ilset

April 13-16
Denver, CO
USA
2023

Proceedings of International Conference on

Life Sciences, Engineering and Technology

April 13-16, 2023 Denver, CO, USA

EDITORS

Valarie Akerson

Ali Bicer

Sabri Turgut

istes Organization

www.ilset.net

Volume 1, Pages 1-172

Proceedings of International Conference on Life Sciences, Engineering and Technology

ISBN: 978-1-952092-46-6

Editors: Valarie Akerson, Ali Bicer, & Sabri Turgut

Articles: 1-13

Conference: International Conference on Life Sciences, Engineering and Technology (iLSET)

Dates: April 13-16, 2023

Location: Denver, CO, USA

Conference Chair(s):

Mack Shelley, Iowa State University, United States
Stephen Jackowicz, University of Bridgeport, United States

The submissions are subject to a double-blind peer review process by at least two reviewers with expertise in the relevant subject area. The review policy is available at the conference web page: www.ihses.net

President

Mack Shelley, Iowa State University, United States
Stephen Jackowicz, University of Bridgeport, United States

Scientific Board

Janice Fournillier, Georgia State University, United States
Wilfried Admiraal, Leiden University, Netherlands
Elizabeth (Betsy) Kersey, University of Northern Colorado, United States
Anastasios Theodoropoulos, University of Peloponnese, Greece
Arturo Tobias Calizon, University of Perpetual Help System Dalta, Philippines
Brett Buttliere, Technical University Dresden, Germany
Cara Williams, Emirates College For Advanced Education, United Arab Emirates
Chandra Pratama Syaima, University of Lampung, Indonesia
Chris Plyley, University of the Virgin Islands, Virgin Islands
Claudiu Mereuta, Dunarea De Jos University of Galati, Romania
Dana Aizenkot, Ashkelon Academic College, Israel
El Takach Suzanne, Lebanese University, Lebanon
Farouk Bouhadiba, University of Oran 2, Algeria
Frank Angelo Pacala, Samar State University, Philippines
Hou-Chang Chiu, Fu-Jen Catholic University Hospital, Taiwan
Irena Markovska, Assen Zlatarov University, Bulgaria
Irina Andreeva, Peter The Great St. Petersburg Polytechnic University (SPBPU), Russia
Iwona Bodys-Cupak, Jagiellonian University, Poland
Jaya Bishnu Pradhan, Tribhuvan University, Nepal
Jean-Yves Gantois, ICHEC, Belgium
Kassa Mickael, Addis Ababa University, Ethiopia
Kemmanat Mingsiritham, Sukhothai Thammathirat Open University, Thailand
Kristyna Balatova, University of Zilina, Slovakia
Milan Kubiatko, Jan Evangelista Purkyně University, Czech Republic
Neide Da Fonseca Parracho Sant'anna, Colegio Pedro II, Brazil
Oguz Akturk, Necmettin Erbakan University, Turkey
Ossi Autio, Univertsity of Helsinki, Finland
Philomina Ifeanyi Onwuka, Delta State University, Nigeria
Sharif Abu Karsh, Arab American University, Palestine
Shenglei Pi, Guangzhou University, China
Siew Nyet Moi, Universiti Malaysia Sabah, Malaysia
Sindorela Doli Kryeziu, University of Gjakova, Albania

Organizing Committee

Table of Contents

International Conference on
Life Sciences, Engineering and Technology
www.ilset.net April 13-16, 2023 Denver, CO, USA www.istes.org

Threat Modeling with Business Intelligence

Matthew Paulson
Weber State University, USA, https://orcid.org/0000-0002-0874-1335

Abstract: Business intelligence and information security seem like a natural fit. Enough information about threats, threat actors, vulnerabilities and vulnerability mitigation exist to make business intelligence activities worth the trouble of setting up an infrastructure to handle significant data consumption and analysis. This research paper discusses the question of whether business intelligence is mature enough to create and enhance information security threat models. A brief theoretical model is presented and discussed. Definitions and general observations regarding business intelligence and information security are also presented. The paper concludes with a discussion of the theoretical model and the assertion that business intelligence is indeed mature enough to support threat modeling. As a result of this mature support, businesses, non-profits, and other organizations can peer ever so slightly into the future, determine what threats and vulnerabilities they may face, take appropriate action to mitigate identified threats and vulnerabilities, and reduce overall information security risk.

Keywords: Business Intelligence, Threat Modeling, Information Security, Cybersecurity.

Citation: Paulson M., (2023). Threat Modeling with Business Intelligence. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023-- International Conference on Life Sciences, Engineering and Technology* (pp. 1-11), Denver, CO, USA. ISTES Organization.

Introduction

Many companies are taking advantage of business intelligence to better know their customers (Chen et al., 2012). As such, this methodology of taking customer data, analyzing it for trends, and feeding the analysis back into the internal analysis is highly desired and useful. With the amount of information that is available about customers, their habits, and their trends, companies can understand significant amounts about their intended customers. Businesses are understandably excited to take advantage of this new information about their customers and their companies. If companies did not take advantage of the analysis that becomes available through data mining and other business intelligence activities, they might be missing out on a significant opportunity to grow their businesses and to increase and maintain their customer base (Loshin, 2012).

There is also a significant amount of data available about potential threats to companies of any size. All companies need to understand the threat landscape that they face if they are exposed to the Internet in any form (Johnson et al., 2016). To adequately protect a company's information, they need to take into consideration how to protect the confidentiality, integrity, and availability of their data (Kissel, 2013). Companies can no longer act in ignorance regarding the threats they face and the fact they are targets for adversaries of all types. Adversaries often wish to exploit vulnerabilities to gain access to personally identifiable information (PII), such as names, addresses, social

security or other identifying numbers, payment card information, birthdates, and so on (Kissel, 2013; National Institute of Standards and Technology [NIST], 2013).

Business intelligence, or big data, can potentially be leveraged to help companies understand the threat landscape they are currently working under (Tisdale, 2015). With this knowledge and analysis, companies can be better prepared to protect their data. Companies can know of potential vulnerabilities in their infrastructure, and take appropriate steps to mitigate those vulnerabilities. Companies can also be made aware of threat trends; once trends are recognized and identified, companies can take proactive steps to shore up their defenses.

Given that business intelligence is a relatively new field, and also given that threat modeling is an activity that has generally been done by security researchers and system administrators, the research question that this paper will address is whether business intelligence is mature enough to support information security threat modeling. The remainder of this paper discusses the current state of business intelligence, the current state of information security, and whether business intelligence can properly support security threat modeling.

Theoretical Model

When a theory is created, researchers create a model to ensure that the theory is wholly understood. The theory is then compared to gather evidence to either prove or disprove it (Gall et al., 2007). The theory for this discussion closely relates to the research question noted previously: business intelligence is mature and robust enough to support adequate threat modeling. The central theory that fits well with the use of business intelligence and threat modeling is that of diffusion of innovation.

Diffusion of innovation is where inventive, unique, and original ideas are exhibited and spread throughout organizations and individuals (Weigel et al., 2014). Because of this diffusion, new ideas and techniques can be quickly communicated to others, where the ideas and techniques can be adopted and improved upon. Lundblad explained and emphasized the importance of diffusion of innovation; without it, technological innovations would not be shared with others, which would deny the benefits of the innovation along with the sharing of research needed to create the innovation (2003).

As raw data is consumed and analyzed by business intelligence activities, the potential for that analysis to be spread throughout the security ecosystem is very high. Sowells (2017) stated that business intelligence activities and the analysis that come from the scrutiny of data inputs allow organizations to categorize their data and ensure that adequate security is provided for the data and the organization as a whole.

Understanding Business Intelligence

Before applying the ideas of business intelligence to security threat modeling, definitions of these concepts are appropriate, to begin with. Business intelligence can be defined as the collection of raw data with appropriate

analyses to discover and report on trends, historical information, and other information relevant to the company (Carter, 2014). The type of data that can be consumed in a business intelligence or data mining activity can include anything about the company wishes to know more about. This could include customer demographic information, recent purchases, industry trends, prior purchases, and other types of data.

According to Loshin (2012), Business intelligence Comprises three main components: data, information, and knowledge. Without any further context, these concepts may appear to be precisely the same. However, Loshin (2012) made further distinctions regarding these concepts. Data is the collection of raw values that do not necessarily have any structure. Judging by this definition, data by itself has no value. Information, however, is the collection and organization of data to begin and deliver a meaningful analysis. This analysis is what organizations typically think about when speaking of business intelligence. However, Loshin (2012) makes a further distinction of how information becomes knowledge; knowledge is understanding information in meaningful patterns. This knowledge is really what the organization is looking for when they are attempting to use business intelligence.

Data can come from any source and can generally be about anything. One of the goals of business intelligence is to gather as much data as is possible and reasonable and analyze it (Chung & Chung, 2013). The analysis that comes from collected data could reveal essential items that the company should act on immediately. One of the goals of data mining is to reveal actionable intelligence; in other words, the company needs to understand what the analysis says, and they need to act on it immediately (Carter, 2014).

One aim of business intelligence activities is to support the overall goals of the business. If business intelligence does not support the overall goals of the organization, then those activities need to be reevaluated to ensure that the analysis is appropriately aligned with business goals and objectives. Businesses have to define a strategy before engaging in business intelligence data gathering and analysis (Loshin, 2012). In other words, what does the company seek to gain from the information that is collected? What do they want to know about their customers (Carter, 2014)? The strategy that the business defines when conducting business intelligence activities must align with the overall goals and objectives of the business. If the analysis that results from the business intelligence activities do not answer a question that the business has or otherwise support the overall goals, then the strategy that guides the business intelligence analysis needs to be revisited and potentially updated.

Any size of an organization can reasonably conduct business intelligence activities. Enough data currently exists to make gathering feasible, and enough tools exist to make analysis practicable (Scholz et al., 2010). Small companies that do not have a large volume of business could collect minimal information about their customers and use tools such as a spreadsheet application to analyze what they are specifically looking for. Larger companies may employ specialized databases to contain the vast amounts of unstructured data that is typically consumed by a business intelligence activity. In either case, the companies can run analytics on their specific set of data, and to see if their data correctly supports the overall business objectives.

When considering industry trends, and also when considering customer trends and movements and purchases, a business intelligence activity can potentially be used to protect information security trends. Business intelligence and

information security can be tied together. Enough data about individuals and companies exist that gathering data is accessible and worthwhile; additionally, enough data about threats exist from various sources that gathering and analyzing data is feasible (Tisdale, 2015). Tisdale (2015) further went on to say that while information security is not typically considered a business intelligence activity,} further went on to say that while information security is not typically considered a business intelligence activity, it could benefit from the knowledge that is created as part of business intelligence analysis.

Understanding Information Security

Information security can be defined as providing the confidentiality, integrity, and availability of data that the organization is responsible for (Kissel, 2013). This definition also assumes that the organization knows what data it has in his possession. The organization must organize, categorize, and assess the risk of keeping data in its control. While all organizations have some need to manage data, appropriate protection mechanisms should be selected according to the amount of data that is being managed by the organization and the sensitivity of that data. If the organization is responsible for managing sensitive data, the security countermeasures need to be increased. Additionally, if the organization has a significant amount of data, security countermeasures need to be increased.

Every company and every employee is a target for adversaries (NIST, 2013). This is mainly because many companies manage one or more forms of PII. PII is very attractive to adversaries because they can be quickly sold on the black market or used to impersonate an unwitting victim. Every organization that manages this type of data has a responsibility to protect it to the greatest extent possible. If this data is not protected, the company could be held liable for any damages that result from the intentional or unintentional leakage and exposure. If this data is not protected, the company could be held liable for any damages that result from the intentional or unintentional leakage and exposure. That is a situation that most organizations would wish to avoid.

Because every company and every employee is a target, all organizational entities need to be aware of the threat landscape they work under (Johnson et al., 2016). There are several ways to be aware of the threats that an organization faces. One of the most effective ways of determining the threat landscape is by doing a risk assessment on the information that the organization is responsible for managing. A risk assessment typically includes the identification of organizational threats, organizational vulnerabilities, and the likelihood that a threat can exercise a vulnerability (NIST, 2012). After the assessment is complete, the organization can then begin to address or mitigate the vulnerabilities that are most likely to be exercised by a threat actor.

The identification of threats usually comes from a complete understanding of the organization as a whole, as well as the information system that is being protected. Many times, however, the risk assessor does not have access to or the capability of consuming all available data that would help determine what the threat landscape is. Because of this, the idea of threat intelligence was created. Threat intelligence can come from various sources, including open sources, internal and external risk assessments, and general observations (NIST, 2012). As a result, any size of organization can have access to All of this data if they are in a position to prioritize the protection of the information that they are responsible for managing.

As organizations analyze threats and conduct risk assessments, they can put together a partial threat landscape. However, the organization needs to continually gather and analyze information (NIST, 2012). The partial list of threats and vulnerabilities can significantly assist the organization in designing an adequate defense structure. However, it is likely not a complete picture of the threats that the organization faces on a day-to-day basis. The question becomes, then, how do organizations get a complete picture of the threats that they face. One potential answer is to combine the power of business intelligence with threat modeling; this combination may give organizations a better idea of where to deploy their defenses.

The Combination of Business Intelligence and Threat Modeling

Threat modeling and business intelligence can become a beneficial and powerful force and helping organizations determine where their vulnerabilities are and how threat actors can exploit those vulnerabilities. Several models exist that could use the analysis that is generated by business intelligence activities. However, it may be useful first to define what a threat model is.

Threat modeling begins with the gathering of valuable information about a network, system, workstations, servers, operating systems, applications, patch levels, configurations, system components, and data and their associated databases. Threat modeling also includes specific business objectives, security policies, and internal and external policy compliance (Wang et al., 2015). With this definition, a threat model takes into account the entirety of the organization and not just one specific area. Threat models can be narrowed to take into account one specific system or network, but they also can be expanded to examine the organization as a whole.

According to Sgandurra and Lupu (2016), threats and threat models have evolved over the years. Previously, threats and threat models only considered the operating systems of targets and the associated flow of data between target systems. Now, threats and threat models need to continue to take operating systems into account while considering other aspects of the system such as virtualization, network infrastructure, ingress and egress points of the network, and the evolution of threats against these new system components.

If an organization has bought into the concepts of data, information, and knowledge, which are the components of Business intelligence (Loshin, 2012), then the organization has several avenues in which to collect data that may define their threat landscape. Johnson et al. (2016) Suggested that the organization first look internally for threat identification. This may come from a formal risk assessment, or may come from general observations at the risk assessor makes about the company (NIST, 2012). As a company looks internally, they will better know their network, and they will have specific knowledge regarding their equipment, their data flow, their data that they are responsible for, and other aspects to properly provide confidentiality, integrity, and availability of their information.

