilities causes job stress, and previous studies examining the relationship between job stress and psychological well-being among these workers are very limited (Hwang & Han, 2024).

3. Materials and Methods

Building on the insights from previous research, the next section outlines the materials and methods used in this study to systematically investigate the health and social factors affecting care workers.

Materials

The survey paper used for the quantitatve research is attached as a part of Supplement. The interview questions used for qualitative is attached in Supplementary Table S1.

Methods

A mixed-methods study was employed, combining qualitative and quantitative research methods. Both approaches were done simultaneously.

Quantitative Research: Data was collected through a survey on the health status of care workers, followed by an analysis to identify significant results between variables.

Quantitative Research: In-depth interviews were conducted to identify expressions of job recognition in various categories.

Participants

The participants were defined as current or former care workers in South Korea whose age is between 18 and 69 years. To recruit proper participants, recruitment was done through online careworker communities such as 'Naver Cafe', and 'Naver Band', social welfare organizations, and carework labor unions. This study employed a mixed-methods approach, incorporating quantitative data from survey responses of care workers (n = 345) and qualitative insights from in-depth interviews with a total of nine care workers (n = 9).

1) Quantitative research

A survey was conducted with care workers (n = 345) using both online and offline methods. The survey collected responses related to various factors, including detailed occupation type, age, gender, wage, education level, household income, number of household members, whether they are the head of the household, leisure time, chronic illnesses, health issues (e.g., back pain, anxiety, depression), job satisfaction, job stress, caregiving frequency, caregiving hours, differences between actual working hours and contracted working hours, night shifts, frequency of night shifts, and overall satisfaction.

Mental and physical health status were assessed using validated instruments: The Patient Health Questionnaire-9 (PHQ-9) for depressive symptoms (range: 0–27), the Generalized Anxiety Disorder-7 (GAD-7) scale for anxiety symptoms (range: 0–21), and the Oswestry Disability Index (ODI) for lower back pain-related disability (expressed as a percentage, with higher scores indicating greater impairment).

2) Qualitative research

Content analysis based on interviews with 9 care workers Interviews were also conducted. Six main questions, and several detailed questions related to topics such as: job content, reasons for choosing the job, physical and mental health issues triggered by work, compensation, work environment, and driving force for job continuity were asked.

Analysis

1) Quantitative research

Care workers were categorized into detailed occupation types, including certified caregivers, child-care providers, do-

mestic workers, disability support workers, and others. Kruskal-Wallis tests were performed to analyze differences between occupation types regarding age, wage, working hours, job satisfaction, job stress, and health scores. Dunn's Test was then used to determine if the differences between the groups were statistically significant. All statistical analyses were performed using R software, version 4.4.1.

2) Qualitative Research

The interview was then analyzed based on frequently mentioned themes, including *general characteristics, recruitment process, entry process, wage perceptions, job perceptions, and the impact on mental health*.

4. Results

Quantitative Research

1) Statistical Analysis of All Survey Participants (Careworkers)

(1) General characteristics

The survey respondents (n=345) included 42 men (12.2%) and 303 women (87.8%). In terms of job category distribution, disability support workers made up the largest proportion (193 respondents, 55.9%), followed by childcare teachers (69 respondents, 20%), Certified caregivers (61 respondents, 17.7%), domestic workers (10 respondents, 2.9%), and others (12 respondents, 3.5%) as shown in Figure 1.

Figure 2 shows the general characteristics of the survey participants. Among the survey respondents, 133 individuals (29.2%) identified themselves as the primary income earner of their household, meaning that the majority were not the main breadwinners. Regarding wage satisfaction, the most common responses were "neutral" (127 respondents, 37.5%) and "satisfied" (118 respondents, 34.8%). In terms of educational attainment, the highest proportion of respondents had attended or graduated from university (195 respondents, 57.5%). Among chronic illnesses, hypertension had the highest number of responses, with 59 individuals (17.1%) reporting the condition.

(2) Working Hours and Leisure Time

In Figure 3, the median and mean of participants' working hours and leisure time are shown. Working hours were measured based on the question: "*Over the past month, how many hours per week, on average, did you engage in care work?*" The median working hours were 36 hours, while the average working hours were 30.8 hours per week. The maximum recorded working hours were 150 hours. In response to the follow-up question: "*Over the past three months, was there a difference between your actual working hours and the contracted working hours?*", 56 respondents indicated that there was a discrepancy, suggesting that reported working hours may differ from either contracted or actual working hours. Regarding leisure time, responses to the question: "*Over the past year, how many hours per day, on average, did you have for leisure? (Leisure time refers to free time before or after obligatory activities such as eating, sleeping, working, and household chores.)*" showed a median leisure time of 2.25 hours and an average leisure time of 2.78 hours per day.

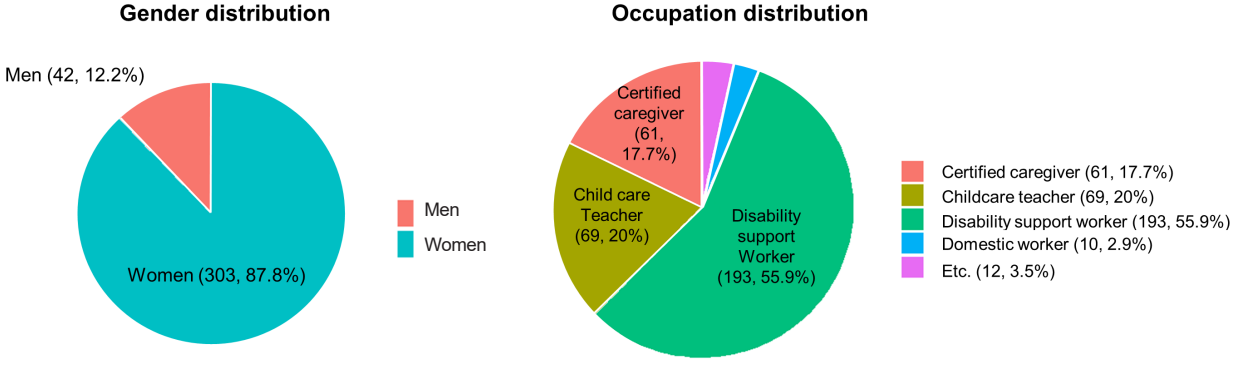


Figure 1. Gender and Occupation Distribution of Participants.

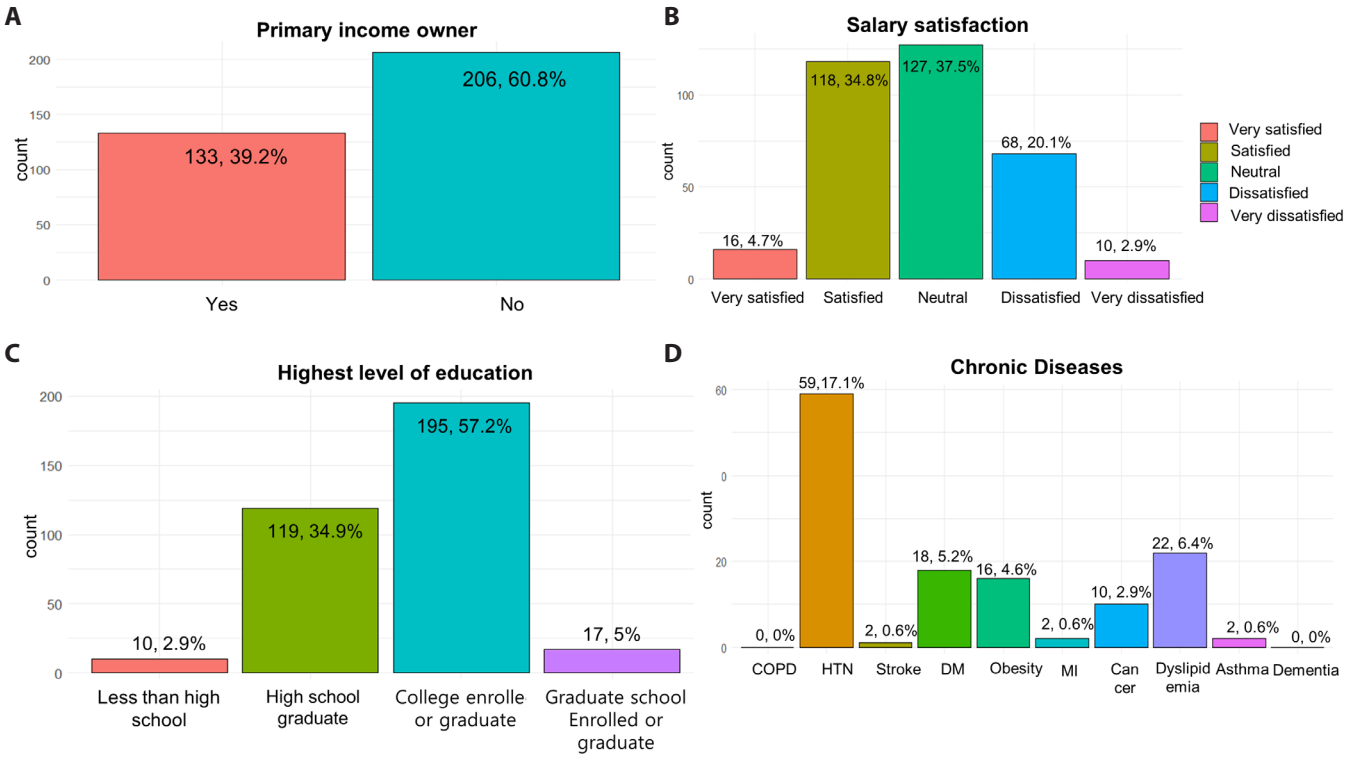
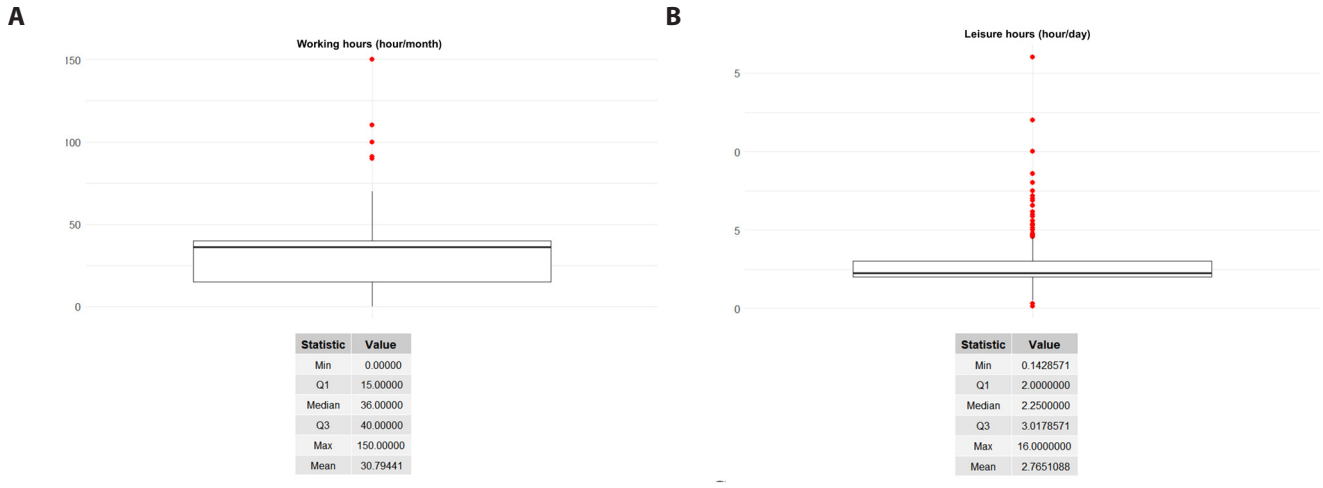


Figure 2. Other Response Distribution - (A) Primary Income Earner (B) Salary Satisfaction (C) Highest Level of Education (D) Chronic Disease.



Statistic	Value
Min	0.00000
Q1	15.00000
Median	36.00000
Q3	40.00000
Max	150.00000
Mean	30.79441

Statistic	Value
Min	0.1428571
Q1	2.0000000
Median	2.2500000
Q3	3.0178571
Max	16.0000000
Mean	2.7651088

Figure 3. Box Plot of (A) Working Hours (B) Leisure Hours.

(3) Average Monthly Wage and Household Total Income

For the question regarding average monthly wage, the responses showed a median of 1.9 million KRW and an average of 1.81 million KRW. For total household monthly income, the responses recorded a median of 4.2 million KRW and an average of 4.34 million KRW as shown in Figure 4.