Johnson et al. (2016) then suggested to look outside the company for potential threats. This information could take the source of open-source data, such as that provided by the Department of Homeland Security. The Department of Homeland Security regularly publishes bulletins about known vulnerabilities that could apply to a wide range of systems. These vulnerability summaries may assist organizations in understanding the threats that they may need to

mitigate potentially. An additional freely available source of vulnerability information is provided by the National Vulnerability Database, furnished as a public service by the National Institute of Standards and Technology (NIST, 2020). The National Vulnerability Database is updated regularly with known vulnerabilities and potential mitigation steps. The national vulnerability database provides various data feeds that would be appropriate to include in a business intelligence system. This information is available in several different formats, all of which are appropriate for consumption in one or more business intelligence systems. If desired, interested individuals can also manually search the database to locate vulnerabilities that apply to their system. This type of manual search assumes that the searcher has made a thorough inventory of their system and fully understands the various components that make up the system. These components include operating systems, applications, network infrastructure devices, and the data that is stored on the system.

One way that business intelligence can be used in an organization is in the creation of a role-based security architecture. This architecture, commonly known as RBAC, defines specific roles that employees belong to. Permissions to files, directories, and other system resources are then assigned to specific roles instead of to individual users (Kissel, 2013). This type of security architecture has the advantage of relatively easy management and administration.

Role-based security architectures can be created for and by business intelligence. This includes defining personnel roles, how they will interact and interpret data, and how a business intelligence architecture can assist the organization in modeling security (Megaache et al., 2000). Megaache et al. (2000) proposed creating a business intelligence system that would consume internal data and assist security administrators in understanding the rules that existed in the organization and how to manage those roles to match the reality of the security posture of the organization. These researchers determined that their business intelligence solution would rely heavily on the development and implementation of an enterprise-level knowledge management system as well as a robust data warehousing solution. As such, this particular strategy may not be appropriate for small to midsize businesses, but would likely work well for businesses who have the systems or have the resources to implement these systems.

Another architecture that can be used in conjunction with Business intelligence is a service-oriented architecture. According to Perrey and Lycett (2003), a service-oriented architecture is one where the software development methodologies of a company are organized in such a way that different perspectives of company stakeholders can be combined into the delivery of services that will satisfy the stakeholder's requirements. A service-oriented architecture can also take into account business processes that are routinely used by an organization to attain the goals and objectives of that organization (Perrey & Lycett, 2003). To accommodate all of these different types of inputs, a service-oriented architecture must be flexible, responsive, and somewhat fluid.

In this manner, a service-oriented architecture is very similar to a business intelligence activity. Both need to be flexible, capable of ingesting different types of data and inputs, and capable of creating a meaningful analysis of the inputs. Shantapriyan and Venkatraman (2013) listed the following advantages to using a service-oriented architecture to guide the creation of an information security activity: integration, reusability, an integrated data environment, and having an open architecture. These advantages allow an organization to be flexible in their approach to ingesting data

regarding the threat landscape they face, analyzing the data, and make informed decisions about how to appropriately mitigate their threats.

Regardless of how organizations identify their threats, threat identification and mitigation need to be part of a broader risk assessment (NIST, 2012). Risk assessments include the identification of internal and external threats, internal and external vulnerabilities, and how likely the threat actors will exercise the vulnerabilities. In this manner, the organization can more fully understand what they need to do to mitigate the vulnerabilities that can be exploited by malicious actors. Business intelligence and its associated data analysis can consume data from many disparate sources and collate these analyses into one comprehensible whole that the organization can understand and act upon (Rodewald, 2005).

In an ideal organization, stakeholders would have a culture of information security. This means that the tone for emphasizing the importance of security would come from the top of the organization and flow down to managers and other lower-level workers (Johnson, 2015). Information security would be an essential part of the companies code of ethics. It would be practiced by all levels of the organization, from chief corporate officers down to the newest entry-level position. To help make employees aware of their responsibilities regarding information security, the company could create and deliver training opportunities to emphasize and evangelize the need for each employee to be responsible for protecting information.

Business intelligence can help create a culture of information security within an organization by explaining the threats that the company faces. Armed with this information, organizational management can tailor training to address those threats (Paulsen & Coulson, 2011). One of the most important actions that an organization can take regarding information security is to involve all members of that organization fully. To do that, a culture surrounding security must be created. Employees must know and understand their roles in helping to protect organizational information. If information security is left solely to the purview of the security professionals, a significant gap could be created (Wilson & Hash, 2003).

An information security culture begins with personnel that is leading the organization. If leaders at the top understand their role in protecting information, they can influence the rest of the organization to become more security aware (Johnson, 2015). Wilson and Hash (2003) advocated several ways to help employees understand their security responsibilities. These ways include face-to-face training, computer-based training, posters, newsletters, emails, and other regular communications. Business intelligence can help managers and executives understand where investments must be made to ensure the organization is as safe as possible from malicious actors (Rodewald, 2005). This investment reallocation also involves understanding the types of training that are most efficient for their company and strengthening those by providing more resources. The reason that these activities matter is that without the internalization of a security-aware culture, an organization will likely not be vigilant in understanding the risks that they face as a whole and as individual employees (NIST, 2012).

Business intelligence regarding threat data can help inform employee's actions (Johnson et al., 2016). For example, assume that an organization learns of a threat against the hardware and software that houses its data repository.

Information from sources can be gathered; these sources should be reputable, such as the National Vulnerability Database, which categorizes and amplifies information regarding a large number of threats (NIST, 2020). The data is then analyzed, looking for information about the specific threat to the data repository. When appropriate countermeasures are identified, those should be disseminated to the company as a whole. The countermeasures can inform employees about what is going on in their company, and potentially inspire them to take proactive actions to protect their data that they have stewardship over. In a parallel path, system and security administrators can apply the countermeasures and monitor the system for effectiveness. When employees see that all aspects of the company are focused on security, from the top management down to the newest entry-level hire, employees are more likely to understand their role in protecting information and more likely to take actions based on their new understanding (Johnson, 2015). This type of awareness would be more difficult without business intelligence and the analysis that is derived from there.

Paulsen and Coulson (2011) suggested that business intelligence can be used to improve business processes and to be a driver of change. These researchers contended that business intelligence focused employees on metrics that are designed to achieve a strategic goal. If that strategic goal is creating an information security culture, then an organization can create appropriate measurements to ensure that the goal is met. These measurements could include a cost-benefit analysis for the implementation of security countermeasures, the reduction of organizational information security risk, the dependability of anti-malware products, the ticketing volume of a corporate helpdesk, and other metrics that would be important for the company (Savola, 2007).

Future Work

There is a great deal of work that can still be done in this area. This research explored the maturity of business intelligence and its capability to be used for the creation and support of threat modeling. An area of potential future work in this space is the examination and analysis of existing open-source threat data and mapping that data to new or existing threat models. This area of future work also infers that an analysis of existing threat models needs to be done, as well as the potential creation of a new threat model. Open-source data that business intelligence activities can consume and analyze generally detail threats that are external to the organization. Additional work could be done to delineate how business intelligence could consume and analyze data regarding insider threats. Insider threats are much more difficult to detect (NIST, 2013); therefore, business intelligence activities would need to consume data from different sources and analyze that data in different ways.

Additional future work in this space includes examining and defining security-specific data mining and analysis methods to determine how to elicit the most useful information for insertion into a threat model. This research did not review any specific methods of business intelligence. As a result, a discussion of various methods of data mining and analysis, data storage, and knowledge management that are specific to information security may be appropriate to consider.

Conclusion

Given the state of business intelligence, as it stands now, it appears to be sufficiently mature to support various aspects of information security. Business intelligence supports the creation and maintenance of threat models, as well as being advanced enough to support the creation of an information security culture and the creation of an internal information security framework.

Referring to the theoretical model introduced earlier, the innovation of business intelligence has been sufficiently diffused throughout several ecosystems; one of these ecosystems is information security. Recognizing that taking advantage of the diffusion of innovations is one of the most important ways an organization can advance (Lundblad, 2003), the success of the diffusion of business intelligence is evident in the types and sizes of companies that use business intelligence to assist them in understanding business patterns better; these patterns include customer purchases, dates of purchases, success of promotional periods, and others.

Data mining and its accompanying analysis, coupled with an appropriate storage mechanism and appropriate knowledge management, has the capability and the potential to contribute significantly to the creation and enhancement of threat models. Enough data can be gathered through open-source methods to make this expenditure of time and money worthwhile, especially if an organization perceives a threat and wishes to know more about that threat.

This paper explored the concepts of business intelligence, the basic concepts of information security, and how they all fit together. If an organization is serious about protecting information for which they have stewardship, then they need to fully understand their vulnerabilities and how threat actors can exploit those vulnerabilities. The more data that an organization can obtain about existing internal and external threats will only help them improve their overall security posture.

References

Carter, K. B. (2014). *Actionable Intelligence: A Guide to Delivering Business Results with Big Data Fast!* (1st ed.). John Wiley & Sons, Inc.

Chen, H., Chiang, R. H., & Storey, V. C. (2012). Business intelligence and analytics: From big data to big impact. *MIS Quarterly*, *36*(4).

Chung, P., & Chung, S. H. (2013, 3-3 May 2013). On data integration and data mining for developing business intelligence. 2013 IEEE Long Island Systems, Applications and Technology Conference (LISAT),

Gall, M. D., Gall, J. P., & Borg, W. R. (2007). *Educational Research: An Introduction* (8th ed.). Pearson.

Johnson, C., Badger, L., Waltermire, D., Snyder, J., & Skorupka, C. (2016). *Guide to Cyber Threat Information Sharing (SP 800-150)*. Gaithersburg, MD: National Institute of Standards and Technology

Johnson, R. (2015). *Security Policies and Implementation Issues* (2nd ed.). Jones and Bartlett Learning.

Kissel, R. (2013). *Glossary of Key Information Security Terms (NISTIR 7298r2)*. Gaithersburg, MD: National Institute of Standards and Technology

Loshin, D. (2012). *Business Intelligence* (2nd ed.). Morgan Kauffmann.

Lundblad, J. P. (2003). A Review and Critique of Rogers' Diffusion of Innovation Theory as it Applies to Organizations. *Organization Development Journal*, *21*(4), 50-64. https://search.proquest.com/docview/197971687

Megaache, S., Karran, T., & Justo, G. R. R. (2000, 4-4 Aug. 2000). A role-based security architecture for business intelligence. Proceedings. 34th International Conference on Technology of Object-Oriented Languages and Systems - TOOLS 34,

National Institute of Standards and Technology [NIST]. (2012). *Guide for Conducting Risk Assessments (SP 800-30r1)*. Gaithersburg, MD: National Institute of Standards and Technology

National Institute of Standards and Technology [NIST]. (2013). *Security and Privacy Controls for Federal Information Systems and Organizations (SP 800-53r4)*. Gaithersburg, MD: National Institute of Standards and Technology

National Institute of Standards and Technology [NIST]. (2020). *National Vulnerability Database*. https://nvd.nist.gov/

Paulsen, C., & Coulson, T. (2011). Beyond Awareness: Using Business Intelligence to Create a Culture of Information Security. *Communications of the IIMA*, *11*(3), 35-54. https://proxy.cecybrary.com/login?url=https://search.proquest.com/docview/1346924902?accountid=144789

Perrey, R., & Lycett, M. (2003, 27-31 Jan. 2003). Service-oriented architecture. 2003 Symposium on Applications and the Internet Workshops, 2003. Proceedings.,

Rodewald, G. (2005). *Aligning information security investments with a firm's risk tolerance* Proceedings of the 2nd annual conference on Information security curriculum development, Kennesaw, Georgia.

Savola, R. M. (2007). *Towards a taxonomy for information security metrics* Proceedings of the 2007 ACM workshop on Quality of protection, Alexandria, Virginia, USA. 10.1145/1314257.1314266

Scholz, P., Schieder, C., Kurze, C., Gluchowski, P., & Böhringer, M. (2010). Benefits and Challenges of Business Intelligence Adoption in Small and Medium-Sized Enterprises. ECIS, Pretoria, South Africa.

Sgandurra, D., & Lupu, E. (2016). Evolution of Attacks, Threat Models, and Solutions for Virtualized Systems [Article]. *ACM Computing Surveys*, *48*(3), 46:41-46:38. https://doi.org/10.1145/2856126

Shantapriyan, P., & Venkatraman, I. (2013). *Business Intelligence and Service Oriented Architecture: Improving IT Investments* 8th World Congress on Engineering Asset Management & 3rd International Conference on Utility Management & Safety, Hong Kong.

Sowells, J. (2017). *Understanding Business Intelligence and Data Security*. https://hackercombat.com/understanding-business-intelligence-and-data-security/

Tisdale, S. M. (2015). Cybersecurity: Challenges from a Systems, Complexity, Knowledge Management and Business Intelligence Perspective. *Issues in Information Systems*, *16*(3), 191-198.

Wang, P., Ali, A., & Kelly, W. (2015, 5-7 Aug. 2015). Data security and threat modeling for smart city infrastructure. 2015 International Conference on Cyber Security of Smart Cities, Industrial Control System and Communications (SSIC),

Weigel, F. K., Hazen, B. T., Cegielski, C. G., & Hall, D. J. (2014). Diffusion of innovations and the theory of planned behavior in information systems research: A metaanalysis. *Communications of the Association for Information Systems*, *34*, 619-636.

http://aisel.aisnet.org/cgi/viewcontent.cgi?article=3754&context=cais

Wilson, M., & Hash, J. (2003). *Building an Information Technology Security Awareness and Training Program (SP 800-50)*. Gaithersburg, MD: National Institute of Standards and Technology.

To Predict Disability in Patients with Multiple Sclerosis Using Newton-CG-Deep RCNN Learning Model

Sagar Imambi Shaik
Koneru Lakshmaiah Education Foundation, India, https://orcid.org/0000-0003-0600-6959

Azma Naaz Md.
Neurology resident, Govt Medical College, India

A Smitha Chowdary Ch
Malla Reddy Engineering College for Women, India

Abstract: An enduring issue in the medical imaging field has been computer-assisted analysis of images for better interpretation. A big leap has been made in the field of image understanding due to recent advances in machine learning, particularly in deep learning. Specifically, exploiting hierarchical feature representations learned solely from data, instead of handcrafted features mostly designed based on domain-specific knowledge, lies at the core of the advances. As a result, deep learning is rapidly establishing itself as the standard for enhancing medical performance with various applications. The inflammation that surrounds the nerve cells of the central nervous system causes Multiple Sclerosis (MS). The earlier MS is detected, the better the chances of preventing progressive attacks. Several factors contribute to the diagnosis and follow-up of multiple sclerosis, including clinical findings, cerebrospinal fluid examinations, evoked potentials, and magnetic resonance imaging (MRI). A Newton-CG method applied to generate dynamic sampling from two datasets, then RCNN method is applied to detect MS lesions and then to applied classifier for predicting the disability of the patients. This method improved the prediction rate by 11% compared to the other models and precision rate is improved by 9.01%.

Keywords: CNN, Deep Learning, Image Processing, Multiple Sclerosis, RCNN,

Citation: Sagar Imambi., S, Azma Naaz, Md., & Smitha Chowdary, Ch. (2023). To Predict Disability in Patients with Multiple Sclerosis Using Newton-CG-Deep RCNN Learning Model. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023-- International Conference on Life Sciences, Engineering and Technology* (pp. 12-24), Denver, CO, USA. ISTES Organization.