(4) Job-Related Scores

The job satisfaction score had a median of 28 points, while the job stress score had a median of 29 points as shown in

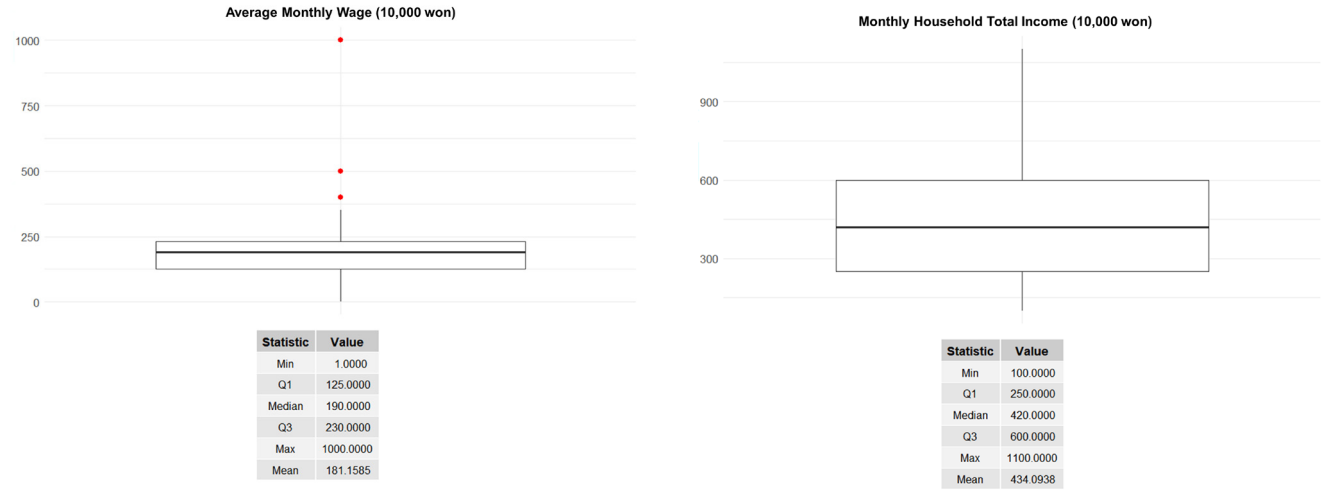


Figure 4. Boxplot of Average Monthly Wage and Household Total Income.

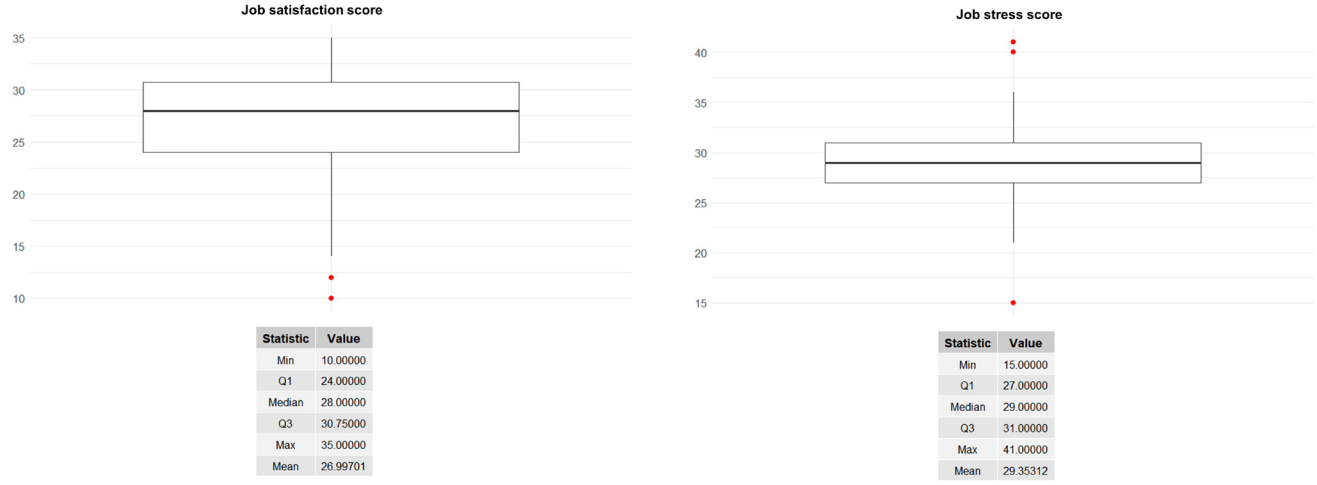


Figure 5. Box Plot of Job-related Scores.

Figure 5.

(5) Physical and Mental Health Scores

The PHQ-9 score had a median of 1 point, the GAD-7 score had a median of 0 points, and the Oswestry Disability Index (ODI) (%) score was 4.44 points as shown in Figure 6.

(6) Working Hours and ODI Percent

Figure 7 shows that longer working hours are associated with lower ODI percentage scores (slope: 0.031, R square: 0.019, P value: 0.10188). A higher ODI percent score indicates more severe lower back pain. While it can be inferred that severe lower back pain may limit working hours, the correlation is not clearly defined based on the distribution. Therefore, further research with a larger sample size is necessary.

(7) Job Satisfaction and Physical and Mental Health Scores

Figure 8 demonstrates that the higher job satisfaction scores are correlated with lower ODI percent, PHQ score and GAD scores. Since lower ODI percent, PHQ, and GAD scores indicate better health, it can be inferred that being in

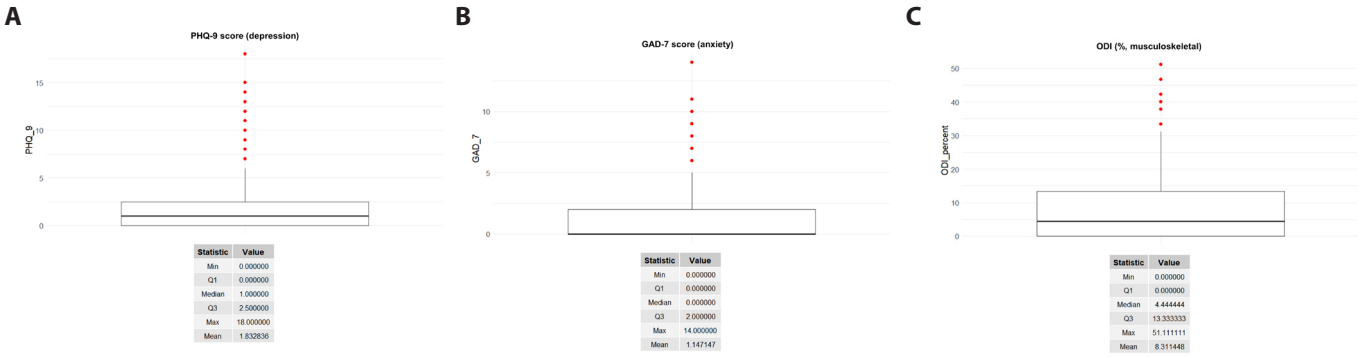


Figure 6. Boxplot of Physical and Mental Health Scores: (A) PHQ-9 score, (B) GAD-7 score, (C) ODI %.

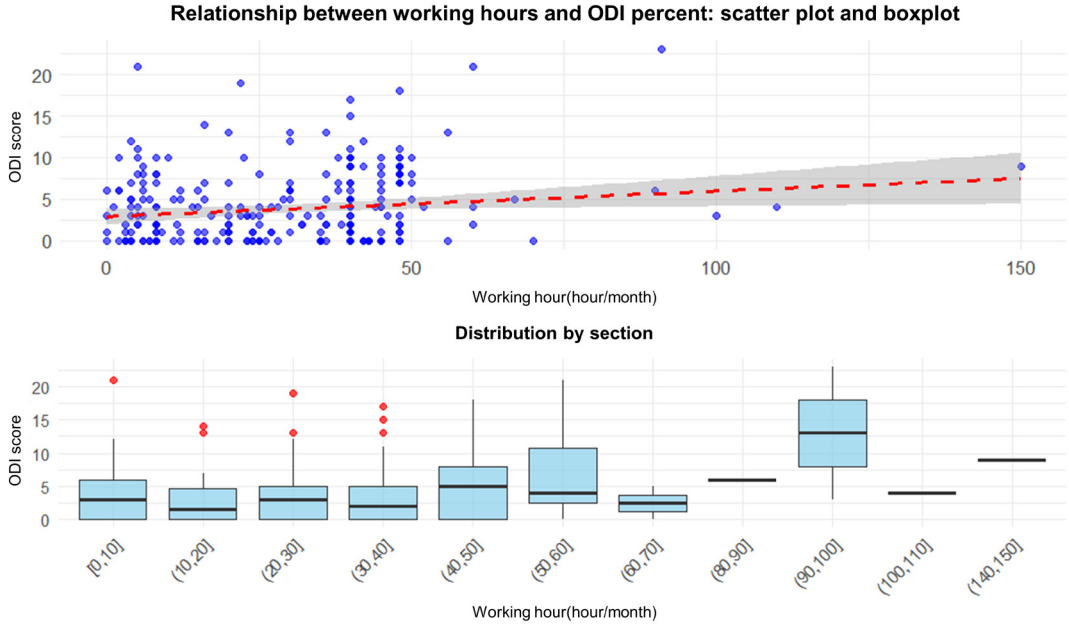


Figure 7. Relationship between Working Hours and ODI Percent: Scatter Plot and Boxplot.

good health contributes to higher job satisfaction. Conversely, low job satisfaction may have a negative impact on mental health, further reinforcing this correlation.

(8) Leisure Time and Physical and Mental Health Scores

The correlation analysis between the responses to the question "I am given sufficient breaks during work" (*1: Strongly Disagree, 2: Disagree, 3: Agree, 4: Strongly Agree*) and health scores showed a negative correlation across all measures: ODI (slope: –1.17, $p < 0.001$), PHQ (slope: –0.94, $p < 0.001$), and GAD (slope: –0.58, $p < 0.001$) (see Figure 9). This indicates that workers who receive sufficient breaks tend to have better physical and mental health.

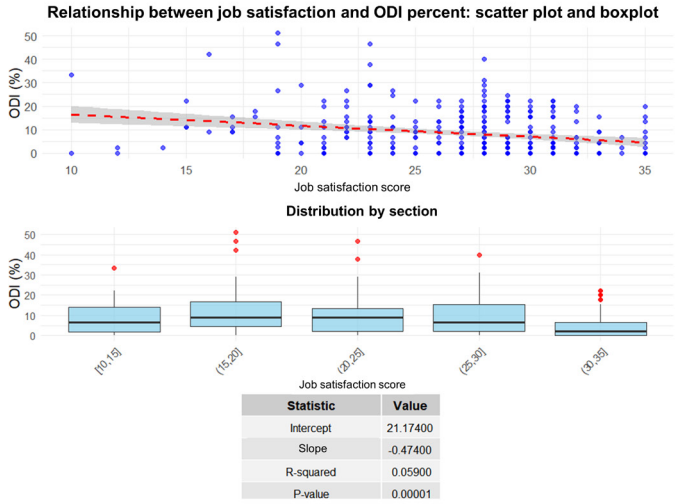
2) Statistical Analysis of Differences Among Care Work Subcategories

Statistical analyses of differences among work subcategories were conducted. For the results below, differences were considered statistically significant when $p < 0.05$. The adjusted P-value, indicated in the tables below, refers to a P-value that has been modified to account for multiple comparisons.

(1) Age Distribution by Job Category

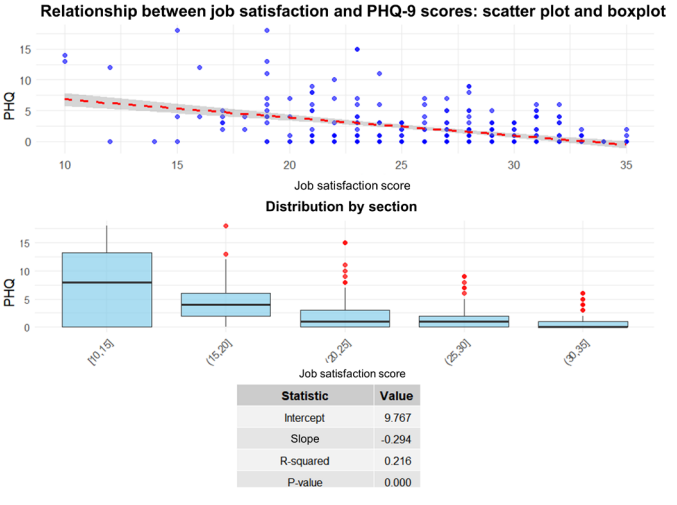
As shown in Figure 10, analysis of age by job category

A



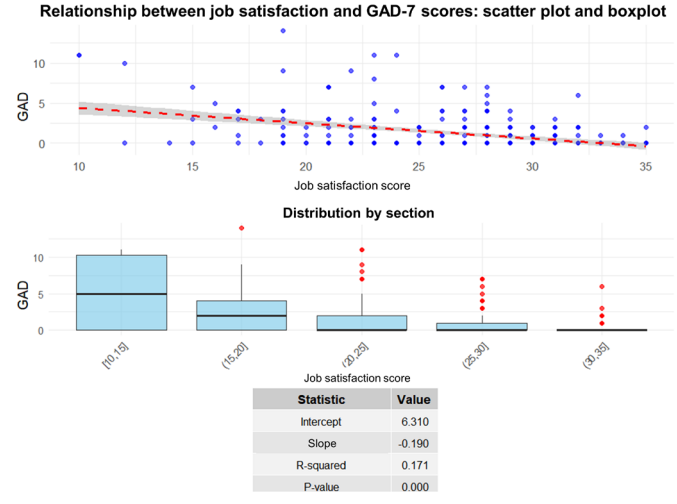
Statistic	Value
Intercept	21.17400
Slope	-0.47400
R-squared	0.05900
P-value	0.00001

B



Statistic	Value
Intercept	9.767
Slope	-0.294
R-squared	0.216
P-value	0.000

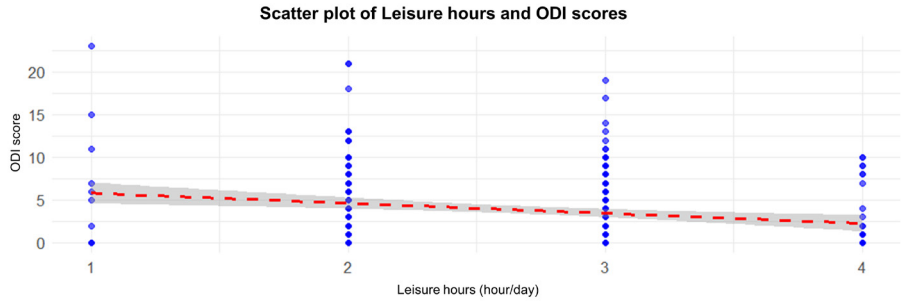
C



Statistic	Value
Intercept	6.310
Slope	-0.190
R-squared	0.171
P-value	0.000

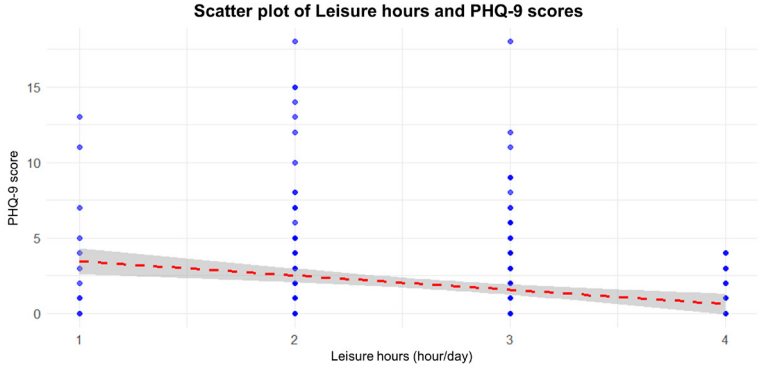
Figure 8. Relationship between Job Satisfaction Scores and Health Scores: Scatter Plot and Boxplot (A) ODI Scores, (B) PHQ-9 Scores, (C) GAD-7 Scores.

A



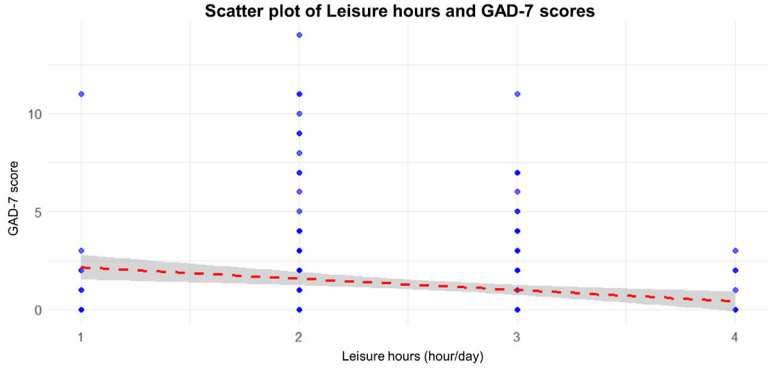
Statistic	Value
Intercept	6.99500
Slope	-1.17700
R-squared	0.03700
P-value	0.00048

B



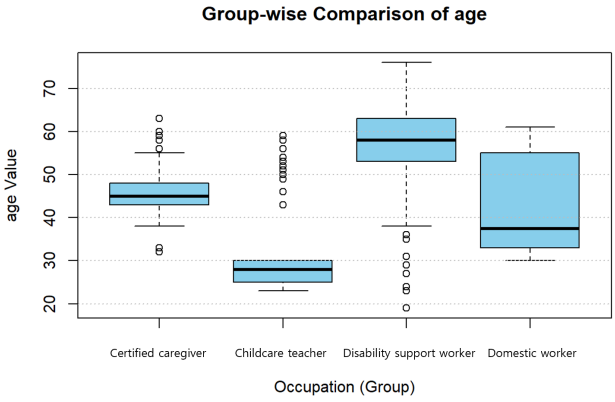
Statistic	Value
Intercept	4.40000
Slope	-0.94400
R-squared	0.04600
P-value	0.00008

C



Statistic	Value
Intercept	2.73100
Slope	-0.57900
R-squared	0.03300
P-value	0.00093

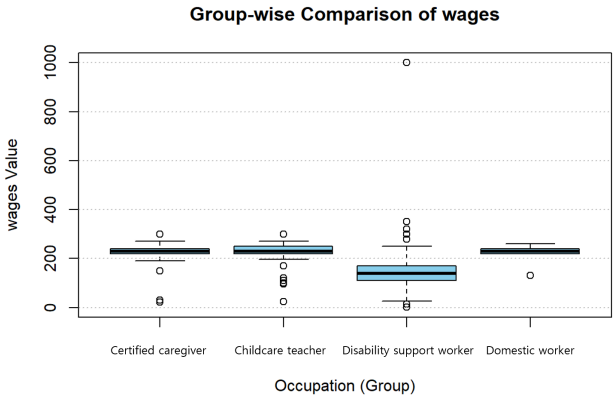
Figure 9. Scatter Plot of Leisure Time and Health Scores: (A) ODI Scores, (B) PHQ Scores, (C) GAD Scores.



Dunn's Test for Age

comparison	P adjusted
Certified caregiver - Childcare teacher	**< 0.001**
Certified caregiver - Disability support worker	**< 0.001**
Childcare teacher - Disability support worker	**< 0.001**
Certified caregiver - Domestic worker	1.000
Childcare teacher - Domestic worker	0.335
Disability support worker - Domestic worker	**0.003**

Figure 10. Boxplot of Age Distribution by Job Category and Post-hoc Analysis Using Dunn's Test.



Dunn's Test for Wages

comparison	P adjusted
Certified caregiver - Childcare teacher	1.000
Certified caregiver - Disability support worker	**< 0.001**
Childcare teacher - Disability support worker	**< 0.001**
Certified caregiver - Domestic worker	1.000
Childcare teacher - Domestic worker	1.000
Disability support worker - Domestic worker	**< 0.001**

Figure 11. Boxplot of Wage Distribution by Job Category and Post-hoc Analysis Using Dunn's Test.

was conducted based on responses to the survey item, "Please indicate your age", comparing different job categories. The Kruskal-Wallis test indicated statistically significant differences in age across the job categories, rejecting the null hypothesis.

A follow-up Dunn's test revealed that the age of disability support workers was statistically significantly higher than that of certified caregivers, childcare teachers, and domestic workers. Furthermore, certified caregivers were found to be significantly older than childcare teachers.

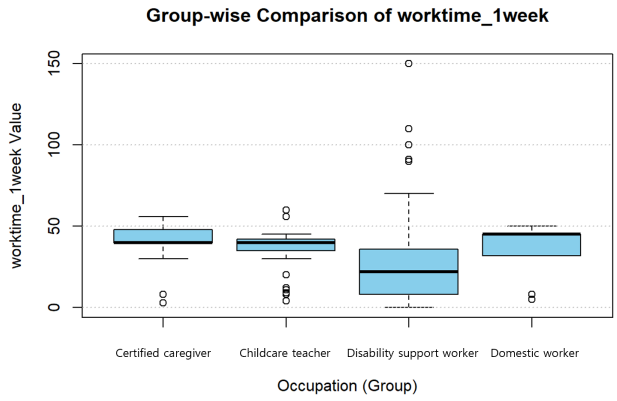
(2) Wage Distribution by Job Category

Figure 11 shows analysis of wage by job category based of wage by job category was based on responses to the survey item "What was your average monthly income (after tax) over the past three months? (____ ten thousand KRW)", comparing different job categories. The Kruskal-Wallis test indicated statistically significant differences in wage across the job categories, rejecting the null hypothesis.

A follow-up Dunn's test revealed that the wages of disability support workers were statistically significantly lower than those of certified caregivers, childcare teachers, and domestic workers.

(3) Working Hours Distribution by Job Category

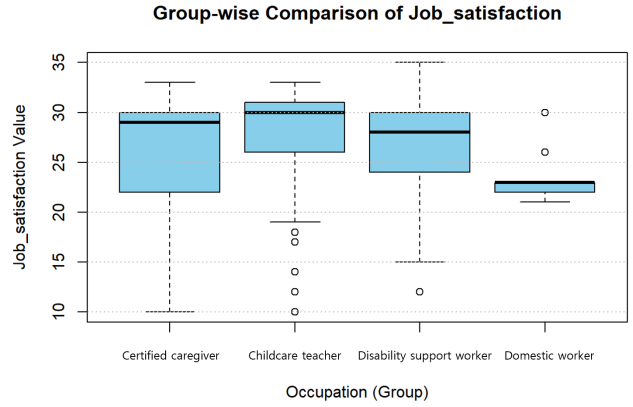
Analysis of working hours by job category was based on responses to the survey item "Over the past month, how many hours per week, on average, did you engage in care



Dunn's Test for Work Time (/ 1 week)

comparison	P adjusted
Certified caregiver - Childcare teacher	0.069
Certified caregiver - Disability support worker	**< 0.001**
Childcare teacher - Disability support worker	**< 0.001**
Certified caregiver - Domestic worker	1.000
Childcare teacher - Domestic worker	1.000
Disability support worker - Domestic worker	**0.002**

Figure 12. Boxplot of Working Hours Distribution by Job Category and Post-hoc Analysis Using Dunn's Test.



Dunn's Test for Job Satisfaction

comparison	P adjusted
Certified caregiver - Childcare teacher	0.290
Certified caregiver - Disability support worker	1.000
Childcare teacher - Disability support worker	0.053
Certified caregiver - Domestic worker	**0.027**
Childcare teacher - Domestic worker	0.001
Disability support worker - Domestic worker	**0.027**

Figure 13. Boxplot of Job Satisfaction Distribution by Job Category and Post-hoc Analysis Using Dunn's Test.

work? (Total _ hours)", comparing different job categories as shown in Figure 12. The Kruskal-Wallis test indicated statistically significant differences in working hours across the job categories, rejecting the null hypothesis.

A follow-up Dunn's test revealed that the working hours of disability support workers were statistically significantly lower than those of Certified caregivers, childcare teachers, and domestic workers.

(4) Job Satisfaction Distribution by Job Category

Figure 13 presents the analysis of job satisfaction by job category conducted by aggregating responses to job satisfaction-related questions into a composite score and comparing the scores across different job categories.

The Kruskal-Wallis test indicated statistically significant differences in job satisfaction across the job categories, rejecting the null hypothesis.

A follow-up Dunn's test revealed that the job satisfaction of domestic workers was statistically significantly lower than that of certified caregivers and disability support workers.

(5) Job Stress Distribution by Job Category

Analysis of job stress by job category was conducted by aggregating responses to job stress-related questions into a composite score and comparing the scores across different job categories.

The Kruskal-Wallis test found no statistically significant differences in job stress across the job categories, thus failing to reject the null hypothesis (see Figure 14).

(6) Lower Back Pain Distribution by Job Category

Analysis of low back pain by job category was conducted by converting survey responses into Oswestry Disability Index (ODI) percent scores and comparing them across different job categories, as shown in Figure 15.

The Kruskal-Wallis test indicated statistically significant differences in low back pain across the job categories, rejecting the null hypothesis. The median ODI percent scores, in descending order, were: certified caregivers, domestic workers, disability support workers, and childcare teachers.

A follow-up Dunn's test revealed that, except for the difference between certified caregivers and domestic workers, all other pairwise comparisons of low back pain showed statistically significant differences.

Figure 14. Boxplot of Job Stress Distribution by Job Category.