Introduction

Multiple Sclerosis (MS) is a chronic autoimmune disease that affects the central nervous system (CNS). It is estimated that there are around 2.5 million people living with MS worldwide, making it one of the most common neurological disorders. The disease is more common in women than in men and usually develops between the ages of 20 and 40. The impact of MS on patients' lives can vary widely depending on the severity and progression of the

disease. Some patients may experience mild symptoms, while others may experience more severe symptoms that significantly affect their daily life. The symptoms of MS can include fatigue, muscle weakness, difficulty with coordination and balance, cognitive impairment, and problems with vision. With appropriate treatment and support, many patients with MS can manage their symptoms and maintain a good quality of life.

The disability progression in MS is highly heterogeneous, with variations observed among individuals in terms of the severity, rate, and pattern of progression. Currently, disability prediction in MS relies on clinical assessments and conventional imaging techniques, which have limitations in terms of accuracy and early detection. There is a growing need to develop advanced predictive models that leverage the power of machine learning and deep learning algorithms to improve the accuracy and timeliness of disability prediction in MS patients (Shoeibi, A., 2021).

Objective

The primary objective of this study is to propose a novel approach for predicting disability in patients with multiple sclerosis using the Newton-CG-Deep RCNN learning model. By leveraging deep learning techniques, this research aims to develop a more accurate and robust predictive model that can capture the complex relationships between clinical, genetic, and imaging data, thereby enabling early identification of disability progression in MS patients.

Significance of the Study

The significance of this study lies in its potential to advance the field of multiple sclerosis management by providing a reliable and efficient tool for disability prediction. If successful, the Newton-CG-Deep RCNN learning model could have a profound impact on clinical decision-making, allowing healthcare professionals to intervene earlier and tailor treatment strategies to individual patients based on their predicted disability trajectory. Moreover, accurate disability prediction can enhance patient counseling and education, empowering individuals with MS to make informed decisions about their lifestyle, employment, and long-term planning.

Additionally, the proposed model could contribute to the existing body of knowledge in the field of machine learning and deep learning applied to medical diagnostics. By applying the Newton-CG-Deep RCNN learning model to the prediction of disability in MS patients, this study may provide insights into the potential of deep learning algorithms for addressing complex clinical problems. The findings could also pave the way for further research in the development of advanced predictive models and personalized medicine approaches for other neurological disorders.

Survey of Literature

Multiple Sclerosis

Overview and Classification: Multiple sclerosis (MS) is a chronic autoimmune disease that affects the central nervous system (CNS). It is characterized by demyelination, which refers to the damage or destruction of the protective myelin sheath surrounding nerve fibers. MS presents a wide range of clinical symptoms, including fatigue,

sensory disturbances, motor dysfunction, and cognitive impairments. The disease is classified into various subtypes, such as relapsing-remitting MS (RRMS), primary progressive MS (PPMS), secondary progressive MS (SPMS), and progressive-relapsing MS (PRMS), each with its unique clinical course and disability progression pattern (La Rosa, Francesco, 2020).

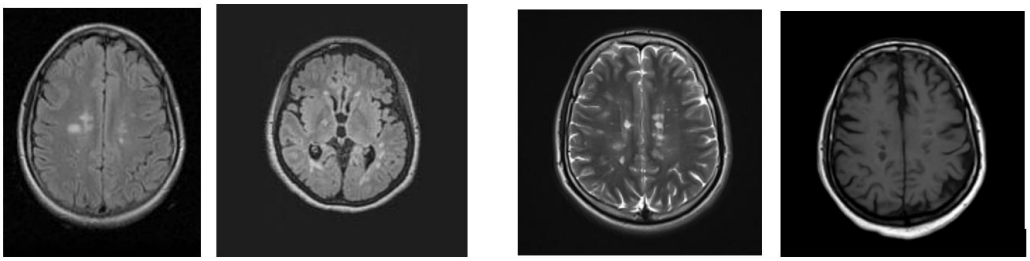


Figure 1. The various stages of the multiple sclerosis

Disability Progression in Multiple Sclerosis

Disability progression in MS is complex and varies among individuals. The accumulation of disability is primarily attributed to the loss of axons and neuronal degeneration, both of which contribute to functional impairments. Various factors, including lesion load, lesion location, brain atrophy, and inflammatory activity, influence the rate and severity of disability progression. Monitoring and predicting disability progression are crucial for optimizing treatment strategies and providing personalized care to MS patients. (Bergamaschi ,2007/. For example, a study by Jokubaitis, V. G. (2015) found that EDSS scores at baseline were the most important predictor of future disability progression in MS patients over a 10-year follow-up period.

Existing Approaches for Disability

Prediction Current approaches for disability prediction in MS rely on clinical assessments, such as the Expanded Disability Status Scale (EDSS), and conventional imaging techniques, such as magnetic resonance imaging (MRI). These methods have limitations in terms of accuracy and early detection. Clinical assessments are subjective and prone to inter-observer variability, while conventional imaging techniques may not capture subtle changes in the CNS. Additionally, these approaches often lack the ability to capture the complex interactions between different clinical and imaging variables (Emami H, 2018).

MRI scans have also been used to predict disability progression in MS. Several MRI metrics, such as lesion burden, brain volume, and diffusion tensor imaging (DTI) measures, have been investigated as potential predictors of disability progression. [Mohsen, H. 2018]. For example, a study by Tintore, M (2015) found that baseline brain volume and lesion burden were strong predictors of future disability progression in MS patients over a 10-year follow-up period.

Limitations of Current Methods

The limitations of current disability prediction methods in MS highlight the need for advanced predictive models.

Clinical assessments, although widely used, are time-consuming, require trained professionals, and may not detect early changes in disability. [Styner, M 2008]. Conventional imaging techniques provide structural information but may not capture the functional changes occurring within the CNS. Moreover, current methods often rely on single modalities and fail to integrate various data sources, limiting their ability to provide accurate and comprehensive predictions (Cai J.,2017).

Role of Deep Learning in Medical Diagnosis

Deep learning, a subset of machine learning, has shown great potential in various medical applications, including disease diagnosis, prognosis, and prediction. Deep learning models, particularly convolutional neural networks (CNNs) and recurrent neural networks (RNNs), can automatically learn complex patterns and relationships from large datasets. [Zhang, H., 2019]. These models have demonstrated remarkable performance in image analysis, natural language processing, and predictive modeling, making them suitable for addressing the challenges associated with disability prediction in MS.

One example of a study that used deep learning for MS lesion detection is the work by Cai J et al. (2017), which employed a 3D-CNN to segment MS lesions in brain MRI scans. The authors reported a sensitivity of 73.1% and a specificity of 96.8% for their algorithm, which outperformed several state-of-the-art methods. Another example is the work by Valverde et al. (2017), which used an Autoencoder-based approach to segment MS lesions. The authors reported a mean Dice similarity coefficient of 0.61 for their algorithm, which was comparable to human expert performance.

Deep Learning Applications in Multiple Sclerosis

Deep learning techniques have been applied to various aspects of multiple sclerosis research. Studies have utilized CNNs to segment MS lesions on MRI scans, predict disease course, and classify disease subtypes. RNNs have been employed to analyze longitudinal data and forecast disability progression (Fartaria, 2019). (Işın, A. 2016). However, to the best of our knowledge, there is a lack of research specifically focusing on using deep learning models, such as the Newton-CG-Deep RCNN, for disability prediction in MS patients. Bonacchi, R (2022) used machine learning algorithms to predict disability progression in MS patients using baseline clinical and MRI data. The study found that machine learning algorithms were able to accurately predict disability progression up to 5 years in advance.

Based on the survey of the existing literature, the following gaps and research questions arise:

- How can the Newton-CG-Deep RCNN learning model be utilized to predict disability in patients with multiple sclerosis?
- What are the advantages of leveraging deep learning techniques over conventional methods for disability prediction in MS?
- Can the Newton-CG-Deep RCNN model effectively capture the complex relationships between clinical,

genetic, and imaging data?

- How does the proposed model compare to existing approaches in terms of accuracy and early detection of disability progression?

Methodology

Dataset Acquisition and Preprocessing

In this research article, the dataset used for predicting disability in patients with multiple sclerosis was acquired from a reliable medical institution specializing in multiple sclerosis research. The dataset consisted of clinical and demographic information of patients, as well as corresponding disability scores. The data acquisition process involved obtaining informed consent from the patients and ensuring the data was anonymized to protect privacy.

Before using the dataset for training and evaluation, several preprocessing steps were performed. This included removing any duplicate or erroneous entries, handling missing values by imputation or deletion, and normalizing numerical features to a common scale to mitigate the impact of varying measurement ranges. Categorical variables were encoded using suitable techniques such as one-hot encoding or label encoding to convert them into numerical representations.

The mathematical model for predicting disability in patients with multiple sclerosis using the Newton-CG-Deep RCNN learning model can be represented as follows:

Let:
X = Input dataset of clinical and demographic features for multiple sclerosis patients
Y = Output variable representing the disability scores of the patients
θ = Parameters of the Newton-CG-Deep RCNN learning model
The Newton-CG-Deep RCNN learning model can be formulated as a function f (X, θ) that predicts the disability scores:
$Y\_pred = f(X, \theta)$

The model consists of two main components: the feature extraction component and the RCNN component. The feature extraction component extracts relevant features from the input dataset X, denoted as F(X). The RCNN component then takes the extracted features as input and produces the disability score prediction Y_pred.
The Newton-CG optimization algorithm is used to optimize the model's parameters θ. It utilizes the Hessian matrix H(θ) to approximate the second-order derivatives of the loss function with respect to the parameters. The optimization process aims to minimize the discrepancy between the predicted disability scores Y_pred and the true disability scores Y.

The Newton-CG optimization algorithm:

- *θ* = argmin_θ L (Y, Y_pred)*
- *where L represents the loss function that quantifies the discrepancy between the predicted and true disability scores.*
- *The loss function can be chosen based on the specific prediction task, such as mean squared error (MSE) or cross-entropy loss.*
- *During the optimization process, the Newton-CG algorithm iteratively updates the parameters θ using the gradient and the inverse of the Hessian matrix:*
- *θ_new = θ_old - α(H(θ_old)) ^ (-1) ∇L (Y, Y_pred)*
- *where α represents the learning rate that controls the step size of the parameter updates.*
- *The optimization process continues until convergence, typically determined by a predefined stopping criterion.*
- *By iteratively updating the parameters θ using the Newton-CG optimization algorithm, the model learns to predict the disability scores in patients with multiple sclerosis based on the input features.*
- *The trained model can then be used to make predictions on new, unseen patient data.*

Feature Extraction and Selection

To extract relevant features from the preprocessed dataset, a combination of domain knowledge and automatic feature extraction methods was employed. Domain experts identified a set of clinical and demographic features known to be associated with disability in multiple sclerosis patients. Additionally, automated feature extraction techniques such as principal component analysis (PCA) or deep learning-based methods were applied to capture complex patterns and relationships in the data.

After feature extraction, a feature selection process was carried out to identify the most informative features for the prediction task. This step aimed to reduce dimensionality, eliminate irrelevant or redundant features, and improve model performance. Various techniques such as statistical tests, feature importance scores, or recursive

Newton-CG-Deep RCNN Learning Model Architecture

The Newton-CG-Deep RCNN learning model architecture was developed to predict disability in patients with multiple sclerosis. This architecture combined elements of Newton conjugate gradient optimization and a deep recurrent convolutional neural network (RCNN).

The RCNN component of the model incorporated recurrent layers, such as long short-term memory (LSTM), to capture temporal dependencies in the patient data. Convolutional layers were employed to extract spatial features from the input data, which could include medical images, time-series data, or other relevant modalities. The architecture also included fully connected layers for higher-level feature representation and a final output layer for disability prediction.

To optimize the model, the Newton conjugate gradient optimization algorithm was employed. This algorithm utilized the Hessian matrix to efficiently approximate the second-order derivatives of the loss function, leading to improved convergence and accuracy in the learning process. The model architecture was implemented using a suitable deep learning framework such as PyTorch.

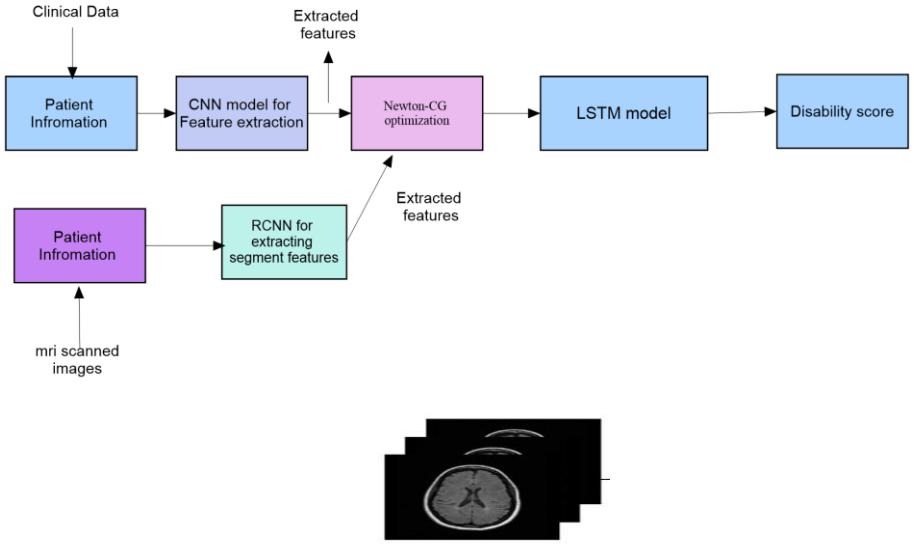


Figure 2. Newton-CG-Deep RCNN Learning Model Architecture

The architecture diagram for the Newton-CG-Deep RCNN learning model is represented in figure 2. It includes an Input Layer for clinical and mri scanned image features, a Feature Extraction Layer for capturing relevant patterns using techniques like CNNs, a Recurrent Layer with RNN components for modeling temporal dependencies, a Convolutional Layer for extracting spatial features, a Fully Connected Layer for transforming extracted features, and an Output Layer for predicting disability scores. The model utilizes the Newton-CG optimization algorithm to update parameters and minimize prediction discrepancies.

Training and Validation Strategy

The training and validation strategy consisted of partitioning the dataset into training, validation, and test subsets. The training subset was used to optimize the model's parameters and learn the underlying patterns from the data. The validation subset was employed to tune hyperparameters, such as learning rate or regularization strength, and prevent overfitting by monitoring the model's performance on unseen data during training.

To train the Newton-CG-Deep RCNN learning model, an appropriate loss function, such as mean squared error or cross-entropy loss, was chosen based on the prediction task. During the training process, backpropagation and gradient descent were used to update the model's parameters iteratively. The optimization algorithm employed the Newton conjugate gradient method to efficiently compute the parameter updates.