(7) Anxiety Distribution by Job Category

Figure 16 illustrates the analysis of anxiety by job category conducted by converting survey responses into Generalized Anxiety Disorder-7 (GAD-7) scores and comparing them across different job categories.

The Kruskal-Wallis test indicated statistically significant differences in anxiety across the job categories, rejecting the null hypothesis.

A follow-up Dunn's test revealed that certified caregivers and domestic workers had statistically significantly higher GAD-7 scores compared to childcare teachers and disability support workers.

(8) Depression Distribution by Job Category

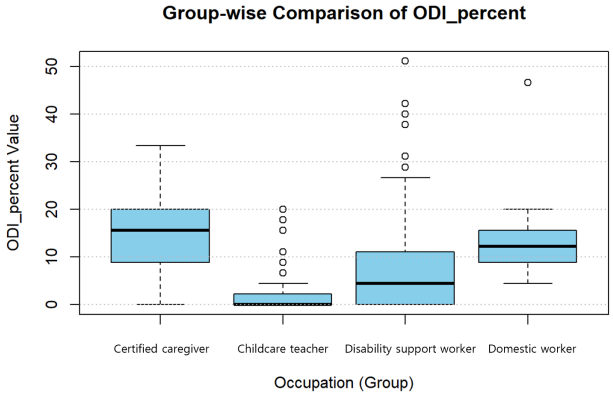
Figure 17 presents the analysis of depression by job category conducted by converting survey responses into Patient Health Questionnaire-9 (PHQ-9) scores and comparing them across different job categories.

The Kruskal-Wallis test indicated statistically significant differences in depression across the job categories, rejecting the null hypothesis.

A follow-up Dunn's test revealed that disability support workers had statistically significantly lower PHQ-9 scores than certified caregivers and domestic workers.

(9) Relationship Between Wage and Working Hours by Job Category

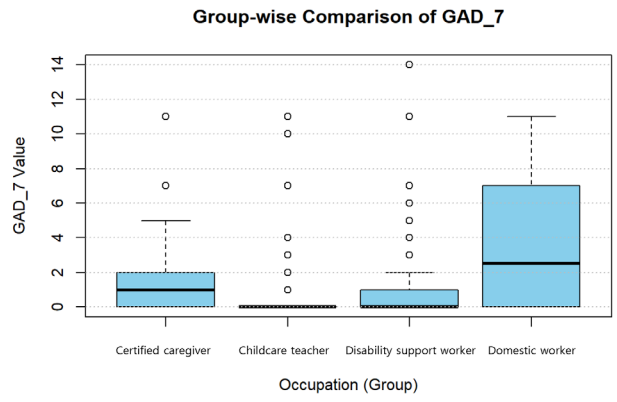
Overall, wages and weekly working hours show a positive correlation, indicating that higher working hours are generally associated with higher wages. However, there are groups



Dunn's Test for ODI percent

comparison	P adjusted
Certified caregiver - Childcare teacher	**< 0.001**
Certified caregiver - Disability support worker	**< 0.001**
Childcare teacher - Disability support worker	**< 0.001**
Certified caregiver - Domestic worker	1.000
Childcare teacher - Domestic worker	**< 0.001**
Disability support worker - Domestic worker	**0.045**

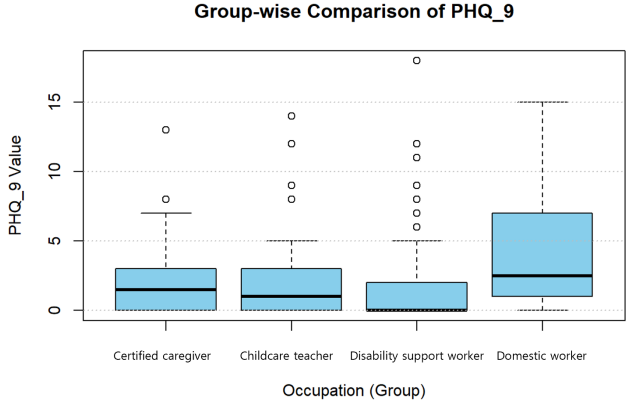
Figure 15. Boxplot of Lower Back Pain Distribution by Job Category and Post-hoc Analysis Using Dunn's Test.



Dunn's Test for GAD-7

comparison	P adjusted
Certified caregiver - Childcare teacher	**< 0.001**
Certified caregiver - Disability support worker	**< 0.001**
Childcare teacher - Disability support worker	0.572
Certified caregiver - Domestic worker	0.843
Childcare teacher - Domestic worker	**0.002**
Disability support worker - Domestic worker	**0.007**

Figure 16. Boxplot of Anxiety Distribution by Job Category and Post-hoc Analysis Using Dunn's Test.



Dunn's Test for PHQ-9

comparison	P adjusted
Certified caregiver - Childcare teacher	0.568
Certified caregiver - Disability support worker	**0.025**
Childcare teacher - Disability support worker	0.785
Certified caregiver - Domestic worker	0.328
Childcare teacher - Domestic worker	0.064
Disability support worker - Domestic worker	**0.012**

Figure 17. Boxplot of Depression Distribution by Job Category and Post-hoc Analysis Using Dunn's Test.

with low weekly working hours regardless of income level. While no distinct trends were observed between job categories, certified caregivers and childcare teachers tended to have relatively higher wages and weekly working hours compared to other occupations. (see Supplementary Figure S1)

(10) Relationship Between Age and ODI by Job Category

Examining the overall distribution, ODI percent scores do not show a strictly proportional relationship with age. However, the maximum ODI percent score tends to increase with age, while scores below the maximum are more evenly distributed. Additionally, the age distribution of childcare teachers is primarily concentrated in two groups: those under 30 and those over 45, whereas the age distribution of certified caregivers is more centered compared to disability support workers. (see Supplementary Figure S1)

(11) Relationship Between Working Hours and Anxiety, Lower Back Pain and Depression by Job Category

Weekly working hours were relatively high among certified caregivers and childcare teachers. However, the relationship between weekly working hours and health scores did not exhibit a clear trend. (see Supplementary Figure S2)

(12) Relationship Between Weekly Working Hours, Job Satisfaction, and Job Stress by Job Category

Weekly working hours were relatively high among certified caregivers and childcare teachers. However, the relationship between weekly working hours and job satisfaction or job stress did not exhibit a clear trend (see Supplementary Figure S3)

Qualitative Research

The study involved a total of nine participants who were interviewed based on the questions outlined in Supplementary Table S1. Each interview lasted approximately 60 to 90 minutes. The interview period spanned from early to late October 2024. Each session was conducted by one or two researchers. To ensure the confidentiality of participants, they were assigned codes based on their professional fields in alphabetical order, rather than using their real names. The basic demographic information of the participants is presented in Table 1.

1) General characteristics

Table 2 was compiled based on both the interview details and additional research. Notably, both household managers and domestic workers were found to participate in regular "monthly" training sessions. Since the format of basic education for household managers closely resembles that of domestic workers, it has been omitted from further discussion.

The expressions related to the process and motivation for entering the profession can be broadly categorized into three main themes as shown in Table 3. The first theme that emerged from the interviews was that entry and re-entry into these professions were relatively easy. A domestic worker stated, "Even if I take a break, it's relatively easy to start again. There are many opportunities for reemployment through various associations." (Participant 1). Similarly, a childcare teacher mentioned, "It is easy to enter the field." (Participant 5).

The second theme highlighted the role of referrals and networking. A disability support worker stated in the interview, "Through the process of assisting people with disabilities, relationships naturally form, and I receive new job opportunities through these connections." (Participant 9). Some participants independently found new care recipients through personal connections. However, others reported a high dependency on agencies, making it difficult to secure work autonomously.

Lastly, participants frequently mentioned limited job options for their age group. Most interviewees were middle-aged, in their 50s or 60s, and noted that the range of available professions was narrow, leading them to choose from a restricted set of options.

Table 1. Basic Information of Research Participants

NO	Gender	Occupation	Years of Employment
1	Female	Household manager	5
2	Female	Domestic worker	5
3	Female	Patient caregiver	10
4	Female	Patient caregiver	8
5	Female	Childcare teacher	2
6	Female	Childcare teacher	3
7	Female	Child-care provider	7
8	Female	Certified caregiver	15
9	Female	Disability support worker	16

Table 2. Summary of the Hiring Process by Occupation

Occupation	Certification	Internship	Training
Household manager	Not required	Not required	Initial training: 10 hours over two days. No legally required courses, but relevant training is recommended for professionalism and credibility.
Domestic worker	Not required	Not required	Ongoing training: Once a month, 2-3 hours.
Patient caregiver	Not required	Not required	Hospitals conduct training once a month.
Childcare teacher	Required	240+ hours of internship at childcare institutions	To obtain a Level 2 Childcare Teacher certificate, an associate degree or higher is required, along with completion of 17 childcare-related courses (51 credits).
Childcare provider	Not required	Not required	Government-supported 'Childcare Service' requires mandatory 120 hours (standard curriculum) or 40 hours (alternative course for those with similar qualifications). No mandatory training for private agencies.
Certified Caregiver	Required	160-hour internship at a care facility or home	320-hour training required (80 hours of theory, 80 hours of practical training, 160 hours of field practice).- In
Disability Support worker	Not required	10-hour internship at a support agency	In 2009, a total of 68 training hours were required.

2) Cross-Analysis Results

This study qualitatively analyzed the experiences of care workers by identifying key themes based on interview data. The findings were categorized into five main areas, each reflecting common themes from the participants' responses. The results, along with the frequency of responses, are presented in Table 4.

(1) Perception of wage

The perception of wage was divided into positive and negative experiences and classified into four subcategories: Low Salary Compared to Workload, Commission and Overtime Issues, Supplementing Family Income and Additional Income.

In cases of dissatisfaction, participants generally felt underpaid for the work intensity, and overtime or commission issues contributed to psychological stress. In contrast, those who were satisfied found that the income helped with economic difficulties, and some also viewed it as supplemental income even if it wasn't their main source of income.

(2) Coping Strategies in Unfair Situations

Coping strategies in unfair situations were classified into three subcategories: acceptance, emotional expression, and formal reporting.

(i) Acceptance (No Other Choice): *"There are no other options, so I just tolerate it. I'm afraid if I raise an issue, it will cause even bigger problems." (Participant 5)*

(ii) Emotional Expression: *"I just suppress my anger. I'm afraid if I speak out, I'll face disadvantages." (Participant 7)*

(iii) Formal Reporting: *"Once I reported an issue to the district office, but it was so complicated that I won't do it again." (Participant 4)*

Participants generally handled unfair situations personally or sought institutional help when needed. The majority of participants tolerated the situation and expressed emotional reactions internally. Only a few participants attempted to resolve issues through formal reporting.

(3) Internal and External Perception of the Job

Internal perception refers to how participants themselves view the job, while external perception refers to how those around them perceive the participant's job. Both internal and external perceptions were divided into positive and negative categories. Internal perceptions were classified into five categories, while external perceptions were divided into three subcategories as shown in Table 5.

Regarding internal perception, participants experienced personal satisfaction and fulfillment, but also struggled with low social recognition. In terms of positive aspects, responses varied between enjoyment (3) and a sense of gratitude (3), while negative aspects such as burnout (2) and lowered self-esteem (3) also emerged. External perceptions were split between positive and negative feedback, with expressions of customer gratitude positively influencing job satisfaction. On the other hand, low social recognition and repetitive tasks often led to dissatisfaction.

(4) Mental Health Impact Factors and Coping Strategies

Factors influencing mental health and coping strategies were classified into three subcategories.

- **(i) Stress Factors**

Table 3. Common Themes Related to the Occupational Entry Process

Related Themes	Summary of expression
Ease of entry	Easy re-entry
	No difficulty
Referral and Job Matching	Introduction through acquaintances
	Matched through an agency
Limited Occupational Choices	One of the few job option for people in age group of 50-60s

Table 4. Perceptions of salary with illustrative interview quotations

Negative	Low Salary Compared to Workload
	"The salary is too low for the intensity of the work. Even when I do over-time, I don't get proper compensation." (Participant 3)
	Commission and Overtime Issues
	"The commission is deducted too much. No matter how hard I work, I end up with very little pay." (Participant 6)
Positive	Supplementing Family Income
	"I'm grateful for this job because it helps support my family's livelihood." (Participant 8)
	Additional Income
	"It's not a lot of money, but it helps with buying essentials, so I'm satisfied." (Participant 2)

Stress mainly stemmed from external factors like the work environment, relationships with customers, and work intensity.

o “Working in a place with no air conditioning on hot summer days was really tough. I’d be sweating a lot and feel exhausted after work. I didn’t want to go home then.” (Participant 5)

o “Some customers wouldn’t use the cup we cleaned, instead asking for a tumbler. It often felt like we were shadow workers.” (Participant 7)

• (ii) Impact of Stress

Psychological impacts included lowered self-esteem and feelings of depression.

o “When we’re treated like this, I sometimes wonder if I’m doing something wrong. I often think, why do I have to do all this?” (Participant 3)

Physical symptoms included headaches and fatigue.

o “When I get home, I immediately look for medicine because of the headache. It’s not that the work is hard, but the tension makes me more tired.” (Participant 6)

• (iii) Coping Strategies

o “During breaks, I eat snacks or do stretching exercises to relieve tension. Without that, I wouldn’t be able to continue for long.” (Participant 4)

Social coping involved conversations with colleagues.

o “Talking with coworkers who are doing the same job really helps. We all empathize because we go through similar things.” (Participant 2)

Lastly, formal form of support was also utilized.

“I got support through health checkups from Green Hospital. It would be great if there were more support like this.” (Participant 8)

5. Discussion and Conclusions

These results provide a comprehensive picture of the challenges and experiences of care workers. The following discussion interprets these findings in light of current policy and practice, and suggests directions for future improvement.

This quantitative study aimed to identify the correlations between various factors, such as wages, job satisfaction, job stress, and health scores of care workers through statistical analysis. Both online and offline surveys were conducted, and all respondents who completed the survey were included as research participants. The key findings of this study are as follows.

This study identified correlations between health scores and other factors among care workers. Among chronic diseases, hypertension was found to have the highest prevalence. The health scores examined in this study (ODI percent (lower back pain), PHQ-9 (depression), and GAD-7 (anxiety)) all indicate better physical or mental health when the scores are lower. The ODI percent score showed an inverse relationship with working hours, suggesting that an increase in working hours has a visible impact on the deterioration of physical health conditions such as lower back pain. Additionally, higher job satisfaction was associated with lower ODI percent, PHQ, and GAD scores, indicating that maintaining physical and mental health during care work is linked to higher job satisfaction.

This study also identified differences among subcategories of care work. For example, as previously mentioned, the average age of disability support workers was statistically significantly higher than that of certified caregivers, childcare teachers, and domestic workers. Furthermore, the wages of disability support workers were statistically significantly lower than those of certified caregivers, childcare teachers, and domestic workers. The working hours of disability support workers were also statistically significantly lower than those of certified caregivers, childcare teachers, and domestic workers, while their PHQ-9 (depression) scores were statistically significantly lower than those of both certified caregivers and domestic workers.

The results above suggest that establishing an environment that supports the physical and mental well-being of care workers may have a positive long-term impact on the care labor sector. They also suggest that the higher average

Table 5. Internal and External perception of the job with illustrative interview quotations

Internal	+	**Enjoyable and Diverse** *"This job gives me the opportunity to meet various people and allows me to showcase my abilities." (Participant 9)*
	-	**Lowered Self-Esteem** *"People seem to look down on this job, so sometimes my self-esteem takes a hit." (Participant 3)*
External	+	**Gratitude and Respect** *"Sometimes customers say thank you, and it really lifts my spirits. On those days, I feel happy." (Participant 6)*
	-	**Shadow Workers** *"We are often treated like shadow workers, and that’s the hardest part." (Participant 7)*

age of disability support workers may lead to fewer working hours, which in turn results in lower wages but has a positive impact on depression scores.

However, as other factors may influence age, wages, working hours, and depression scores, further research is warranted. In particular, unknown social factors may contribute to the relatively high average age of disability support workers. Moreover, being designed as a cross-sectional study, this study analyzes correlations rather than causal relationships and it is not possible to draw definitive conclusions regarding causality.

Although quantitative research on wages, health scores, and working hours of care workers in South Korea has been increasing recently, studies that specifically analyze the correlations between these variables remain limited. Serving as a starting point for further statistical analyses, this study may help identify the key factors necessary for improving the working environment of care workers.

This study sheds light on the structural problems faced by care workers, which are linked to their health and social perceptions. It is expected to contribute to redefining the value of care work and improving policies related to workers' health and welfare. The study also aims to share the findings with welfare organizations such as "푸른초장 (NGO that assists care workers)", hoping to positively influence the situation. The insights gathered from the study will also help inform future educational programs for care workers, focusing on improving their physical and mental health.

The study's findings provide a foundation for various activities moving forward. Educational materials can be developed and distributed to care workers, providing them with accurate information about their current situation and guiding them toward understanding their future direction. The study revealed cases where resolving unfair situations was challenging, so the educational materials will include information on legal reporting procedures and rights. Additionally, the materials will provide guidance on preventing musculoskeletal disorders, such as joint protection and exercises to reduce strain.

During the research process, one major challenge faced was the lack of available quantitative data on care workers' health, which was necessary for the study. Initially, the plan was to use existing data, but due to insufficient numerical data, the research approach was adjusted. A new survey was designed and distributed to gather the necessary data, which allowed for the successful completion of the quantitative part of the research. However, the study could only identify correlations rather than causal relationships. To address this limitation, further interviews with the survey participants will be conducted to explore the detailed causes behind the relationships identified in this study. In addition, conducting a cohort study rather than a cross-sectional study, as a follow-up study, would enable the investigation of causal relationships.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.69841/igee.2025.018.

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Jun. 2025, Volume.2 No.2

igee proceedings

pISSN: 3022-5183 eISSN: 3022-5191

IGEE Proc 2025;2(2):133-147
https://doi.org/10.69841/igee.2025.020

Article

Bridging the Accessibility Gap: Investigating Challenges and Best Practices for Visually Impaired Individuals in STEM and Finance in North America – Policy Implications for South Korea†

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Background: Global accessibility mandates exist, yet blind and low-vision learners and professionals still face major barriers in STEM and finance; this study explores those gaps to guide South Korean policy.

Methods: Conducted a scoping review of accessibility laws and landmark cases and thematically analysed seven semi-structured interviews with blind South Koreans active in STEM or finance.

Results: The data show chronic shortages of accessible materials and software, limited institutional support, technological lag, and heavy psychosocial strain, whereas North American exemplars demonstrate effective solutions.

Conclusion: South Korea can close the STEM-finance accessibility gap only through systemic reforms—universal design, enforceable digital standards, and professional support structures—rather than relying on individual resilience.

Keywords Accessibility, STEM & Finance, Visually Impaired

1. Introduction

Accessibility has become an international priority. For example, the European Accessibility Act (EAA), adopted in 2019, will require a wide range of products and services – from consumer electronics (TVs, smartphones, computers) to ticketing machines and websites – to meet common accessibility standards by 28 June 2025 (AccessibleEU, 2025). In the United States, the Americans with Disabilities Act (ADA) has been updated to cover digital content: in April 2024 the Department of Justice issued a final rule mandating that state and local government websites and mobile apps conform to WCAG 2.1 AA standards

Received: June 17, 2025 **Revised:** June 19, 2025
Accepted: June 20, 2025
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†This research is supported by the Social Engagement Fund (SEF) 2024.

(Civil Rights Division, U.S. Department of Justice, [2024, April 24]). The DOJ has also begun addressing new technologies; for instance, it issued guidance explaining how algorithms and artificial intelligence in hiring can unintentionally discriminate against people with disabilities (Civil Rights Division, U.S. Department of Justice, 2022). These developments underscore a broad consensus that accessible design is essential online, aligned with the Web Content Accessibility Guidelines (WCAG) – a single international standard for web accessibility – and with legal mandates around the world. This study supports SDG 4 (Quality Education) and SDG 10 (Reduced Inequalities) by addressing barriers that exclude visually impaired individuals from equal access to education and digital participation in STEM and finance.

Focus on STEM and Finance

STEM and finance are critical to the modern economy but pose special accessibility challenges that have often been overlooked. Both domains rely heavily on graphical and data-driven interfaces (spreadsheets, charts, dashboards, scientific diagrams, etc.), which are inherently visual. For example, many advanced science and computing curricula rely on programming tools and graphics environments that are not accessible to blind learners (University of Washington, AccessComputing, n.d.). These challenges are compounded by cultural attitudes: as one expert cautioned, focusing only on "hero" success stories of exceptional individuals can mislead others into thinking "just do it like that," whereas such anecdotes may mask the systemic hurdles that most blind students face. In sum, the visual intensity of STEM/finance fields and ingrained biases make these sectors particularly critical – yet relatively neglected – arenas for accessibility policy.

North America

North America offers mature accessibility frameworks and practical models worth studying. In the U.S. and Canada, laws like the ADA (U.S.) and similar statutes mandate broad accessibility, and government and industry often cooperate on implementation. Major corporations and institutions exemplify best practices: for instance, Microsoft explicitly states that "accessibility is woven into the fabric of what we design and build from Day 1" (Microsoft, n.d.), and Pearson (a leading educational publisher) commits to making all its learning materials accessible so that "all students can learn from our products" (Pearson, n.d.-a) .Finance firms also invest in accessibility infrastructure; one visually impaired interviewee working in finance in New York, described Bloomberg's dedicated accessibility team that supports screen-reader users in investment analytics. These established efforts – backed by both legal requirements and cross-sector partnerships – provide a rich set of lessons and proven solutions that can inform policy in other countries.

Empirical Research

This paper integrates new qualitative research to ground the policy discussion in both empirical and legal context. The research began with an in-depth literature review on the experiences of visually impaired individuals in STEM and finance, followed by legal analysis of the Americans with Disabilities Act (ADA) and related accessibility frameworks. To contextualize the regulatory landscape, the study also examined landmark court cases involving digital accessibility and workplace discrimination, offering insight into how legal standards are interpreted in practice.

Building on this foundation, we conducted seven in-depth interviews with blind or low-vision South Koreans who have studied or worked in STEM and finance—many of them based in North America. These interviews reveal concrete experiences with inaccessible tools and environments, as well as adaptive strategies and institutional support. These personal narratives—presented here alongside legal and policy analysis—highlight real-world barriers and reform opportunities. By incorporating these lived experiences, the study ensures that policy recommendations are informed by both structural frameworks and the day-to-day realities of visually impaired students and professionals.

2. Accessibility Regulations Reshaping the Global Landscape

European Accessibility Act (EAA)

The European Accessibility Act (EAA) is an EU directive adopted in 2019 that establishes a set of common accessibility requirements for certain products and services across the European Union. Formally titled *Directive (EU) 2019/882*, this act aims to remove barriers in the internal market by harmonizing minimum accessibility standards and strengthening the rights of persons with disabilities to access goods and services in the EU. As a directive, the EAA sets binding goals (i.e. the accessi-

bility outcomes to be achieved) but leaves it to each Member State to decide the exact national measures or regulations to implement those goals. In effect, the EAA introduces EU-wide baseline rules for accessibility while giving countries flexibility in how to execute them in detail.

1) Scope and Application

The EAA's requirements apply broadly to digital and ICT-related goods and services offered in the EU, covering both public and private sector providers. Unlike earlier EU accessibility laws that only addressed public sector websites, the EAA extends to private companies' products and services as well – any covered product placed on the market or service provided to consumers must comply, regardless of whether the provider is a government entity or a business (Directive (EU) 2019/882, 2019). The Act specifically targets a wide range of technologies used in daily life (including in education and employment contexts). Notable examples of covered areas include:

- Consumer ICT Products: general-purpose computer hardware and operating systems, self-service terminals (such as ATMs, ticketing and check-in machines, and information kiosks), consumer telecommunication and audiovisual equipment (like smartphones or smart TVs), and e-readers (Directive 2019/882, 2019).
- Digital Services: electronic communications services (telephony and internet access services), services providing access to audiovisual media (digital TV content platforms), certain aspects of passenger transport services (ticketing, real-time travel information on apps/websites, etc.), consumer banking services, e-books (digital books and dedicated reading software), and e-commerce services (online shopping platforms) (Directive 2019/882, 2019).

These categories cover many of the digital tools used by people in educational and workplace settings – for instance, accessible computers, e-book readers, and communication applications benefit students and employees with disabilities. However, it should be noted that the EAA's list of covered goods and services is specific; it does not explicitly include certain niche domains like specialized educational software or scientific laboratory tools, which are discussed further below

2) Implementation

The EAA came into force on June 27, 2019, and EU Member States were given a three-year window (until June 28, 2022) to transpose the directive into their national laws. This transposition period allowed each country to adopt or update its legislation to meet the EAA's requirements. The accessibility requirements become mandatory starting June 28, 2025, after which all products and services within the EAA's scope must conform to the specified accessibility criteria before being offered on the market (Directive 2019/882, 2019). In practical terms, any covered product placed on the EU market after mid-2025 must be accessible by design, and likewise any new or updated services (such as websites or apps for banking, e-commerce, etc.) provided to consumers must meet the accessibility standards from that date forward. The EAA includes mechanisms to enforce these obligations: for example, manufacturers of covered products are required to undergo a conformity assessment and affix the CE marking to declare that their product meets the EAA's accessibility criteria. Member States must carry out market surveillance to ensure that products comply with the requirements, and they are empowered to take corrective actions if a product is found non-compliant. For services, providers must supply information about the accessibility of their services (for instance, in general terms and conditions or an equivalent document), and national authorities are tasked with monitoring compliance of services and handling complaints or reports of inaccessibility (Directive 2019/882, 2019).