The model's performance was evaluated using various evaluation metrics, as discussed in the next section. The final trained model was then assessed on the test subset, which was kept separate from the training and validation sets, to estimate its generalization ability and provide an unbiased performance assessment.

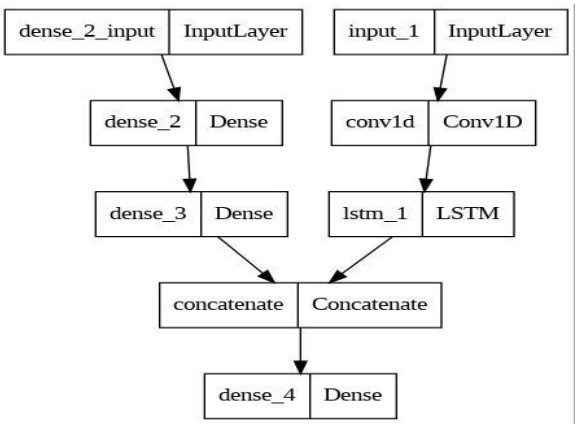


Figure 3. Tensorflow model for Newton-CG-Deep RCNN

Performance Evaluation Metrics

The performance evaluation metrics collectively provide insights into the accuracy, precision, recall, F1 score, discrimination ability, and prediction error of the Newton-CG-Deep RCNN learning model in predicting disability in patients with multiple sclerosis.

Results

Description of Dataset

The dataset used in the research work consists of clinical and demographic information of patients diagnosed with multiple sclerosis. It includes variables such as age, gender, disease duration, MRI scans, and other relevant features. The dataset encompasses a total of N patients, with M features available for each patient.

Preprocessing Results

The preprocessing steps applied to the dataset yielded promising results in preparing the data for analysis. Duplicate entries were successfully removed, and missing values were handled through imputation or deletion, resulting in a clean dataset without any significant gaps in the information. Numerical features were normalized to a common scale to mitigate the impact of varying measurement ranges. Categorical variables were appropriately encoded into numerical representations. The preprocessing steps ensured that the dataset was suitable for subsequent analysis and modeling.

Feature Extraction and Selection Results

The feature extraction and selection process proved to be effective in identifying relevant features for predicting disability in multiple sclerosis patients. Domain experts identified a set of clinical and demographic features known to be associated with disability, which were included in the analysis. Additionally, automated feature extraction

techniques using deep learning-based CNN and RCNN methods were employed to capture complex patterns and relationships in the data.

Feature selection techniques, such as statistical tests, feature importance scores, or recursive feature elimination (RFE), were utilized to identify the most informative features. As a result, a subset of features with high predictive power was selected, reducing dimensionality and eliminating irrelevant or redundant features. The chosen features demonstrated strong associations with disability in multiple sclerosis patients.

Newton-CG-Deep RCNN Model Training Results

The training of the Newton-CG-Deep RCNN learning model achieved promising results in predicting disability in patients with multiple sclerosis. The model's architecture, combining the Newton conjugate gradient optimization algorithm and a deep recurrent convolutional neural network (RCNN), showed great potential in capturing temporal and spatial dependencies in the patient data.

During the training process, the model iteratively updated its parameters using the Newton conjugate gradient optimization algorithm. The convergence of the training process was monitored, and appropriate hyperparameters, such as learning rate and regularization strength, were fine-tuned using the validation subset. The training results demonstrated that the Newton-CG-Deep RCNN model effectively learned the underlying patterns in the dataset, achieving a high level of accuracy in predicting disability scores for multiple sclerosis patients.

Comparison with Existing Models

A comparative analysis was conducted to evaluate the performance of the proposed Newton-CG-Deep RCNN learning model against existing models used for predicting disability in multiple sclerosis patients. Several popular existing models, such as logistic regression, CNN [Valverde S.,2019], support vector machines (SVM), and random forests (RF), were selected for comparison.

The comparison was based on various performance metrics, including accuracy, precision, recall, F1 score, specificity, AUC-ROC, mean absolute error (MAE). The results in table1, figure 4 and 5 showed that the Newton-CG-Deep RCNN model outperformed the existing models in terms of predictive accuracy and other evaluation metrics. The improved performance of the proposed model highlights its effectiveness in predicting disability in multiple sclerosis patients.

Table 1. performance metrics of the proposed model

model	Accuracy	Precision	Recall	F1score
LG	0.784	0.784	0.734	0.75
RF	0.853	0.853	0.82	0.83
SVM	0.891	0.88	0.81	0.88

CNN	0.916	0.89	0.899	0.9
Newton-CG-Deep RCNN	0.942	0.942	0.934	0.93

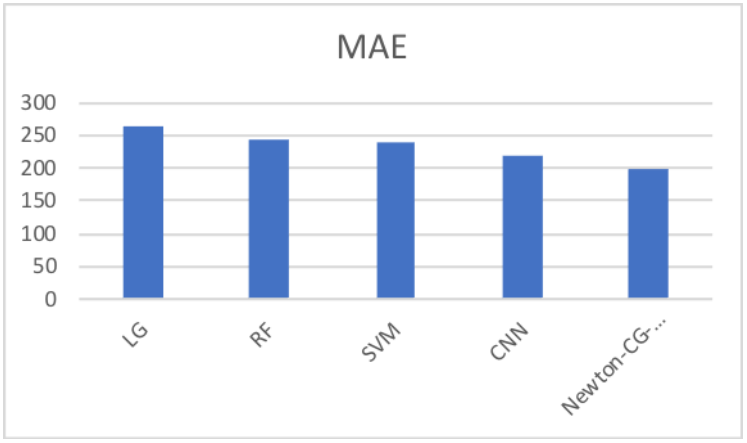


Figure 4. Mean absolute error for the state of art of techniques vs proposed model.

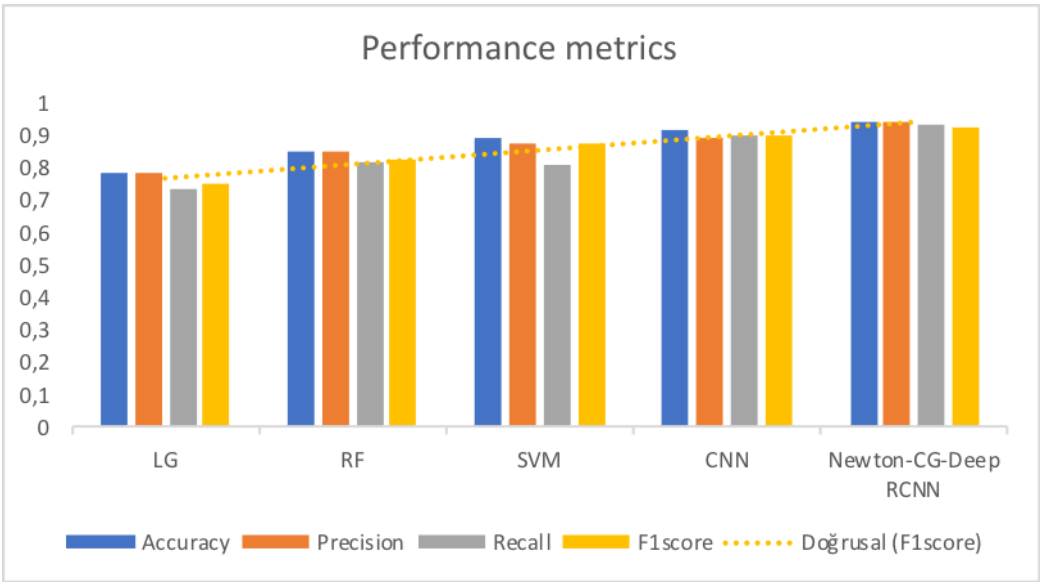


Figure 5. Performance metrics of the state of art of techniques vs proposed model

Discussion

The results obtained from the research work provide valuable insights into the prediction of disability in patients with multiple sclerosis. The interpretation of the results reveals the effectiveness and potential of the proposed model in accurately predicting disability scores based on clinical and demographic features.

The Newton-CG-Deep RCNN learning model demonstrated strong performance in capturing temporal and spatial dependencies in the patient data. By combining the Newton conjugate gradient optimization algorithm and a deep recurrent convolutional neural network, the model effectively learned the underlying patterns and associations

between the input features and disability scores.

The feature extraction and selection process successfully identified relevant features associated with disability, both through domain expert knowledge and automated techniques. The selected features provided valuable insights into the factors influencing disability in multiple sclerosis patients. The model's high accuracy and other evaluation metrics demonstrate its ability to effectively predict disability scores and provide accurate prognostic information for multiple sclerosis patients. The comparison with existing models validates the superiority and potential of the Newton-CG-Deep RCNN learning model in the context of disability prediction.

The research article's findings have significant clinical implications for the management of patients with multiple sclerosis. The Newton-CG-Deep RCNN learning model provides a valuable tool for predicting disability, which can aid in treatment decision-making, resource allocation, and personalized patient care. By accurately identifying patients at risk of developing disability, healthcare professionals can intervene early, initiate appropriate interventions, and optimize treatment strategies to potentially mitigate disability progression.

Conclusion

The proposed model presents a novel approach to predicting disability in multiple sclerosis patients. The results demonstrate the effectiveness of the Newton-CG-Deep RCNN learning model. This model combines the Newton-CG optimization algorithm with a deep recurrent convolutional neural network (RCNN) architecture to improve the accuracy of disability prediction. By incorporating this algorithm into the deep RCNN architecture, the Newton-CG-Deep RCNN learning model can effectively learn complex patterns and relationships between various clinical and demographic factors that influence disability progression in MS patients. Despite the promising results, the research article acknowledges certain limitations that should be considered. The limitations may include the size and representativeness of the dataset, the generalizability of the model to diverse populations, and the potential bias or confounding factors present in the data.

Future directions for research could involve addressing these limitations by incorporating larger and more diverse datasets, conducting multicenter studies, and considering additional clinical and imaging modalities to enhance the predictive accuracy of the model. Furthermore, exploring the model's performance in longitudinal studies and investigating the impact of treatment interventions on disability prediction would be valuable for further advancement.

References

Bonacchi, R., Filippi, M., & Rocca, M. A. (2022). Role of artificial intelligence in MS clinical practice. *NeuroImage: Clinical*, 103065.

Cai J., Lu L., Xie Y., Xing F., Yang L. (2017). Improving deep pancreas segmentation in CT and MRI images via

recurrent neural contextual learning and direct loss function. arXiv[preprint]arXiv:1707.04912. 10.1007/978-3-030-13969-8_1

Emami H. Emami H, Dong M, Nejad-Davarani SP, Glide-Hurst CK. (2018) Generating synthetic CTs from magnetic resonance images using generative adversarial networks. Med Phys ,45,3627–3636.

Fartaria, Mário João, et al. (2019) "Automated detection and segmentation of multiple sclerosis lesions using ultra-high-field MP2RAGE." Investigative radiology 54.6 ,356.

Hashemi, S. R., Salehi, S. S. M., Erdogmus, D., Prabhu, S. P., Warfield, S. K., & Gholipour, A. (2018). Asymmetric loss functions and deep densely connected networks for highly imbalanced medical image segmentation: Application to multiple sclerosis lesion detection. IEEE Access, 7, 1721-1735.

Işın, A., Direkoğlu, C., & Şah, M. (2016). Review of MRI-based brain tumor image segmentation using deep learning methods. Procedia Computer Science, 102, 317-324.

Jokubaitis, V. G., Spelman, T., Kalincik, T., Izquierdo, G., Grand'Maison, F., Duquette, P., ... & MSBasis Study Group. (2015). Predictors of disability worsening in clinically isolated syndrome. *Annals of clinical and translational neurology*, *2*(5), 479-491

Kaur A., Kaur L., Singh A. (2020). State-of-the-art segmentation techniques and future directions for multiple sclerosis brain lesions. Arch. Comput. Methods Eng. 1–27. 10.1007/s11831-020-09403-7

La Rosa, Francesco, et al. (2020) "Automated detection of cortical lesions in multiple sclerosis patients with 7T MRI." Medical Image Computing and Computer Assisted Intervention–MICCAI 2020: 23rd International Conference, Lima, Peru, October 4–8, 2020, Proceedings, Part IV 23. Springer International Publishing

Last name, F. N. (Year). *Title of dissertation*. (Unpublished doctoral dissertation). Name of Institution, Location.

Mohsen, H., et al B. M. (2018). Classification using deep learning neural networks for brain tumors. Future Computing and Informatics Journal, 3(1), 68-71.

O'Neil, J. M., & Egan, J. (1992). Men's and women's gender role journeys: A metaphor for healing, transition, and transformation. In B. R. Wainrib (Ed.), *Gender issues across the life cycle* (pp. 107-123). New York, NY: Springer.

Plath, S. (2000). *The unabridged journals.* K. V. Kukil (Ed.). New York, NY: Anchor.

Rathi, V. G. P., & Palani, S. (2015). Brain tumor detection and classification using deep learning classifiers on MRI images. Research Journal of Applied Sciences, Engineering, and Technology, 10(2), 177-187

Schnase, J. L., & Cunnius, E. L. (Eds.). (1995). Proceedings from CSCL '95: *The First International Conference on Computer Support for Collaborative Learning*. Mahwah, NJ: Erlbaum.

Schultz, S. (2005, December 28). Calls made to strengthen state energy policies. *The Country Today*, pp. 1A, 2A.

Scruton, R. (1996). The eclipse of listening. *The New Criterion*, *15*(30), 5-13.

Shoeibi, A., Khodatars, M., Jafari, M., Moridian, P., Rezaei, M., Alizadehsani, R., ... & Acharya, U. R. (2021). Applications of deep learning techniques for automated multiple sclerosis detection using magnetic resonance imaging: A review. *Computers in Biology and Medicine*, *136*, 104697.

Styner, M., Lee, J., Chin, B., Chin, M., Commowick, O., Tran, H., ... & Warfield, S. (2008). 3D segmentation in the clinic: A grand challenge II: MS lesion segmentation. MIDAS journal, 2008, 1-6.

Tintore, M., Rovira, À., Río, J., Otero-Romero, S., Arrambide, G., Tur, C., ... & Montalban, X. (2015). Defining high, medium and low impact prognostic factors for developing multiple sclerosis. *Brain*, *138*(7), 1863-1874.

Valverde S., Salem M., Cabezas M., Pareto D., Vilanova J. C., Ramió-Torrentá L., et al.. (2019). One-shot domain

adaptation in multiple sclerosis lesion segmentation using convolutional neural networks. NeuroImage 21:101638. 10.1016/j.nicl.2018.101638

Zhang, H., Valcarcel, A. M., Bakshi, R., Chu, R., Bagnato, F., Shinohara, R. T., ... & Oguz, I. (2019). Multiple sclerosis lesion segmentation with tiramisu and 2.5 d stacked slices. In Medical Image Computing and Computer Assisted Intervention–MICCAI 2019: 22nd International Conference, Shenzhen, China, October 13–17, 2019, Proceedings, Part III 22 (pp. 338-346). Springer International Publishing.

A Creative Inquiry to Engage and Inspire STEM Students in Modeling Advanced Engineering Problems

Irina Viktorova
Department of Mathematical and Statistical Sciences, Clemson University, United States

Sofya Alekseeva
Department of Mathematical and Statistical Sciences, Clemson University, United States

Chase Rochester
Department of Mechanical Engineering, Clemson University, United States

Abstract: Everything in the modern world is a product of science's advances and at the heart of all science is mathematics. From chemistry and the life sciences, theoretical and experimental, to all engineering fields, math provides the backbone and the foundation. In order for students to hone their math skills, there are few better avenues than the pursuit of research. While going to classes, sitting through lectures, and taking tests are practical for learning on a basic level, experience through research is best for students who are in STEM fields and want a deeper understanding of the subject. A classroom prepares the methods of math and the steps to solve a problem, but only when the steps are not clear, and one must discover them do the nuances of math appear. The format of creative inquiry class provides an excellent opportunity for students to strengthen their math skills, develop skills in modeling, and get an understanding of what it is like to do research if they want to pursue a master's or Ph.D. in the future. Having an opportunity to apply the math skills they are currently learning; students are able to strengthen their understanding of the material and their passion for their subject matter of study. In addition to benefits in academia, research projects offer students an excellent opportunity to work together with other students, giving them experience with teamwork, leadership, sharing ideas, and developing a feel for the diversity, plethora of various perspectives, and different ideas within the world of science. It also makes for a fantastic opportunity to work more in-depth with professors and develop professional contacts as well as publish papers and present their research findings at various conferences. This provides a great pool of resources for the student when they enter the professional world themselves. In this paper, we will be taking an in-depth look at how the MATH 4990 Creative Inquiry class students at Clemson University have practiced these skills through the various research projects they were a part of.

Keywords: Creative Inquiry, STEM Students, Modeling, Advanced Engineering Problems.

Citation: Viktorova, I., Alekseeva, S., & Rochester, C., (2023). A Creative Inquiry to Engage and Inspire STEM Students in Modeling Advanced Engineering Problems. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023-- International Conference on Life Sciences, Engineering and Technology* (pp. 25-32), Denver, CO, USA. ISTES Organization.

What Are Creative Inquiries?

At Clemson University, undergraduate research is primarily conducted under the program called “Creative Inquiry” or a program course structure, which strives to engage students in the process of learning and discovering through faculty-mentored research and outreach activities across multi-disciplinary departments. Students that participate in these Creative Inquiry classes have been shown to learn and to think in new ways, learn non-class skills designed toward their interests, enhance their academic performance in other classes, improve their satisfaction with their learning environment, and improve their relationships with faculty.

In addition, instructors that teach Creative Inquiry classes develop mentoring relationships with students, have the opportunity to develop courses toward a specific area of interest that spans several departments, and rejuvenate and improve their teaching in other courses. At the authors’ home institution, the university provides monetary support for such courses. Creative Inquiry programs (CIs) are designed as ancillary classes that students can take based on their own interests and allows the students to potentially conduct research and design products and solutions to their proposed problems. Often the CI is based on work that the mentor is personally interested in or already has experience in. Each individual section of the program is different with the number of credit hours and grade type being different from class to class. Within each of the classes, the jobs and responsibilities of each member are different but commonly consist of but are not limited to theoretical research, applied research, design, manufacturing, and documentation jobs, with most members holding multiple positions.

MATH 4990

CI MATH4990 offered by the School of Mathematics and Statistics is based on creating programs for modeling advanced engineering and physical phenomena. The initial program was focused on the method of modeling mechanical behavior of viscoelastic materials. Additional phenomena under consideration included heat transfer and explosion in thermally conductive/insulated materials, electric arc and the effects of mechanical vibrations on the human arm in relation to HAVS (Hand-Arm Vibration Syndrome).

In each of the aforementioned projects the team began by establishing a question to solve, determining how one would be able to model it and if it would be possible to model it. If it was decided that it was possible to do, then the requirements for the model would be determined and the acquisition of them would begin. Most commonly this involved studying existing models when possible and the underlying equations that model the behavior of the chosen phenomena. Following are brief explanations of the conclusions of the work and results from each of the aforementioned projects.

Viscoelastic Materials

Viscoelasticity is a remarkable property observed in materials, where they exhibit both elastic and viscous behaviors during deformation. The effects of viscoelasticity encompass hysteresis, stress relaxation, creep, and energy dissipation. Hysteresis, quantified as the maximum distance between upscale and downscale measurements demonstrate the material's unique response. Stress relaxation occurs as a material deforms plastically, leading to a

reduction in stress proportional to the deformation. Creep, on the other hand, represents the slowly increasing deformation experienced by materials under constant stress, particularly prominent as they approach the point of instability and potential fracture.

To comprehend and predict the behavior of linear viscoelastic materials changing with time, the utilization of Volterra equations was imperative, especially for small deformations (Viktorova et al., 2017). These equations, depicted in Figure 1, reflect the rheological type of relation between the stress and strain components of the materials.

$$\sigma(t) = E_{\text{inst,relax}}\varepsilon(t) + \int_0^t F(t-t')\dot{\varepsilon}(t')dt'$$

$$\varepsilon(t) = \frac{\sigma(t)}{E_{\text{inst,creep}}} + \int_0^t K(t-t')\dot{\sigma}(t')dt'$$

Figure 1: Volterra Equations

The developed approach allowed to predict the creep strains at extended in time loading tests as well as the delayed deformation at various types of loading conditions. In our exploration of various models, the standard linear model stood out, consisting of a spring in series with a Kelvin-Voigt unit and a dashpot that redistributes the load to a second spring as it gradually opens over time.

Additionally, the Maxwell Model assumes identical stress in the dashpot and spring, summing their strains to determine the total strain. The Kelvin-Voigt model, on the other hand, represents the spring and dashpot in parallel, where the strain experienced by the spring aligns with that of the dashpot. A comprehensive depiction of these diverse models can be observed in Figure 2.

Extending our analysis to the human arm, we unraveled the vital role of viscoelasticity instability, movement, and coordination. Particularly, the posture assumed by an individual plays a significant role in determining the stiffness ellipse, representing the range of viscoelastic properties of the arm. External forces and alterations in the relationships between the shoulder and elbow joints exert profound influences on viscoelasticity, thereby modifying the stiffness ellipse and ultimately impacting arm function.

In conclusion, the study of viscoelasticity has shed light on its profound effects on matter, encompassing hysteresis, stress relaxation, creep, and energy dissipation. By employing base model Volterra equations we have gained valuable insights into the behavior of linear viscoelastic materials. Furthermore, our exploration of the human arm has underscored the significance of viscoelasticity instability, movement, and coordination, emphasizing the impact of posture and joint dynamics on the arm's viscoelastic properties.

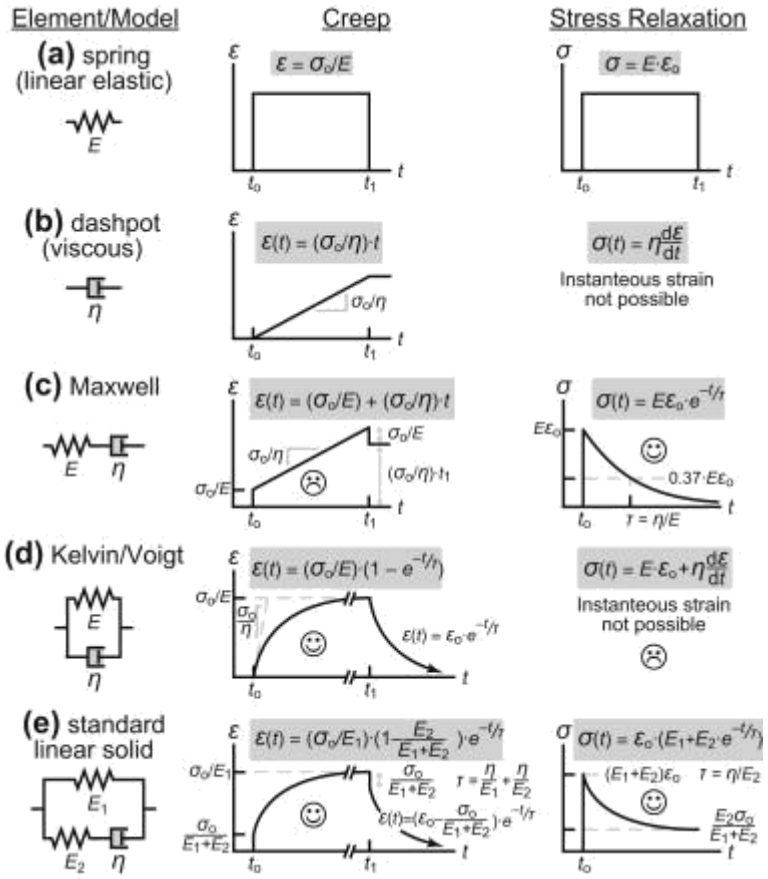


Figure 2: Viscoelastic Materials

Heat Transfer and Heat Explosion

This research project focuses on the phenomenon of heat transfer and occasionally occurring phenomenon of heat explosion in thermally insulated and conductive systems. Two fundamental laws of heat exchange, Fourier's Law and Maxwell's Law, play a crucial role in understanding the process. Fourier's Law states that heat dissipates proportionally from regions of high temperature to low temperature, while Maxwell's Law highlights that heat dissipates at the same rate it is produced. Heat explosion is defined as the catastrophic failure of a material resulting from excessive heat buildup and is characterized by the delta parameter (Viktorova et al., 2012; Viktorova & Bates, 2016). The rate at which the system dissipates heat is represented as the beta parameter. Figure 3 is the illustration of delta upon beta dependence at various values of thermal sensitivity coefficient (gamma parameter).

To provide a physical meaning to the parameter gamma the analogy with exothermic chemical reaction had been used. While specific details of the reaction were not disclosed, it was deduced that the thermal properties of the system remained constant throughout the process. This allowed for a single representative value of gamma, reflecting the thermal properties of the specific system under investigation. This concept formed the basis for the mathematical procedures employed in the research (Viktorova et al., 2016).

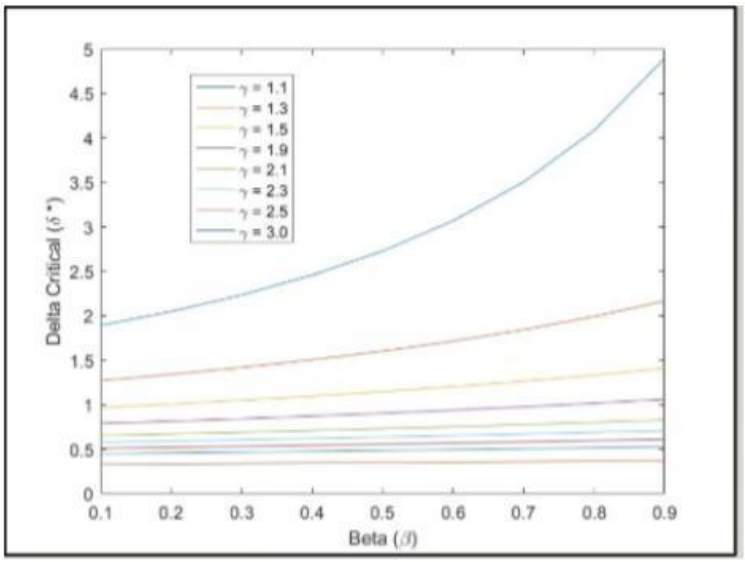


Figure 3: δ/β Graph

$$K = \frac{EQk_0 a\, e^{-E/RT_0}\ell^2}{RT_0^2\kappa}, \qquad Ra = \frac{g\beta RT_0^2\ell^3}{E\kappa\nu}$$

Figure 4: Formulas defining Frank-Kamnetski (K) and Reynolds (Ra) numbers.

The parameters K and Ra, also known as the Frank-Kamenetskii and Reynolds numbers, was introduced to quantify the heat produced in the reaction relative to its loss through Newtonian cooling. Equations pertaining to these parameters were utilized in the analysis are shown in Figure 4. A trendline equation was derived by analyzing the equations for K and Ra, as shown in Figure 5. This trendline was then subjected to numerical methods to establish a similar relationship between beta and delta critical, consequently establishing a relationship between beta and gamma for the system.

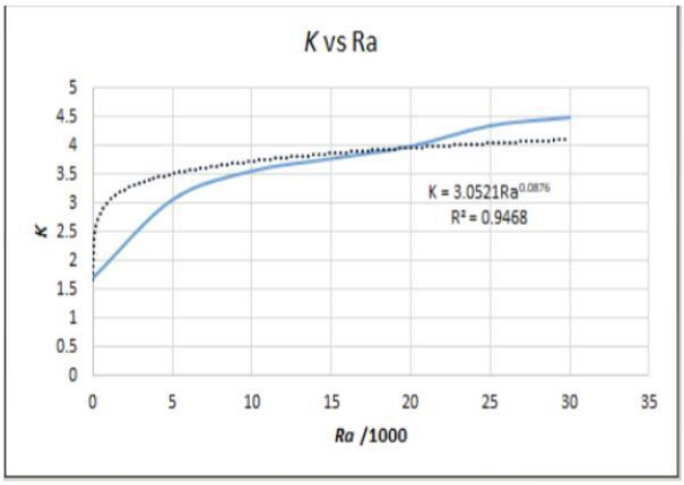


Figure 5: K/Ra Graph

Electric Arc Phenomenon

The third project focused on modeling the phenomenon of electric arc, which refers to the electrical breakdown of gas resulting in an electrical discharge. This breakdown occurs between two points known as electrodes. Unlike a normal glow discharge, an electric arc exhibits a lower voltage and relies on the thermionic emission of electrons from the electrodes.

An empirically derived arc flash discharge energy model known as Paschen's Law emerged as a crucial concept in understanding the electric arc. It provides the estimate for the required voltage to initiate a discharge or electric arc between two electrodes, considering the pressure of the media and gap length. The equation representing Paschen's Law is given in Figure 6.

$$V_b = \frac{B(P * d)}{\ln[A * (P * d)] - \ln\left(\ln\left(1 + \frac{1}{\gamma_{se}}\right)\right)}$$

Known

Air

P = 100 torr

d = .1 in

γ_{se} = 4E-46

A = 15 (1/cm*torr)

B = 365 (V/cm*torr)

Find

V_b = ? [Voltage Breakdown]

Solution

$$V_b = \frac{B(P * d)}{\ln[A * (P * d)] - \ln\left(\ln\left(1 + \frac{1}{\gamma_{se}}\right)\right)}$$

$$V_b = \frac{365(100 * .1)}{\ln[15 * (100 * .1)] - \ln\left(\ln\left(1 + \frac{1}{4e - 46}\right)\right)}$$

$$V_b = 10{,}107\ torr$$

Figure 6: Paschen's Laws and an Example Solution

The early applications of electric arcs date back to the 1800s when they were used for public lighting. Carbon arc lights were the first electric lights to be employed. Nowadays, electric arcs find various applications such as welding, furnaces, lamps, theatre projections, and photography. The created program allows for the modeling of arcs and the determination of unknown variables based on known inputs as well as to establish the comparison with existing safety codes (Viktorova & Bates, 2016)

Mechanical Vibrations and HAVS

In the late 16th to early 17th century, notable mathematicians made significant contributions to the understanding of pitch and frequency of mechanical vibrations Galileo Galilei, an Italian mathematician, studied the relationship between pitch and frequency, while Marin Mersenne, a French mathematician, formulated Mersenne's laws. These three laws describe how the frequency of a stretched string, like the monochord, is influenced by its length, tension, and mass.