3) Minimum Harmonisation and Limitations

The EAA is characterized as a minimum harmonisation directive, meaning it sets a baseline of accessibility requirements that all EU countries must at least meet, but it does not prevent Member States from going further. Countries are free to adopt stricter or broader accessibility rules at the national level (for example, extending accessibility obligations to additional products or services beyond those mandated by the EAA), as long as the minimum standards of the EAA are satisfied (Directive 2019/882, 2019).

Americans with Disabilities Act (ADA)

The ADA is a cornerstone civil rights law ensuring accessibility and nondiscrimination for people with disabilities in the United States. It is organized into several titles, with Title II covering public entities (state and local governments, including public educational institutions) and Title III covering private businesses deemed "places of public accommodation." Under Title II, no qualified individual with a disability can be excluded from participation in, or denied the benefits of, services, programs, or activities of a public entity (extending the mandate of Section 504 of the Rehabilitation Act to all state and local government services)

(Civil Rights Division, U.S. Department of Justice, 2010) (Civil Rights Division, U.S. Department of Justice, 2024). This obligation means public institutions – from city governments to state universities – must proactively ensure that their facilities and services (including digital content) are accessible to persons with disabilities.

Title II entities are required to make reasonable modifications and provide effective communication through auxiliary aids when necessary, so that people with disabilities have equal access, unless doing so would fundamentally alter the program or impose undue burdens (Civil Rights Division, U.S. Department of Justice, Disability Rights Section, 2016).

Title III, on the other hand, prohibits disability-based discrimination by private businesses open to the public (the ADA lists 12 categories of "public accommodations," which include places like banks, restaurants, theaters, retail stores, private schools, and museums) (Civil Rights Division, U.S. Department of Justice, 2010). Title III entities must ensure equal access to their goods, services, and facilities – for example, they must remove barriers in buildings, provide auxiliary aids such as assistive listening devices or Braille materials, and make reasonable policy modifications to serve people with disabilities.

1) 2010 ADA Standards for Accessible Design

Both Title II and Title III entities are subject to the ADA's technical standards for accessibility in the built environment and certain technologies. The 2010 ADA Standards for Accessible Design – adopted as part of DOJ's revised regulations in 2010 – are an updated set of accessibility requirements that replaced the original 1991 standards (Civil Rights Division, U.S. Department of Justice, 2010). These standards incorporate the 2004 ADA Accessibility Guidelines developed by the U.S. Access Board, giving them legal effect for ADA enforcement.

The 2010 Standards cover a wide range of architectural and communication elements, from building features (e.g. entrances, restrooms, signage, seating layouts) to fixtures and equipment. Notably, the 2010 update introduced specific criteria to address modern technology and spaces. For example, automated teller machines (ATMs) and fare machines must now have tactilely discernible input controls, audible speech output, Braille instructions, and other accessible features so that blind or low-vision users can independently use them (Civil Rights Division, U.S. Department of Justice, 2010). (The earlier 1991 rules had required ATMs to be "accessible" but lacked such technical specifics.)

The updated standards also improved requirements for assistive listening systems in assembly areas like classrooms or auditoriums (e.g. requiring standard audio jacks and hearing-aid compatible interfaces), refined reach range and spatial requirements to better accommodate people of short stature or wheelchair users, and set clearer rules for accessible routes and seating in public facilities (Civil Rights Division, U.S. Department of Justice, 2010).

The 2010 ADA Standards thus provide the baseline that architects, product designers, and organizations must follow to ensure any new or renovated physical space (or fixed equipment) is accessible. In practice, compliance with these standards is mandatory for Title II entities and for Title III businesses when building or updating facilities – a crucial consideration for STEM classrooms, laboratories, bank lobbies, or any physical infrastructure in education and finance sectors.

2) Digital Accessibility and the 2024 DOJ Updates

In recent years, the DOJ has underscored that the ADA's accessibility obligations extend into the digital realm. For public entities under Title II, this culminated in a major regulatory update in 2024. The DOJ issued a final rule (effective June 2024) that explicitly requires state and local governments to make their websites and mobile applications accessible to people with disabilities (Civil Rights Division, U.S. Department of Justice, 2024). This rule adopts the Web Content Accessibility Guidelines (WCAG) 2.1 Level AA as the authoritative standard for web and mobile content accessibility in Title II contexts.

In practical terms, any web content a public entity offers – whether it's an official state website, a public university's online learning portal, or a city's mobile app for services – must conform to WCAG 2.1 AA criteria (which cover things like text alternatives for images, keyboard navigation, captioning for multimedia, sufficient color contrast, etc.). The rule applies not only to content that the government creates, but also to content provided through third parties or contractors on the government's behalf (Civil Rights Division, U.S. Department of Justice, 2024). The overarching point of the 2024 update is that digital content is now clearly recognized as a public service that must be accessible. Just as wheelchair ramps and Braille signs are required at a city hall, captions on videos and screen-reader-friendly websites are required on a city's web portals. This new rule provides public entities with clear technical benchmarks and deadlines (large entities must comply by 2026, smaller by 2027) for bringing websites and apps up to standard (Civil Rights Division, U.S.

Department of Justice, 2024).

Although this particular rule is for Title II entities, it reflects a broader trend: the ADA is being actively interpreted to keep pace with technology. The DOJ's guidance in 2022 had already affirmed that *both* public agencies and private businesses should make their websites accessible under the ADA, identifying common barriers like poor screen-reader compatibility and videos without captions (Civil Rights Division, U.S. Department of Justice, Disability Rights Section, 2016).

3) AI-Driven Systems in Employment

Another contemporary development is the ADA's application to artificial intelligence tools and automated systems, particularly in employment (hiring and recruiting) which is critical in STEM and finance fields. In 2022, the Department of Justice and the EEOC jointly released guidance on Algorithms, AI, and Disability Discrimination in Hiring, recognizing the rapid adoption of software-driven hiring assessments (Civil Rights Division, U.S. Department of Justice. [2022, May 12]). They cautioned that employers must ensure these technologies do not unlawfully screen out or disadvantage applicants with disabilities.

The ADA's protections in employment (Title I of the ADA, which applies to both public and private employers) cover "all parts of employment, including how an employer selects, tests, or promotes employees (Civil Rights Division, U.S. Department of Justice. [2022, May 12]). Thus, if a company or government agency uses an AI-powered résumé scanner, online skills test, or video interview algorithm, it **remains responsible** for ADA compliance in that process. For instance, an algorithm that scores applicants by analyzing video interviews could discriminate against a Deaf applicant (if it expects spoken answers or analyzes tone of voice), or a timed online test might unfairly penalize someone with a motor disability. Even if unintentional, such outcomes violate the ADA's mandate that hiring technologies be accessible and not screen out people because of disability. The DOJ/EEOC guidance emphasizes that using a third-party vendor's AI tool is not a safe harbor – the employer is still liable if the tool is discriminatory (Civil Rights Division, U.S. Department of Justice. [2022, May 12]).

Case Study of Law Enforcement in U.S.A

1) Case Study: Payan v. Los Angeles Community College District

Real-world cases help illuminate how ADA requirements are applied and enforced. *Payan v. LACCD* is a landmark Title II case involving digital accessibility in education. In this lawsuit, two blind students at Los Angeles City College (part of LACCD) challenged the accessibility of the college's course materials and technology infrastructure. The evidence revealed a pattern of barriers that prevented blind students from equal participation. For example, one student (*Payan*) was unable to complete homework in an online platform (MyMathLab) because it was not designed to work with screen-reading software, and he was not provided timely alternate formats for his math textbook – causing him to fall behind in class (*Payan v. Los Angeles Cmty. Coll. Dist*., 2021). Additionally, LACC's public website and internal student portal (PeopleSoft) were *not compatible with screen readers*, making essential online resources unusable for blind students.

The college's library databases were also problematic: many research databases had interfaces that a screen reader could not interpret, and the school had no effective practice of vetting or monitoring digital resources for accessibility. These issues meant that blind students had to wait for ad-hoc fixes or report problems themselves, rather than having equivalent access from the start (*Payan v. Los Angeles Cmty. Coll. Dist*., 2021). The students sued under both Title II of the ADA and Section 504 of the Rehabilitation Act, arguing that the college's failure to address these accessibility issues was discriminatory.

The federal court agreed. Even after some procedural wrangling (including analysis of whether the claims should be treated as "disparate impact"), the court found that LACCD had violated the ADA by not providing equal access to its educational programs and materials. The violations cited in *Payan* were directly tied to well-known accessibility standards: the lack of screen reader compatibility and inaccessible PDFs or websites essentially meant the college's digital content did not meet prevailing web accessibility guidelines (WCAG) or best practices for electronic documents (*Payan v. Los Angeles Cmty. Coll. Dist*., 2021).

In the remedy phase, the court issued a sweeping injunction mandating LACCD to overhaul its accessibility efforts. The district was ordered to come into compliance with its

own accessibility policies (the college had an "Alternative Media Production Policy" on paper that wasn't being effectively implemented), to hire a dedicated Dean of Educational Technology to oversee digital access, and to ensure *all* new web content, software, and databases used in classes are accessible to blind students (*Payan v. Los Angeles Cmty. Coll. Dist*., 2021).

The Payan case underscores that digital inaccessibility can amount to illegal discrimination under the ADA. It illustrates Title II's application in a STEM educational context: from online homework platforms to digital libraries, institutions must adopt accessible technology (or timely accommodations) before students are excluded, not react only after a student complains. The case also implicitly referenced standards like WCAG and Section 508 guidelines as measures of accessibility, since the feasibility of "reasonable modifications" to the websites was proven by the plaintiffs.

2) Case Study: U.S. Department of Justice v. University of California, Berkeley

Another instructive case – involving the U.S. DOJ's enforcement against UC Berkeley – demonstrates ADA compliance in online content used in higher education. In 2016, following a complaint by the National Association of the Deaf, the DOJ investigated UC Berkeley's public online offerings (which included free course videos and lectures on platforms like YouTube, iTunes U, and the university's MOOC portal BerkeleyX). The investigation found that "significant portions of UC Berkeley's online content" were not accessible to individuals with disabilities, particularly those who are deaf, hard of hearing, blind, or have manual (motor) impairments. For example, many lecture videos had no captions, making them *"totally inaccessible to people who are deaf or hard of hearing"* (Civil Rights Division, U.S. Department of Justice, Disability Rights Section, 2016). Likewise, some content lacked text transcripts or other alternatives needed by blind users or those who couldn't use a mouse. DOJ concluded that this inaccessible content denied people with disabilities the **full and equal enjoyment** of Berkeley's services, in violation of Title II. It's important to note that much of this content was not part of a for-credit program but rather free educational resources – however, because the university chose to extend these services to the general public, it had to do so in a nondiscriminatory way under the ADA (Civil Rights Division, U.S. Department of Justice, Disability Rights Section, 2016).

In a detailed Letter of Findings, DOJ cited Berkeley's failure to comply with accessibility standards that the university itself had adopted. The University of California system had an IT accessibility policy requiring WCAG 2.0 Level AA compliance, but Berkeley was not enforcing it or monitoring content for compliance (Civil Rights Division, U.S. Department of Justice, Disability Rights Section, 2016). The letter pointed out that Berkeley had services available (e.g. a team to help caption videos or advise faculty on accessible course design) but did not mandate their use, resulting in widespread inaccessibility.

The enforcement outcome was a comprehensive settlement: in 2022, a consent decree was approved by a federal court requiring UC Berkeley to make its content accessible and adhere to specific measures. Under this decree, Berkeley must caption or provide text transcripts for the thousands of videos in its public platforms, ensure its websites and MOOCs meet accessibility standards, and update its policies to institutionalize accessibility going forward. The university also agreed to hire a web accessibility coordinator, conduct regular accessibility testing of its online content, train pertinent staff and faculty, and even bring in an independent auditor to evaluate compliance periodically (Civil Rights Division & Office for Civil Rights, 2023). The standards referenced in the decree align with WCAG 2.0 AA (the prevailing standard at the time of the investigation) – for instance, the remedial measures explicitly call for Berkeley's online courses and videos to conform to WCAG 2.0 AA so that people with hearing, vision, or manual disabilities can "engage in the same interactions and enjoy the same services" with substantially equivalent ease of use as others (Civil Rights Division, U.S. Department of Justice, Disability Rights Section, 2016).