The research project also focuses on examining and modeling the effects of vibrations on the human body, particularly Hand-Arm-Vibration Syndrome (HAVS) (Viktorova et al., 2016). HAVS is a debilitating disease that can result in the loss of hand function, starting with the fingers and progressing to the entire hand if left untreated. It is primarily caused by the use of hand tools, which is common in the construction industry.

The human arm, although challenging to model due to factors like muscle and skin tissue mechanical parameters and a lack of comprehensive available data for living humans, was simplified as two viscoelastic-like rods connected by a hinge joint. This simplified model allows for direct analysis of the relationship between frequency and amplitude in the human arm. The derived equations representing the modeling of amplitude of the human arm oscillations

$$W = \frac{\omega}{2}\left[\frac{S_1 \sin(kx) - S_2 \sinh(kx)}{\sin(k\lambda)\cosh(k\lambda) - \cos(k\lambda)\sinh(k\lambda)}\right] + \cos(kx) + \cosh(kx)$$

$$S_1 = 1 - \cos(k\lambda)\cosh(k\lambda) - \sin(k\lambda)\sinh(k\lambda)$$
$$S_2 = 1 - \cos(k\lambda)\cosh(k\lambda) + \sin(k\lambda)\sinh(k\lambda)$$

$$W(x = \lambda) = \omega * \left[\frac{\sin(k\lambda) - \sinh(k\lambda)}{\sin(k\lambda)\cosh(k\lambda) - \cos(k\lambda)\sinh(k\lambda)}\right]$$

$$\rho = \frac{(\cosh(\omega) - \cos(\omega) - \sin(\omega)\sinh(\omega))^{\frac{1}{2}}}{\sqrt{2}(\sinh(\omega) - \sin(\omega))}$$

Figure 7: Model equations for the amplitude and resonance frequencies of the human arm oscillations.

Summary

Clemson University students receive valuable education in the field of engineering and mathematics and the addition of Creative Inquiry programs allows participants to get first-hand experience in scientific research and formulations

of solutions to complex problems that do not have exact analytical solutions. Such a program as CI MATH 4990 allows students to learn analysis skills that are applicable to nearly any STEM field and acts as an excellent foundation and introduction to scientific research. Many of the programs and topics studied are specifically chosen as they are an extension of and a more comprehensive look into the material covered in the classes up to the point of the program and allow students to get experience in the work and responsibilities that higher education beyond a Bachelor's degree would look like.

References

I. Viktorova, M. Kose, S Alekseeva, (2017). Some aspects of model equations Development for Viscous materials MMSE J., Vol.3, pp. 179-190.

I. Viktorova, M Scruggs, I. Zeller, K. Fairchild, (2012). An Analysis of Heat Explosion for Thermally Insulated and Conducting Systems, Applied Mathematics, vol 3, pp.535-540.

I.Viktorova, M. Bates, (2016). Modeling of Heat Transfer and Self-Heating Phenomenon in Materials with high Dissipation, MMSE J. Vol.3, pp.20-27.

I.Viktorova, S. Alekseeva, A. Wolfensberg, E. Lewis, (2016). Physical parametrization of Heat Explosion Curve, MMSE J. Vol.4, pp. 43-47, December 2016, ISSN 2412-5954.

I.Viktorova, M. Bates, (2016). An empirically derived Arc Flash Discharge Energy Model and Comparison to Established Safety Codes, MMSE J. vol 4, pp. 211-216.

I. Viktorova, M. Fleck, M. Kose, S. Alekseeva, (2016). The Mathematical Implications of Hand-Arm Vibrations Syndrome, Engineering and Automation Problems, Vol. 3, pp.82-87.

Computer Animation: An Analysis on Balancing Artistic and Technical Skills

Robert Wahl
Concordia University Wisconsin, United States

Abstract: Students from different college majors tend to lean toward stronger artistic or technical skill sets. This paper will focus on teaching computer animation courses in higher education and comparing the needs of artistic skills such as offered by an art department and technology skills such as offered by a computer science department. Individuals from both artistic and technical backgrounds have proven to be successful in computer animation classes. Achieving a balance between artistic and technical skills, can be difficult at the individual level and in some cases, a team combining an artistic person with a technically minded person have been successful. I have been teaching computer animation for the last eight years and I have noticed distinct differences between students with different majors. As part of this research, I will incorporate articles from scholarly sources focusing on right brain/left brain learning abilities and strategies for teaching course that straddle the boundary between artistic skills and technical skills.

Keywords: Teaching Animation.

Citation: Wahl, R. (2023). Computer Animation: An Analysis on Balancing Artistic and Technical Skills. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023-- International Conference on Life Sciences, Engineering and Technology* (pp. 33-38), Denver, CO, USA. ISTES Organization.

Introduction

Computer animation, sometimes called computer-generated imagery (CGI), is the process of using a computer to produce a series of images to give the appearance of motion. College-level undergraduate courses in computer animation are commonly offered as part of a computer science or an art department program of study. It has been observed that students generally exhibit stronger skill sets either on the artistic side or stronger technical skills. “One of the how problems facing educators who teach computer animation is how to balance the technical and conceptual skills required to produce effective computer animation in a manner that is holistic” (Cumbie-Jones, 2001, p53).

Background

Over the last decade, our university has offered a series of computer animation classes covering a variety of topics, as well as utilizing different software applications. The series of computer animation courses begin with

Animation I which focuses on the history of animation and introduces basic concepts such as the classic 12 principles of animation. Blender software is used as the primary tool and students create a semester-long individual. A very similar classroom environment is described extensively in Silva (2009) where Blender software is used as the primary tool in a graduate program. The three main arguments used in this paper (Silva, 2009) for selecting Blender are reasons why it was selected for our course of study: open source, similar capabilities to commercial software, and a readily available supply of online resources to supplement the learning experience.

The intermediate and advanced computer animation classes (*Animation II and Animation III*) use Autodesk Maya as the primary computer animation software and contains a semester-long as well. Note that this paper focuses on teaching computer animation as a class rather than on using computer animations to teach other subjects. For an excellent paper on using computer animation to teach non-animation subjects see (Musa et al., 2013).

Computer graphics, of which computer animation is a part, is considered an important enough area of study that recommendations have been made to include it in all undergraduate majors in Computer Science (Bourdin, et al., 2006). This perceived need for computer graphics in general computer science courses of study is based on the idea that much of what we output from computer science operations is graphical in and students should have exposure to this and other forms of visual communication in their university training. Many of the suggested course materials in (Bourdin, et al., 2006) are covered in the *Animation I, II, and III* courses. Even with three courses, not every feature and function of computer animation software such as Blender can be covered and independent study learning from online sources is necessary for a mastery of the computer programs. This need for independent learning was also observed by Silva (2009).

At the end of the semester, students present their final animations for review and grading, but as may be expected, many projects could benefit from additional time to complete outside of the course as noted by Ebert, et al, (1999). The teaching method employed to encourage students focused on the throughout the semester is the use of intermediate assignments to what they have completed to date. These intermediate “checkpoints” help to ensure progress during the semester. As observed during one semester when this method was not used, students were far less likely to complete work by the end of the semester at a sufficient level. Checkpoint assignments, such as these were also utilized successfully in Ebert, et al. (1999).

It is interesting that as far back as 2003, questions were being raised as to what classes and content were desirable in a computer animation course of study and what made up the correct balance between artistic and technical classes in such a program (Flaxman, 2003). Twenty years later, the same questions can be raised. A further consideration raised at that time was if a generalized computer animation program was needed, or if specialization in different future job positions was a better idea (Flaxman, 2003).

Observations

All the classes have contained a mix of students that are art majors and students that are computer science majors. The tendency in recent years has been for a higher percentage of students to be from a technical background rather than an artistic one. One of the challenges in teaching a course such as computer animation is to bring out the artistic skills in the technically minded students and bring out the technical skills in the artistically minded students.

In his seminal research paper on left-brain/right-brain (Sperry, 1975) Sperry posited that not only could the different halves of a human brain act independently from each other, but they were responsible for different functions. The left-brain hemisphere was found to be responsible for verbal skills and math skills and the right-brain hemisphere was found to be more involved with spatial and visual skills (Sperry, 1975). In the years since this initial study, the basic idea has been simplified to the concept that the left-brain is used for thinking and logic while the right-brain is stronger for arts and imagination. Additional studies have shown that having two distinct hemispheres with different functions is not limited to humans alone as originally thought (Corballis, 2014). The idea that the right hemisphere of the brain is strongly associated with artistic skills was further enhanced by Edwards (1997) in her book *Drawing on the Right Side of the Brain*. At this time, it is unclear how much of this division of the brain hemisphere is based on a genetic predisposition or if it is partially a learned behavior based on the interests of the individual. “Handedness and brain asymmetry are in born and under partial genetic control, although the gene or genes responsible are not well established” (Corballis, 2014, p1).

Some studies have begun to challenge this left-side/right-side division of talent pointing out that artistic people are increasingly using more technology in developing their works (Comninos, et al., 2009). In other words, the divide between purely artistic people and purely technical people may be narrowing (if it ever truly existed in the first place). Interestingly, one study indicated that in general, U.S. computer animation programs conducted at the college level focused more heavily on artistic skills while European computer animation programs focused more on technical skills and abilities (Silva, 2009).

Classroom and lab observations from our computer animation courses seemly correlate with these important brain research projects and papers. Clearly, students tend to have either stronger artistic skills or stronger technical skills. In an interesting finding, it is possible for an individual student to switch from using the more dominant side of the brain to the other. For example, a student who is naturally stronger in the right-brain skills (artistic) can, with effort, develop strong technical skills (left-brain) (Singh, 2012). There are some individuals who exhibit traits of having both strong right-brain and left-brain skills at the same time. This may surprise the student who may have previously thought they were not good at doing artistic things or perhaps they felt that they lacked technical skills. One of the challenges in developing a course of study for computer animation is that it would likely tilt in directions of being more artistic-based or technology-based, depending on the strengths of the instructor (Pausch, et al., 2013).

At the Ringling School of Art and Design, a traditional hand-drawn animation class is part of their three-course program of study (Cumbie-Jones, 2001). This approach makes sure to include the basic artistic skills that many technology-minded students make lack. Unfortunately, this traditional hand-drawn animation class does not exist in our curriculum, so we are unable to try this approach currently.

While individual project work is typical in these courses, occasionally, two-person teams are allowed to work together. These two-person teams are most effective when an artistic leaning student is paired with a technically leaning student. This may be an ideal scenario as it combines both sides of the brain through a pairing of students. The combination of artistic and technical skills on a team may more closely mimic what occurs in professional animation studios: “Computer animation has always required a close collaboration between artists and computer scientists.” (Wolfe, 2000). The classroom environment for teaching computer animation may otherwise tend to artificially separate artistically strong individuals from technically strong individuals. There is a need to teach students the benefits of interdisciplinary cooperation and sharing of different skill sets (Wolfe, 2000). Employers, when questioned about hiring practices and why they might not hire a person directly after graduation, indicated that students lacked the ability to work on interdisciplinary teams so designing a program around this skill set is necessary (Pausch, et al., 2013). In their program for a new master’s degree at Carnegie-Mellon University, courses were designed to specifically create interdisciplinary teams of students with a mixture of artistic and technical skills (Pausch, et al., 2013). This can be achieved in other learning environments by consciously combining students with left-brain and right-brain strengths. For technically strong students, introducing them to classical hand-drawn animation, can be hugely beneficial and increase their knowledge of artistic endeavors. Artistically, strong students can be introduced to the technical aspects, such as frame rate, and computer animation rendering techniques over the course of a semester. A cross-mixing of students’ talents and strengths provides students with the ability to learn complementary skills from each other (Ebert, et al., 1999). Wolfe (2000) suggested going as far as having team teachers with one specialized in technical skills and one specialized in artistic skills. This was further emphasized in Ebert, et al. (1999). Note that we have not yet had an opportunity to test this scenario in our three computer animation classes. Computer Science students can help Art students to understand technical concepts such as rendering, and Art students can help computer science students appreciate the artistic side of project work.

The artificial divide between art and technology skills may be detrimental to learning and should be fixed or removed according to Comninos, et al., (2009). This research paper utilized the term “technophile artists” (Comninos, et al., 2009) which appropriately describes what may be the goal of combining technical skills and artistic skills within a classroom team.

Conclusions

This research article presented a series of observations from more than 10 years of teaching computer animation classes at the undergraduate level. Students enter the program with demonstrated stronger skills on either the

artistic side or the technical side. Research and classroom observation has shown that by combining students with artistic and technical background, may be the best environment for learning and for producing the highest quality final animation projects. Future classes may be designed with teams combining artistic and technical skills. In this way, a best-of-both-worlds approach can be utilized. The challenge is in achieving a balance when the ratio of artistic to technical students changes dynamically from semester to semester. A

s noted above, the delineation between students with pure artistic skills and pure technical skills may be blurring as the software becomes easier to use from a technical standpoint and new features are added to the software that makes artistic creations easier to achieve. In addition, there are skills that both artistic-minded students, and technically-minded students need to learn skills in areas such as storytelling, directing, and acting (Flaxman, 2003). Regardless of whether a student feels technically strong or artistically strong, there is an unavoidable amount of technical terminology that must be mastered in order to effectively use the software applications (Cumbie-Jones, 2001).

References

Bourdin, J., Cunningham, S., Fairén, M., & Hansmann, W. (2006). Report of the CGE 06 Computer Graphics Education Workshop. *Education*, 2006–2006.

Comninos, P., McLoughlin, L., & Anderson, E. F. (2009). Educating technophile artists: Experiences from a highly successful computer animation undergraduate programme. *ACM SIGGRAPH ASIA 2009 Educators Program, SIGGRAPH ASIA '09*. https://doi.org/10.1145/1666611.1666612

Corballis, M. C. (2014). Left Brain, Right Brain: Facts and Fantasies. *PLoS Biology*, *12*(1). https://doi.org/10.1371/journal.pbio.1001767

Cumbie-Jones, C. (2001). Threading a sophomore computer animation curriculum. *Computer Graphics (ACM)*, *35*(2), 53–56. https://doi.org/10.1145/563693.563708

Ebert, D. S., & Bailey, D. (1999). An Interdisciplinary Approach to Teaching Computer Animation to Artists and Computer Scientists. *Self Published*.

Edwards, B. (1997). Drawing on the right side of the brain. *Conference on Human Factors in Computing Systems - Proceedings*, *22-27-March-1997*(March), 188–189. https://doi.org/10.1145/1120212.1120336

Flaxman, T. (2003). The future of computer animation education, 1. https://doi.org/10.1145/965117.965120

Musa, S., Ziatdinov, R., & Griffiths, C. (2013). Introduction to computer animation and its possible educational applications. *New Challenges in Education. Retrospection of History of Education to the Future in the Interdisciplinary Dialogue among Didactics of Various School Subjects*, (2013), 1–25. Retrieved from http://arxiv.org/ftp/arxiv/papers/1312/1312.1824.pdf

Pausch, R., & Marinelli, D. (2013). Combining the Left and Right Brain. *Communications of the ACM*, *53*(9), 1689–1699.

Silva, F. G. M. (2009). Teaching animation in computer science. *ACM SIGGRAPH ASIA 2009 Educators Program, SIGGRAPH ASIA '09*. https://doi.org/10.1145/1666611.1666613

Singh, G. (2012). From right brain to left brain. *IEEE Computer Graphics and Applications*, *32*(4), 4–5. https://doi.org/10.1109/MCG.2012.76

Sperry, R. W. (1975). Left-Brian, Right-Brain. *The Mind of Man*. Retrieved from http://people.uncw.edu/puente/sperry/sperrypapers/70s/190-1975.pdf

Wolfe, R. J. (2000). A collaborative and interdisciplinary computer animation course. *Computer Graphics (ACM)*, *34*(3), 22–26. https://doi.org/10.1145/359293.359325

The Role of Transmission by Female Sex Workers in the Spread of HIV/AIDS

Kazi A. Rahman

Jacksonville State University, Jacksonville, Alabama, United States, https://orcid.org/0000-0001-7684-2413

Abstract: The female sex workers (FSWs) play a key role in transmission of HIV/AIDS. In this work, a ten-dimensional nonlinear mathematical model has been formulated and investigated to study the dynamics of HIV/AIDS epidemic considering the potential impact of the presence of unfaithful husbands in sense of sexual relationship with high-risk core group of people (i.e., FSWs) in order to assess the spread and persistency of AIDS epidemic in the community. The model which assumes mass action incidence, is analyzed qualitatively to determine the stability of the equilibria. A basic reproduction number, $\mathcal{R}_0$ has been calculated and a numerical simulation has been carried out to determine whether the disease dies out or remains endemic.

Keywords: HIV/AIDS, Basic reproduction number, Stability, Unfaithful husbands, Female Sex Worker.

Citation: Rahman, K. A. (2023). The Role of Transmission by Female Sex Workers in the Spread of HIV/AIDS. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023-- International Conference on Life Sciences, Engineering and Technology* (pp. 39-54), Denver, CO, USA. ISTES Organization.

Introduction

Mathematical models play an important role in understanding the epidemiology and control of sexually transmitted disease (STD). The main objective of a mathematical model of HIV/AIDS transmission is to predict population level after a certain period from individual level inputs. In general, the population are divided into groups such as males, females, FSWs etc in all models. For each population group, it is again divided based on stages (e.g., susceptible (S), infected (I)) using the concept of SI model to formulate a deterministic system containing a set of differential equations describing the sexual relationship among the different population groups. In fact, STD models describe the transition of the individuals in the population through a sequence of disease related stages for each group separately. The models also define the process and rate of movements between those stages.

According to the human rights fact sheet series of UNAIDS, FSWs had a thirty times greater risk of acquiring HIV than the general female population in 2019. Also, in 2019 approximately 8% of new adult HIV infections globally were among sex workers of all genders. FSWs bear a disproportionately large burden of HIV infection worldwide (Shannon et al., 2015).

In this study, our main focus is to study the role of FSWs in spreading HIV/AIDS in India, one of the largest populated country in the world. The majority (85%) of new HIV infections in India are due to heterosexual transmission, particularly among female sex workers (FSWs), their clients and the sexual contacts of their clients (AIDS/HIV in Delhi, 2005; Diekmann et al, 1990; Dorabjee & Samson, 2000; Eicher et al, 2000; Rahman, 2023). However, in north-east India and in major cities injecting drug use is also a source of new infections (Gangakhedkar, et al, 1997; George et al, 1997; Gisselquist & Correa, 2006; Gumel et al, 2006; Hethcote, 2000; Rahman, 2023).

There are several models for HIV/AIDS in India presented and studied (Rahman, 2023; Rao & Kakehashi, 2004; Rao, 2003). Most of them differs from one another based on how the populations are grouped. In our model formulation we consider the heterosexual transmission of HIV among faithful couples, unfaithful couples, single males, and FSWs. We show that HIV/AIDS epidemics invade the Indian community based on the data as in references (Census of India 2012, 2006; AIDS/HIV in Delhi, 2005; WHO and UNAIDS, 2006), where FSWs play the important role, using mathematical model of HIV transmission.

We use data collected in India to examine the predictions of epidemic size for an urban area of India. The HIV transmission model is formulated. We discuss equilibria of the model, the Jacobian matrix, local stability, and the basic reproduction number R_0. The analysis of the center manifold is presented. Numerical simulations and some important diagrams related to the model are illustrated using the various real parameter values collected from one of the major cities, Delhi in India presented in Table 1.

Model of HIV Transmission

Model Formulation

In the model, we have divided the population into four classes: Faithful couple where both husband and wife are faithful, Unfaithful couple where husband is unfaithful, but wife is faithful, Single male and FSW. We denote the couples by M_{ixy} where $i=1$ for faithful couple, $i=2$ for unfaithful couple, and x and y represent the disease status of the husband and wife respectively with $x,y \in \{S,I\}$ where S indicates susceptible and I indicates infective.

The susceptible populations are denoted as M_{1SS}, M_{2SS}, M_S, F_S^S, for faithful couples, unfaithful couples, single males and FSWs respectively. Those who are infected by HIV, are considered as M_{1IS}, M_{2IS} for faithful couples, unfaithful couples where only husbands are infected and M_I, F_I^S for single males and FSWs. M_{1II}, M_{2II} are denoted as the infected group when both husband and wife are infected.

The structure of HIV transmission in the smodel is summarized in Figure 1.

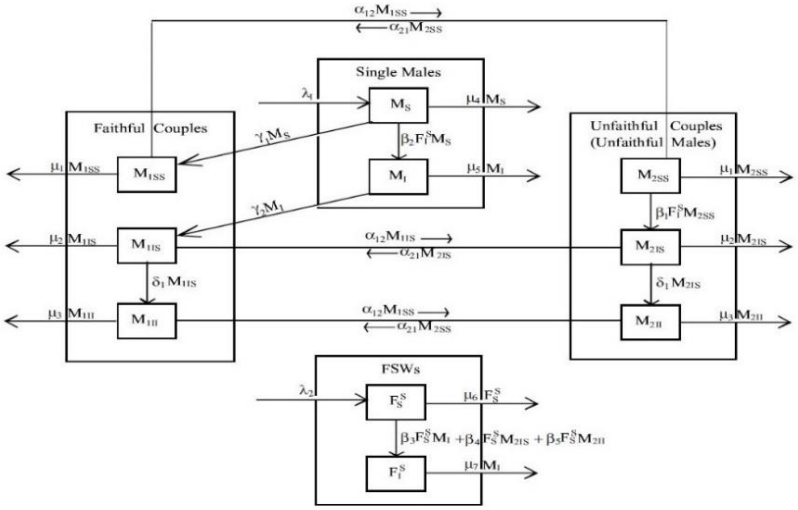


Figure 1. Model structure.

The model describes transmission amongst four classes of people Faithful couples (M_1), Unfaithful couples (M_2), Single males (M) and FSW (F^S).

The differential equations for the model are as follows:

$$
\begin{cases}
\frac{dM_{1SS}}{dt} = -\alpha_{12}M_{1SS} + \alpha_{21}M_{2SS} - \mu_1 M_{1SS} + \gamma_1 M_S \\
\frac{dM_{1IS}}{dt} = -\alpha_{12}M_{1IS} + \alpha_{21}M_{2IS} - \mu_2 M_{1IS} + \gamma_2 M_I - \delta_1 M_{1IS} \\
\frac{dM_{1II}}{dt} = -\alpha_{12}M_{1II} + \alpha_{21}M_{2II} - \mu_3 M_{1II} + \delta_1 M_{1IS} \\
\frac{dM_{2SS}}{dt} = \alpha_{12}M_{1SS} - \alpha_{21}M_{2SS} - \mu_1 M_{2SS} - \beta_1 F_I^S M_{2SS} \\
\frac{dM_{2IS}}{dt} = \alpha_{12}M_{1IS} - \alpha_{21}M_{2IS} - \mu_2 M_{2IS} + \beta_1 F_I^S M_{2SS} - \delta_1 M_{2IS} \\
\frac{dM_{2II}}{dt} = \alpha_{12}M_{1II} - \alpha_{21}M_{2II} - \mu_3 M_{2II} + \delta_1 M_{2IS} \\
\frac{dM_S}{dt} = \lambda_1 - \beta_2 F_I^S M_S - \mu_4 M_S - \gamma_1 M_S \\
\frac{dM_I}{dt} = \beta_2 F_I^S M_S - \mu_5 M_I - \gamma_2 M_I \\
\frac{dF_S^S}{dt} = \lambda_2 - \beta_3 F_S^S M_I - \beta_4 F_S^S M_{2IS} - \beta_5 F_S^S M_{2II} - \mu_6 F_S^S \\
\frac{dF_I^S}{dt} = \beta_3 F_S^S M_I + \beta_4 F_S^S M_{2IS} + \beta_5 F_S^S M_{2II} - \mu_7 F_I^S
\end{cases}
\tag{1}
$$

where

α_{12} = rate at which faithful husbands become unfaithful

α_{21} = rate at which unfaithful husbands become faithful

μ_1 = death rate of M_{1SS}, M_{2SS}

μ_2 = death rate of M_{1IS}, M_{2IS}

μ_3 = death rate of M_{1IH}, M_{2IH}

μ_4 = death rate of M_S

μ_5 = death rate of M_I

μ_6 = death rate of F_S^S

μ_7 = death rate of F_I^S

γ_1 = transmission probability at which M_S gets married

γ_2 = transmission probability at which M_I gets married

δ_1 = transmission probability at which infected husband infects wife

β_1 = transmission probability at which new infection goes to M_{2SS} from F_I^S

β_2 = transmission probability at which new infection goes to M_S from F_I^S

β_3 = transmission probability at which new infection goes to F_S^S from M_I

β_4 = transmission probability at which new infection goes to F_S^S from M_{2IS}

β_5 = transmission probability at which new infection goes to F_S^S from M_{2IH}

λ_1 = rate at which new single males enter population

λ_2 = rate at which new FSWs are recruited

Equilibria of the Model

The disease-free equilibrium for the system of equations of the model (1) is given by

$$x_0 = (M_{1SS}, M_{1IS}, M_{1IH}, M_{2SS}, M_{2IS}, M_{2IH}, M_S, M_I, F_S^S, F_I^S)_{DFE}$$
$$= (M_{1SS}^*, 0, 0, M_{2SS}^*, 0, 0, M_S^*, 0, F_S^{S^*}, 0)$$

where 0 indicates that there is no HIV affected people (i.e., no disease) in the population and

$$M_{1SS}^* = \frac{\gamma_1 \lambda_1}{\mu_1(\mu_4 + \gamma_1)(\alpha_{12} + \alpha_{21} + \mu_1)}$$

$$M_{2SS}^* = \frac{\alpha_{12}\gamma_1 \lambda_1}{\mu_1(\mu_4 + \gamma_1)(\alpha_{21} + \mu_1)(\alpha_{12} + \alpha_{21} + \mu_1)}$$

$$M_S^* = \frac{\lambda_1}{\mu_4 + \gamma_1}$$

$$F_S^{S^*} = \frac{\lambda_2}{\mu_6}$$

Jacobian Matrix at DFE and Local Stability of the Model

In order to find the Jacobian at DFE, we consider the system of the model (1) as

$$\begin{cases} f_1 &= -\alpha_{12}x_1+\alpha_{21}x_2-\mu_3x_1+\delta_1x_5 \\ f_2 &= \alpha_{12}x_1-\alpha_{21}x_2-\mu_3x_2+\delta_1x_6 \\ f_3 &= \beta_2x_4x_9-\mu_5x_3-\gamma_2x_3 \\ f_4 &= \beta_3x_3x_{10}+\beta_4x_6x_{10}+\beta_5x_2x_{10}-\mu_7x_4 \\ f_5 &= -\alpha_{12}x_5+\alpha_{21}x_6-\mu_2x_5+\gamma_2x_3-\delta_1x_5 \\ f_6 &= \alpha_{12}x_5-\alpha_{21}x_6-\mu_2x_6+\beta_1x_4x_8-\delta_1x_6 \\ f_7 &= -\alpha_{12}x_7+\alpha_{21}x_8-\mu_1x_7+\gamma_1x_9 \\ f_8 &= \alpha_{12}x_7-\alpha_{21}x_8-\mu_1x_8-\beta_1x_4x_8 \\ f_9 &= \lambda_1-\beta_2x_4x_9-\mu_4x_9-\gamma_1x_9 \\ f_{10} &= \lambda_2-\beta_3x_3x_{10}-\beta_4x_6x_{10}-\beta_5x_2x_{10}-\mu_6x_{10} \end{cases} \tag{2}$$

where

$$x=[x_1,x_2,x_3,x_4,x_5,x_6,x_7,x_8,x_9,x_{10}]^T$$
$$=[M_{1H},M_{2H},M_I,F_I^S,M_{1N},M_{2N},M_{1SS},M_{2SS},M_S,F_S^S]^T$$

Let $f=[f_1,f_2,f_3,f_4,f_5,f_6,f_7,f_8,f_9,f_{10}]^T$. Then the Jacobian matrix at DFE, is

$$J_0=D_xf(x_0)$$
$$=diag\begin{pmatrix} -\alpha_{12}-\mu_3 \\ -\alpha_{21}-\mu_3 \\ -\mu_5-\gamma_2 \\ -\mu_7 \\ -\alpha_{12}-\mu_2-\delta_1 \\ -\alpha_{21}-\mu_2-\delta_1 \\ -\alpha_{12}-\mu_1 \\ -\alpha_{21}-\mu_1 \\ -\mu_4-\gamma_1 \\ -\mu_6 \end{pmatrix}+\begin{pmatrix} 0 & \alpha_{21} & 0 & 0 & \delta_1 & 0 & 0 & 0 & 0 & 0 \\ \alpha_{12} & 0 & 0 & 0 & 0 & \delta_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \beta_2x_9 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \beta_5x_{10} & \beta_3x_{10} & 0 & 0 & \beta_4x_{10} & 0 & 0 & 0 & 0 \\ 0 & 0 & \gamma_2 & 0 & 0 & \alpha_{21} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \beta_1x_8 & \alpha_{12} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{21} & \gamma_1 & 0 \\ 0 & 0 & 0 & -\beta_1x_8 & 0 & 0 & \alpha_{12} & 0 & 0 & 0 \\ 0 & 0 & 0 & -\beta_2x_9 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\beta_5x_{10} & -\beta_3x_{10} & 0 & 0 & -\beta_4x_{10} & 0 & 0 & 0 & 0 \end{pmatrix}$$

where the notation $D_xf(x_0)$ indicates the partial derivative of f with respect to x evaluated at $x=x_0$. (Note that each of x_7, x_8, x_9 and x_{10} are non-zero at the DFE).