3. Structural Barriers in STEM and Finance

Despite decades of disability rights legislation and awareness efforts, blind and visually impaired individuals in North America continue to face significant structural barriers in both STEM education and technical careers. Disability has historically been treated as peripheral in STEM diversity initiatives, hindering progress and innovation (Mattison et al., 2022). Deep-rooted cultural and physical structures in educational institutions and workplaces still impose substantial obstacles as spaces, tools, and practices were long designed around a narrow notion of "normal" that excludes those with disabilities (Mattison et al., 2022). Below, we ex-

amine these barriers in educational settings (Section 3.1) and in the workplace (Section 3.2), and why they persist despite policies like the Americans with Disabilities Act (ADA).

Educational Challenges

Visually impaired students remain severely underrepresented in STEM fields. Research shows they complete advanced science and math coursework at much lower rates than their sighted peers (Koehler & Picard, 2024; Rosenblum et al., 2025). A major reason is the inaccessibility of core STEM content: important materials such as equations, diagrams, and graphs are often unavailable in braille or other accessible formats when needed. For example, Rosenblum et al., 2025 found that accessible science and mathematics materials were frequently not ready in time for blind students. raphs and charts, ubiquitous in STEM curricula, are "often not available to those with visual impairments" in any tactile or audio form (Koehler & Picard, 2024). This means that blind learners may go through classes without ever fully accessing the visual data or formulae that their sighted classmates take for granted. The result is an education experience missing key pieces, putting these students at an inherent disadvantage.

Beyond static content, many hands-on tools and activities in STEM pose additional barriers. Laboratory experiments, interactive simulations, and coding projects are typically designed with sighted assumptions, making them hard to navigate without adaptation. Visually impaired students "do not have the same opportunities for hands-on learning as sighted peers" in science classes (Rosenblum et al., 2025). Standard lab equipment often provides output only in visual forms (think of microscope readings or chemical color changes), and most programming environments are optimized for visual GUI use. As a consequence, blind students must rely on special accommodations or assistive tech to participate. Teachers often need to create or obtain accessible lab materials – for instance, using tactile models or talking instruments – so that a blind student can perform an experiment. Likewise, mainstream coding platforms may require screen-reader scripts or high-cost adaptive software to be usable (Koehler & Picard, 2024). If such adaptations are not provided, the student's ability to engage with core STEM skills (like data analysis or coding) is limited from the start.

Another structural challenge is the lack of preparedness among many educators and institutions to support inclusive learning. Most general STEM instructors receive little to no training on how to teach students with visual impairments. Common accommodations (e.g. describing visuals aloud, providing materials in Braille or accessible digital formats) are not intuitive without training, and busy faculty often struggle to adapt highly visual curricula on the fly (Koehler & Picard, 2024). Schools often report that a lack of proper staff training and resources for accessibility are major hurdles in effectively supporting students with disabilities. This deficit in knowledge can result in teachers having low expectations for disabled students or even unintentionally neglecting their needs. For example, a teacher might incorrectly assume a blind student is incapable of certain tasks instead of adapting their teaching methods (Bellman et al., 2018). Such attitudes and unmet needs accumulate to leave visually impaired students "at a disadvantage and underprepared to consider careers in the STEM fields" (Koehler & Picard, 2024). In short, when educators are not equipped or willing to include them, blind learners receive a diluted education that falls short of true inclusion.

Finally, the paucity of mentors and role models in STEM further discourages blind students. It is hard to aspire to a career that one has never seen someone like oneself succeed in. Unfortunately, many visually impaired youth "often do not see themselves reflected in STEM careers and lack role models and mentors" to guide them. This structural lack of representation has long-term consequences: without mentors to inspire and advise them, fewer blind students persist in STEM, perpetuating the cycle of underrepresentation. Increasing mentorship opportunities (for example, pairing students with visually impaired STEM professionals) has been highlighted as a vital strategy to counteract this barrier (Koehler & Picard, 2024).

Workplace Challenges

For those blind individuals who do pursue STEM or finance careers, significant structural challenges await in the workplace. A first major hurdle is technological: many essential software tools and platforms in industry are not fully accessible. Professional environments rely on complex data visualization, coding interfaces, and proprietary software (e.g. Excel spreadsheets, CAD programs, or Bloomberg terminals) that often lack robust screen-reader compatibility or keyboard-only operation. As a result, visually impaired employees must jury-rig solutions – using screen readers to

scrape information, or purchasing expensive specialized software – just to do the same work as others (Koehler & Picard, 2024). In an ideal setting, these tools would have universal design features built in; in practice, most were "designed to accommodate a segment of society" with fairly uniform (sighted) abilities (Mattison et al., 2022). Workplace technology and IT systems typically assume users can see dashboards, charts, or code editors, thereby excluding those who are blind by design. This lack of foresight in job tools forces employees with visual impairments to constantly request adaptations or perform additional steps to access information, slowing them down through no fault of their own. It also means that when new technologies roll out, accessibility is an afterthought if it is considered at all. In finance roles, for example, critical software like data visualization dashboards or trading interfaces may not output textual equivalents for charts, leaving blind analysts reliant on colleagues for information that sighted peers get at a glance. These technological barriers reflect a broader issue: employers and workplace cultures historically have not built environments with disability in mind (Mattison et al., 2022).

Compounding the technical barriers are pervasive biases and misconceptions about ability. There remains a stubborn stereotype that visually impaired people are "unfit" for highly technical or quantitative roles. This bias can surface in recruitment (hiring managers overlooking qualified blind candidates) and in the workplace through marginalization of those who are hired.

4. Proposed Innovations: Academic Research Awaiting Real-World Application

Academic and nonprofit research has introduced numerous innovative solutions to make STEM education and finance more accessible for people with visual impairments. These range from tactile learning aids to intelligent software, but many of these promising tools remain underutilized in classrooms and workplaces. Key examples of proposed innovations include:

Tactile and Multimodal Tools for Math & Data:

Researchers advocate using tactile or multimodal representations to convey mathematical and scientific concepts. For instance, 3D-printed models and tactile graphics can help students grasp complex STEM concepts through touch, serving as effective accommodations that aid conceptual understanding and create accessible curricular content for blind or low-vision learners (Koehler & Picard, 2024). Real objects, raised-line diagrams, and audio/touch-integrated graphs allow visually impaired students to explore data and diagrams in non-visual ways, often with superior educational outcomes compared to solely verbal descriptions. Such tools have been shown to enrich STEM learning for all students while leveling the field for those with visual impairments.

Accessible Coding Platforms with Audio/Haptic Feedback:

Inclusive design principles are also being applied to computer science education. Specialized coding platforms and kits have been developed to make programming accessible via sound and touch. For example, the American Printing House's Code Jumper is a physical coding kit that converts block-coding concepts into a tactile, audio-enhanced format – users connect uniquely shaped pods with cords and listen to audio cues, effectively "viewing" code through touch and sound. (PPG Foundation, 2022). Academic initiatives like the National Coding Symposium have highlighted accessible programming languages (e.g. Quorum) and tools that enable students with vision loss to write code using speech or braille outputs. These research-driven platforms show that with creative design, core STEM skills like coding can be taught in a non-visual, multimodal manner. However, most mainstream coding environments still lack such built-in accessibility, indicating a need for wider adoption of these innovations outside of pilot programs.

5. Best Practices Implemented in North America

Education Sector Reforms

1) AccessSTEM (University of Washington)

The AccessSTEM program at UW's DO-IT center exemplifies how higher education can embed accessibility into STEM curricula. AccessSTEM develops training modules and guides so that lectures, laboratories, and online materials are fully compatible with screen readers and Braille. For example, UW encourages faculty to provide tactile graphics (such as swell-form kits or plastic molecule models) and

electronic braille displays in science classes to convey diagrams and equations (DO-IT, University of Washington, n.d.). In practice, all equations are provided as MathML or LaTeX-generated alt text, and PDF or web content is checked against accessibility standards. Faculty mentors and student assistants work one-on-one with blind students to adapt coursework, reflecting the program's unique practice of personalized STEM mentoring. By combining technical guidelines with hands-on support, AccessSTEM creates an inclusive campus environment for visually impaired learners.

2) VLC Math Accessibility Guide (University of Houston)

The University of Houston's Visual Learning Center (VLC) has published a comprehensive Math Accessibility Guide for faculty and publishers (Burgess-Rodrigues et al., n.d.). This guide advises that all mathematical expressions be formatted in accessible markup (e.g. MathML or tagged LaTeX) with accompanying alt text, and encourages the use of assistive technologies such as Nemeth-encoded Braille and DAISY audio for complex equations. In particular, VLC recommends providing multiple formats of math content – for instance, offering recorded audio of textbooks or tactile printouts of graphs – so that blind students can choose the format that works best. This approach parallels the practice where blind students use Nemeth code and recorded texts for math courses, as noted in expert interviews. By codifying these standards, the VLC guide ensures that instructors have clear steps (e.g. adding alt text to graphs, verifying screen-reader compatibility) for making K–12 and college math accessible.

3) Northwestern University's Math Accessibility Guidelines

Northwestern University has developed institutional guidelines to help faculty present math in accessible ways. These guidelines emphasize that all equations and formulas must include textual descriptions (alt text) or be provided through an accessible media (such as a Blackboard equation editor or MathML). Instructors are instructed to use accessible file formats and software whenever possible (Northwestern University School of Professional Studies, n.d.). For example, materials prepared in PowerPoint (with proper slide titles and alt-text for images) are fully readable by screen readers. Northwestern also recommends offering tactile supports (Braille or embossed prints) for complex diagrams. Unique to Northwestern's approach is formal review: course content is periodically audited by accessibility specialists, and instructors attend training on inclusive pedagogy. Together, these practices illustrate how formal university policies can reinforce the use of inclusive tools and ensure compliance with accessibility standards.

Industry and Workplace Innovations

1) IBM (International Business Machines): Pioneering Corporate Accessibility

IBM stands out as a long-time leader in workplace accessibility, with efforts dating back several decades. In fact, IBM researchers were instrumental in creating some of the first screen-reading technologies. Notably, IBM developed a software called Screen Reader in the 1980s, originally a proprietary program that gave blind users spoken access to text on IBM computer terminals (Cooke, n.d.). This innovation was so influential that "screen reader" became the generic term for such assistive software across the industry. Building on this legacy, IBM cultivated an internal culture of inclusive design and continued to release assistive solutions (for instance, early Braille printers and talking interfaces) as well as to contribute to accessibility standards. In the modern era, IBM systematically integrates accessibility features into its enterprise products and devotes specialized teams to ensure compliance with standards like WCAG and Section 508. A concrete example is IBM's analytics software, which is designed to work seamlessly with popular screen readers (such as JAWS on Windows) and even provides customizable auditory cues for blind users. In the user settings of IBM SPSS tools, a visually impaired user can enable sound feedback for interface events, helping them navigate data analysis tasks through non-visual means. IBM also publishes extensive documentation for users with disabilities, describing how to optimize the software for accessibility (IBM, n.d.).

2) Bloomberg: Accessible Financial Data Visualization

Bloomberg incorporates accessibility in both its products and research collaborations. The Bloomberg Terminal's Voluntary Product Accessibility Template (VPAT) shows support for screen readers, keyboard navigation, and high-contrast display modes (Bloomberg, n.d.). In addition to these compliance features, Bloomberg partnered with Carnegie Mellon University on auditory displays of financial data. In practice, complex charts (e.g., stock price graphs) can be "sonified"

so that rising and falling data are conveyed by changes in pitch and tone. As one accessibility expert noted, a stock app can describe charts with voiceover or with a rising pitch for higher values. This work echoes Bloomberg's innovation: blind analysts can interpret market trends through sound (for example, a rising tone as prices climb) (Bloomberg, 2018). By combining standard assistive features (VPAT-verified UI) with pioneering techniques like data sonification, Bloomberg offers blind users both compliance and cutting-edge tools.

3) Pearson

Pearson embeds accessibility into its educational products and publishing practices. Its digital textbooks and learning platforms include full-text descriptions, keyboard navigation, and compatibility with screen readers and text-to-speech engines (Pearson, n.d.). Importantly, Pearson produces alternative formats for learners with visual impairments: for mathematics content, they offer DAISY audio books and collaborate with specialists to transcribe equations into Nemeth Braille (NISO, n.d.). This mirrors the approach seen in higher education, where instructors rely on recorded or embossed texts for blind students. Unique to Pearson is an internal accessibility policy requiring that all new content meet WCAG standards before release, along with ongoing training for content creators on how to write descriptive alt text and format mathematical material in accessible ways (Pearson, n.d.-a). As a result, educators using Pearson materials report that most content "just works" with a screen reader when these guidelines are followed.

4) Google

Google's commitment to accessibility is evident across its web-based products and workplace tools, with a strong focus on empowering individuals with visual impairments. Google Workspace applications like Docs, Sheets, and Forms are engineered for compatibility with screen readers and keyboard navigation, enabling many blind professionals to perform daily tasks such as reporting and project collaboration (Google, n.d.-a). Beyond productivity suites, Google integrates artificial intelligence to enhance visual accessibility, offering features like automatic alt text generation for images in services like Google Photos and email (Google, 2017; Google, n.d.). Furthermore, Google provides dedicated screen readers: ChromeVox is built into Chromebooks (Google, n.d.-c), and TalkBack offers spoken feedback for the open-source Android platform (Google, n.d.-b), fostering an ecosystem where both Google employees and third-party developers contribute to accessible features. This comprehensive approach ensures that blind engineers and analysts at Google can utilize mainstream technologies with minimal added effort, promoting inclusive participation.

5) Microsoft

Microsoft actively champions accessibility across its product ecosystem, with a significant emphasis on supporting individuals with visual impairments. Its core operating system, Windows, integrates Narrator, a robust built-in screen reader that verbalizes text and describes on-screen elements, enabling navigation and interaction for blind users (Microsoft, n.d.-b). Furthermore, Microsoft 365 applications, including Word, Excel, and PowerPoint, are meticulously designed with comprehensive accessibility features such as strong screen reader support, efficient keyboard navigation, and integrated accessibility checkers to facilitate the creation and consumption of accessible content (Microsoft, n.d.-c). Microsoft also harnesses artificial intelligence to directly assist the visually impaired through innovations like the Seeing AI app, which describes surroundings, reads text, and identifies objects, offering real-time auditory insights into the visual world (Microsoft, n.d.-a). Browser experiences, such as Microsoft Edge, are enhanced with features like Immersive Reader and Read Aloud, catering to users with low vision (Microsoft, n.d.-d). These diverse and integrated efforts underscore Microsoft's dedication to fostering an inclusive digital environment, allowing individuals with visual impairments to engage seamlessly with technology.

6. Interview-Based Insights

Background and Methodology

We conducted seven semi-structured interviews with legally blind participants in South Korea's STEM and finance sectors. Participants held roles such as software developer, financial analyst, university instructor, and teacher, and were all engaged in STEM or finance fields (see Table 1 for interviewee demographics). Interviews focused on accessibility in education and work, unmet needs, coping strategies, and institutional support. We transcribed and thematically analyzed these interviews, coding for recurrent patterns related to barriers, tools, support, and psychological factors.

Table 1. Demographics of Interviewees

ID	Occupation	Experience	Remote / Face-to-face Interview
P1	Assistive Technology Developer / CEO	• Master of Business Administration, Graduate School of Business Administration • Current Director, Product Planning Team	Remote
P2	Science and Engineering Professor	• Ph.D. in Rehabilitation Science and Technology • Professor, KAIST (Korea Advanced Institute of Science and Technology)	Face-to-Face
P3	Artificial Intelligence Developer	• Ph.D. in Linguistics and M.S. in Computer Science • Principal Machine Learning Engineer	Remote
P4	Google Developer	• B.A. in Political Science and International Relations, double-major in Computer Science • Software Engineer at Google	Remote
P5	Artificial Intelligence Developer	• M.S. in Computer Science • Ph.D. Candidate in Computer Science, University of Washington • Worked on AI model development at Big Tech	Remote
P6	Financial Analyst	• B.A. in Psychology, Harvard University, PhD candidate at MIT Sloan School of Management • Vice President, Credit Analyst at investment banking firm	Face-to-Face
P7	Math Teacher	• Over 20 years experience as a Mathematics Teacher • Mathematics Teacher, School for the Blind • Mathematics Teacher, School for the Blind	Remote

Key Themes from Interviews

1) Accessibility Barriers (Education and Workplace)

Severe lack of accessible learning materials. One special education teacher remarked that instructional content for braille users is very limited, saying he has *"never received a braille math guide in [his] 20-year career"*. Students and educators must often invent solutions: for example, a math teacher described manually affixing braille labels or using 3D-printed tactile graphics to convey diagrams – tasks that "normal teachers" would not need to do, which he found burdensome. Even course content posed challenges: a visually impaired computer science student recalled that engineering math ("engineering math, like what engineers learn") involved so much material that he "had a lot of trouble" mastering it without accommodation.

In the workplace, visual content and unadapted tools slowed participants. A software developer noted that interpreting charts and graphs by listening is much slower: *"the biggest problem is speed… to understand the graph quickly…, it can take a long time"* when reading data instead of looking. He also said simple coding tasks (like debugging syntax errors) are time-consuming because *"there is a lot to read but reading speed is not as fast,"* which delays project work and debugging. Similarly, code review was challenging; one developer explained that reviewing a colleague's lengthy code changes requires him to *"read every line one by one… so it does take a lot of time"*.In finance, an analyst described how many corporate reports are issued as inaccessible PDFs, forcing him to use OCR tools on each page because the *"document production companies… can apply an accessibility lock"* on filings.In short, inaccessible formats and reliance on visual interfaces created significant hurdles for interviewees.

2) Assistive Tools and Technology

Interviewees relied heavily on assistive technologies, but also noted gaps. All used screen-reading software: a developer said he mostly uses JAWS and finds the free NVDA now "can do almost everything," and he also employs Windows Narrator and Mac VoiceOver as needed. An analyst listed his tools: Bloomberg and Excel with a screen reader (JAWS), plus PDF-to-text OCR converters, iPhone and iPad, and a braille display (Focus) for reading data. A teacher described using braille note-takers and even 3D-printed models so students could feel graphs. Interviewees also stuck to familiar platforms: for example, one preferred older software versions instead of forced updates, since "he gets used to things" and updates can introduce new barriers. Overall, while core assistive tools (screen readers, braille displays) covered basic tasks, advanced STEM content often required creative adaptations beyond out-of-the-box solutions. Table 2

Table 2. Tools & Services used by STEM Field Visually Impaired Employees

Domain	Tools Used	Purpose
Development & Coding	• VSCode, Emacs, Google Colab, Jupyter Notebook	Writing code, debugging, research analysis
Data Analysis	• Python (Pandas, NumPy, Matplotlib), R	Data processing, statistical analysis, machine-learning model development
Financial Analysis	• Bloomberg Terminal, Excel, Word, Nuance PDF Converter	Financial-data analysis, corporate report writing
Graphics & Visualization	• OCR (InftyReader, Gemini, ChatGPT), AI-based image description	Improving access to graphics and diagrams
Document Work	• Google Docs, Confluence, Notion	Collaborative document creation, research record management
Presentation	• Preparing presentation materials and enhancing accessibility for visually impaired users	Preparing presentation materials and enhancing accessibility for visually impaired users
Collaboration Tools	• Slack, MS Teams, JIRA, GitHub, GitLab	Remote collaboration, code review, project management

demonstrates the tools and services used by visually impaired individuals in the STEM field.

3) Coping Strategies and Self-Advocacy

Participants developed personal strategies to work around obstacles. A common approach was investing extra time and self-study. One developer said that when accessibility bugs arise, he simply "asks a friend to explain" the screen output, since automated narration is often insufficient. If an essential tool is inaccessible, he "spends a lot of time learning" or switches to an alternative tool as needed. Many described using multiple sensory channels in tandem: for example, code reviewers would listen and read braille in parallel, and an analyst noted that while tables have many columns, he can "navigate with keyboard shortcuts" because he is accustomed to their structure. When possible, participants leveraged social support: the math teacher relied on a trained aide (the School Work Support Person) to help prepare materials, mitigating some burdens. Importantly, none of these solutions was straightforward. One developer still found code review "not an easy thing," saying that even with screen-reader support he had to laboriously inspect each change.

4) Institutional Support

Interviewees consistently reported inadequate formal support structures. In classrooms, the availability of designated aides helped only partially. For instance, the math teacher noted that a newly introduced support-assistant program has resolved some issues (like preparing diagrams) that were previously intractable. However, he cautioned that these assistants are not always highly trained, so many accessibility problems still ultimately fall on the teacher. In workplaces, support was often virtually non-existent. One developer bluntly observed that because he is "the only blind person on the team," any accessibility problems "are generally left for me to solve". In other words, he had no company advocate and had to address all tech issues himself. Similarly, the financial analyst found that even when procedures exist (e.g. requesting accessible reports), they depended on informal relationships; he often had to "call and tell them the document is inaccessible" to get files unlocked.

However, some exceptions—particularly in North America—highlight the potential for institutional responsiveness. A visually impaired analyst recounted his experience at JPMorgan, where he was provided with a dedicated intern to assist him in daily work. During an on-site interview at his workplace, the research team observed accessible features such as tactile and auditory elevator buttons—indicating that the building itself had implemented physical accessibility infrastructure. Notably, the analyst emphasized his close collaboration with Bloomberg's accessibility team, with whom he "communicated frequently" to improve the usability of financial analysis tools. He described his colleagues as proactive and supportive, noting that they actively sought ways to accommodate his needs and integrate accessibility considerations into team workflows. This case illustrates how institutional culture and peer support, when prioritized, can significantly mitigate the structural gaps that visually impaired professionals often face.

5) Psychological and Emotional Burdens.

Beyond practical issues, the interviews suggested an emotional toll. While not always expressed explicitly, frustrations surfaced in comments about expectations and isola-

tion. An academic interviewer (a professor) warned that focusing on "heroic" success stories can be counterproductive – such narratives may imply that only exceptional effort, rather than systemic change, leads to progress. This sentiment resonated with participants' experiences of being singled out. For example, the sense of being the lone blind person who must fix everything implies a lonely burden; as one developer noted, without colleagues who share his needs, every new tool or update becomes a personal challenge. These accounts hint that interviewees often felt pressure to perform without complaint or outside help. The need to constantly "keep up" (investing extra time and resourcefulness) likely contributes to stress, even if respondents primarily described concrete solutions rather than affect. In sum, the interviews revealed not only logistical barriers but also an undercurrent of emotional strain from shouldering challenges largely alone.

Implications of Findings

These interview insights point to clear policy implications for South Korea. First, systemic support must replace reliance on individual effort. For education, the lack of accessible STEM materials signals a need for national standards and funding: for example, requiring that textbooks and resources (especially in math and science) be produced in braille or digital accessible formats. Teacher training should include accessible STEM pedagogy so instructors can implement best practices rather than scrambling with ad-hoc workarounds. In higher education and workplaces, institutions should adopt universal design in teaching and operations – for instance, mandating that new software and courseware be tested for screen-reader compatibility. Second, stronger institutional support structures are warranted.

The Korean government already provides classroom assistants , but interviews suggest these aides need specialized training for STEM contexts. Policies could establish certification or continuing education for support staff in STEM education. Similarly, companies should be held accountable for accessibility: regulations could require enterprises (especially in tech and finance) to ensure that internal tools and public documents (e.g. financial filings) meet accessibility guidelines.

The finance example of locked PDFs suggests a need for enforcement of standards (akin to North American rules) so that all reports are available in screen-readable formats. Third, technology and accommodations require investment. Participants' reliance on older or specialized tech (braille displays, OCR tools) highlights a gap that policy can address by subsidizing assistive devices and encouraging innovation in accessible technology. Additionally, creating support networks (such as mentoring or peer groups) could alleviate the isolation felt by some interviewees. Finally, policy communication should avoid emphasizing only "heroic" outcomes; instead, it should spotlight ordinary users' needs to foster realistic expectations and empathy. In summary, the interviews show that blind STEM students and workers face consistent hurdles—from classroom resources to workplace tools to emotional strain—that are not being resolved at a structural level.

7. Conclusion

SDG 4 emphasizes inclusive and equitable access to education for all, including persons with disabilities, and calls for the elimination of gender and disability disparities in education. SDG 10 focuses on empowering and promoting the social, economic, and political inclusion of all individuals, regardless of disability status. By examining structural barriers and proposing practical, policy-driven solutions to improve digital and educational accessibility in STEM and finance, this study contributes to both goals. It supports the global commitment to ensure that no one is left behind in the transition to a digital economy.

This study has highlighted the persistent accessibility challenges that blind and visually impaired individuals face in STEM and finance—fields that are increasingly vital to economic opportunity yet structurally exclusionary by design. While recent legal reforms in the U.S. and Europe, such as the ADA's digital mandates and the EAA's market-wide accessibility requirements, mark substantial global progress, critical implementation gaps remain—particularly in STEM-specific technologies and workplace systems. Despite promising innovations in accessible design and the existence of model institutions and companies in North America, adoption remains uneven, and cultural attitudes continue to reinforce the marginalization of people with disabilities in technical domains.

Through seven in-depth interviews with South Korean professionals and students, this research uncovered not only technical barriers but also the emotional and institutional toll of navigating inaccessible environments without systemic

support. These findings underscore that structural reform—not individual resilience—must be at the center of future policy. Bridging this accessibility gap is not only a matter of compliance or inclusion—it is a strategic imperative for fostering innovation, talent, and equity in Korea's digital future.

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