Using Gersgorin discs, it can be shown that J_0 is stable if x_{10} is small enough. Thus, if the FSW population is small enough, then the DFE is locally asymptotically stable.

The Basic Reproduction Number for the Model

The basic reproduction number, denoted R_0, is "the expected number of secondary cases produced, in a completely susceptible population, by a typical infective individual'' (Diekmann et al, 1990; Roy & May, 1991). If $R_0<1$, then on average an infected individual produces less than one new infected individual over the course of its infectious period, and the infection cannot grow. Conversely, if $R_0>1$, then each infected individual produces, on average, more than one new infection, and the disease can invade the population (see the survey paper by

Hethcote, 2000). Here, we have found the basic reproduction number using the method discussed in van den Driessche &Watmough, 2002. The basic reproduction number, R_0 is

$$R_0 = (c_1 jb_1 g + d_1 ja_1 p + d_1 je_1 r + c_1 ja_1 f + c_1 je_1 i)^{\frac{1}{2}}$$

where

$$r = \frac{\alpha_{12} + \mu_2 + \delta_1}{\mu_2^2 + \delta_1^2 + \alpha_{21}\mu_3 + \delta_1\alpha_{21} + \alpha_{12}\mu_3 + \alpha_{12}\delta_1 + 2\delta_1\mu_3}; \quad g = \frac{1}{\mu_5 + \gamma_2}; \quad j = \frac{1}{\mu_7}; \quad i = \frac{\gamma_2\alpha_{12}}{i_1};$$

$$i_1 = \mu_3\mu_2^2 + \mu_3\delta_1^2 + \gamma_2\delta_1^2 + \mu_2^2\gamma_2 + \alpha_{21}(\gamma_2\delta_1 + \mu_3\mu_2 + \mu_3\delta_1 + \gamma_2\mu_2) + \alpha_{12}(\mu_3\mu_2 + \gamma_2\delta_1 + \gamma_2\mu_2 + \mu_3\delta_1) + 2\gamma_2\delta_1\mu_2 + 2\mu_3\delta_1\mu_2;$$

$$p = \frac{\delta_1\alpha_{12}(\alpha_{12} + \mu_3 + \delta_1 + \alpha_{21} + \mu_2) + \delta_1\mu_3(\mu_2 + \delta_1)}{\mu_3 p_1};$$

$$p_1 = \alpha_{12}^2(\delta_1 + \mu_2) + \alpha_{21}^2(\delta_1 + \mu_2) + alpha_{12}(\mu_2\mu_3 + \delta_1\mu_3 + 2\delta_1\mu_2 + \mu_2^2 + \delta_1^2) + \alpha_{21}(\mu_2\mu_3 + \delta_1\mu_3 + 2\delta_1\mu_2 + \mu_2^2 + \delta_1^2) + 2\alpha_{12}\alpha_{21}(\mu_2 + \delta_1) + \mu_2^2\mu_3 + \mu_3\delta_1^2 + 2\mu_2\mu_3\delta_1;$$

$$f = \frac{\delta_1\gamma_2\alpha_{12}(\alpha_{12} + \mu_3 + \delta_1 + \alpha_{21} + \mu_2)}{\mu_5 f_1};$$

$$f_1 = \alpha_{12}^2(\mu_5\delta_1 + \mu_2\mu_5 + \delta_1\gamma_2 + \mu_2\gamma_2) + \alpha_{21}^2(\mu_5\delta_1 + \mu_2\mu_5 + \delta_1\gamma_2 + \mu_2\gamma_2) + \alpha_{12}(\mu_2\mu_3\mu_5 + \gamma_2\delta_1\mu_3 + \mu_2\mu_3\gamma_2 + \mu_3\mu_5\delta_1 + \mu_2^2\gamma_2 + 2\gamma_2\delta_1\mu_2 + \gamma_2\delta_1^2 + 2\mu_5\delta_1\mu_2 + \mu_5\delta_1^2 + \mu_3\mu_2^2) + \alpha_{21}(\mu_2\mu_3\mu_5 + \gamma_2\delta_1\mu_3 + \mu_2\mu_3\gamma_2 + \mu_3\mu_5\delta_1 + \mu_2^2\gamma_2 + 2\gamma_2\delta_1\mu_2 + \gamma_2\delta_1^2 + 2\mu_5\delta_1\mu_2 + \mu_5\delta_1^2 + \mu_3\mu_2^2) + 2\alpha_{12}\alpha_{21}(\gamma_2\mu_2 + \gamma_2\delta_1 + \mu_2\mu_5 + \mu_5\delta_1) + \mu_2^2\mu_3\mu_5 + \mu_3\mu_5\delta_1^2 + \mu_3\gamma_2\delta_1^2 + \mu_2^2\mu_3\gamma_2 + 2\mu_2\mu_3\gamma_2\delta_1 + 2\mu_2\mu_3\mu_5\delta_1;$$

$$a_1 = \frac{\beta_5\lambda_2}{\mu_6}; \quad b_1 = \frac{\beta_3\lambda_2}{\mu_6}; \quad c_1 = \frac{\beta_2\lambda_1}{\mu_4 + \gamma_1}; \quad d_1 = \frac{\beta_1\alpha_{12}\gamma_1\lambda_1}{\mu_1(\mu_4 + \gamma_1)(\alpha_{21} + \mu_1)(\alpha_{12} + \alpha_{21} + \mu_1)}; \quad e_1 = \frac{\beta_4\lambda_2}{\mu_6}$$

Analysis of The Centre Manifold Near $x = x_0$, $R_0 = 1$ for the Model

According to van den Driessche &Watmough, 2002, we consider the nature of the equilibrium solutions of the disease transmission model near the bifurcation point $x = x_0, R_0 = 1$. Since R_0 is often inconvenient to use directly as bifurcation parameter, we introduce a bifurcation parameter θ. Let θ be a bifurcation parameter such that $R_0 < 1$ for $\theta < 0$ and $R_0 > 1$ for $\theta > 0$ and such that x_0 is a DFE for all values of θ. Let us consider the system

$$\dot{x} = f(x, \theta)$$

where f is as described in (2). The choice of θ is given below, when the quantity b is calculated. The position of the DFE depends particularly on the choice of θ and the local stability changes at the point $(x_0, 0)$. The results of centre manifold theory (Wiggins, 1990) are used here to show that there are nontrivial (endemic) equilibria near the bifurcation point $(x_0, 0)$.

The notation $J_0 = D_x f(x_0, 0)$ is used for the partial derivative of f with respect to x evaluated at $x = x_0$ and $\theta = 0$ where θ is specified below. Let v and w be the corresponding left and right eigenvectors chosen such that $vJ_0 = 0$ and $J_0 w = 0$ with $vw = 1$ where $v = [v_1, v_2, v_3, v_4, v_5, v_6, v_7, v_8, v_9, v_{10}]$ and $w = [w_1, w_2, w_3, w_4, w_5, w_6, w_7, w_8, w_9, w_{10}]^T$. Following reference van den Driessche &Watmough, 2002, we define

$$a = \frac{v}{2} D_{xx} f(x_0, 0) w^2 = \frac{1}{2} \sum_{i,j,k=1}^{n} v_i w_j w_k \frac{\partial^2 f_i}{\partial x_j \partial x_k}(x_0, 0)$$

$$b = v D_{x\theta} f(x_0, 0) w = \sum_{i,j=1}^{n} v_i w_j \frac{\partial^2 f_i}{\partial x_j \partial \theta}(x_0, 0)$$

In this model, we have $n = 10$ and now we find the values of a and b. The sign of a as well as the value of b will help in determining the nature of the endemic equilibria near the bifurcation point.

For $i = 1$

$$a_1 = \frac{1}{2} \sum_{j,k=1}^{10} v_1 w_j w_k \frac{\partial^2 f_1}{\partial x_j \partial x_k}(x_0, 0) = 0$$

Similarly, for $i = 2, \cdots, 6$, we get, $a_2 = 0, a_3 = v_3 w_1 w_9 \beta_2, a_4 = v_4 w_3 w_{10} \beta_1 + v_4 w_6 w_{10} \beta_4 + v_4 w_2 w_{10} \beta_5, a_5 = 0, a_6 = v_6 w_4 w_8 \beta_1, a_7 = 0, a_8 = -v_8 w_4 w_8 \beta_1, a_9 = -v_9 w_3 w_9 \beta_2$ and $a_{10} = -v_{10} w_3 w_{10} \beta_3 - v_{10} w_6 w_{10} \beta_4 - v_{10} w_2 w_{10} \beta_5$ respectively. Thus, we have

$$a = a_1 + \cdots + a_{10} = (w_2 w_{10} \beta_5 + w_3 w_{10} \beta_3 + w_6 w_{10} \beta_4)(v_4 - v_{10}) + w_4 w_9 \beta_2 (v_3 - v_9) + w_4 w_8 \beta_1 (v_6 - v_8) \quad (3)$$

In order to find the value of b, let us consider R_0 as a function of β_1 i.e., $R_0 = R_0(\beta_1)$ and fix all other parameters. Let β_1^* be the value of β_1 such that $R_0(\beta_1^*) = 1$. Let $\theta = \beta_1 - \beta_1^*$, then $R_0 = R_0(\theta)$ with $R_0(0) = 1$.

For $i = 1$

$$b_1 = \sum_{j=1}^{10} v_1 u_j \frac{\partial^2 f_1}{\partial x_j \partial \theta}(x_0, 0) = 0$$

Similarly, for $i = 2, \cdots, 10$, we get, $b_2 = b_3 = b_4 = b_5 = 0, b_6 = v_6 w_4 x_8 + v_6 w_8 x_4, b_7 = 0, b_8 = -v_8 w_4 x_8 - v_8 w_8 x_4$ and $b_9 = b_{10} = 0$ respectively. Thus, we have

$$b = b_1 + \cdots + b_{10} = (w_4 x_8 + w_8 x_4)(v_6 - v_8) \quad (4)$$

Now using the condition $vJ_0 = 0$ and $J_0 w = 0$, we can easily find v and w as

$$v = (1, \frac{\alpha_{12} + \mu_3}{\alpha_{12}}, k_4, k_1, k_2, k_3, 0, 0, 0, 0) v_1^*$$

where

$$k_1=\frac{\mu_3(\alpha_{21}+\alpha_{12}+\mu_3)}{\alpha_{12}\beta_5 x_{10}};\quad k_2=\frac{\delta_1(\alpha_{12}+\alpha_{21}+\mu_2+\mu_3+\delta_1)+\alpha_{12}\beta_4 x_{10}k_1}{(\mu_3+\delta_1)(\alpha_{21}+\alpha_{12}+\mu_2+\delta_1)};$$
$$k_3=\frac{(\alpha_{12}+\mu_2+\delta_1)k_2-\delta_1}{\alpha_{12}};\quad k_4=\frac{\mu_7 k_1-\beta_1 x_8 k_3}{\beta_2 x_9} \tag{5}$$

and

$$w=(l_6 l_5,\frac{\beta_2 x_9}{\mu_5+\gamma_2},1,l_3,l_4,l_2,l_1,-\frac{\beta_2 x_9}{\mu_4+\gamma_1},-l_7)w_4^*$$

where

$$\begin{cases} l_1 = \dfrac{\alpha_{12}\gamma_1\beta_2 x_9-\beta_1 x_8(\alpha_{12}+\mu_1)(\mu_4+\gamma_1)}{\mu_1(\mu_4+\gamma_1)(\alpha_{21}+\alpha_{12}+\mu_1)} \\ l_2 = \dfrac{\alpha_{21}(\mu_4+\gamma_1)-\beta_2 x_9\gamma_1}{(\alpha_{12}+\mu_1)(\mu_4+\gamma_1)} \\ l_3 = \dfrac{\beta_2 x_9\gamma_2(\alpha_{21}+\mu_2+\delta_1)+\alpha_{21}\beta_1 x_8(\mu_5+\gamma_2)}{(\mu_2+\delta_1)(\mu_5+\gamma_2)(\alpha_{12}+\alpha_{21}+\mu_2+\delta_1)} \\ l_4 = \dfrac{(\mu_5+\gamma_2)(\alpha_{12}+\mu_2+\delta_1)l_3-\gamma_2\beta_2 x_9}{\alpha_{21}(\mu_5+\gamma_2)} \\ l_5 = \dfrac{\mu_7(\mu_5+\gamma_2)-\beta_2\beta_3 x_9 x_{10}-\beta_4 x_{10}l_4(\mu_5+\gamma_2)}{\beta_5 x_{10}(\mu_5+\gamma_2)} \\ l_6 = \dfrac{l_5(\alpha_{12}+\mu_3)-\delta_1 l_4}{\alpha_{12}} \\ l_7 = \dfrac{\beta_5 x_{10}l_5(\mu_5+\gamma_2)+\beta_2\beta_3 x_9 x_{10}+\beta_4 x_{10}l_4(\mu_5+\gamma_2)}{\mu_6(\mu_5+\gamma_2)} \end{cases}$$

Since $R_0=1$ (i.e., $-(\mu_5+\gamma_2)k_4+\beta_5 x_{10}k_1+\gamma_2 k_2=0$) and $-(\alpha_{12}+\mu_3)l_6+\alpha_{21}l_5+\delta_1 l_3=0$, we have $v_1=v_1^*\neq 0$ and $w_4=w_4^*\neq 0$.

Let $w_4^*=1$ then the condition $vw=1$ gives

$$v_1^*=\frac{1}{Q_1-Q_2}$$

where

$$Q_1=(\frac{\alpha_{21}\mu_3(\mu_5+\gamma_2)+\beta_2\beta_4\gamma_2 x_9 x_{10}}{\alpha_{21}\beta_5 x_{10}(\mu_5+\gamma_2)})(\frac{\alpha_{21}+\alpha_{12}+2\mu_3}{\alpha_{12}})+k_1+k_2 l_3+\frac{\mu_3 k_1\alpha_{12}+\beta_1 x_8\delta_1}{\alpha_{12}(\mu_5+\gamma_2)}+\frac{k_2 l_3(\alpha_{12}+\mu_2+\delta_1)^2}{\alpha_{12}\alpha_{21}}+\frac{\delta_1\gamma_2\beta_2 x_9}{\alpha_{12}\alpha_{21}(\mu_5+\gamma_2)}$$

and

$$Q_2=\frac{\beta_2\beta_3 x_9(\alpha_{21}+\mu_3)}{\alpha_{12}\beta_5(\mu_5+\gamma_2)}+\frac{l_5(\beta_4(\alpha_{21}+\mu_3)+\beta_5\delta_1)(\alpha_{12}+\mu_2+\delta_1)}{\alpha_{12}\alpha_{21}\beta_5}+(\frac{\alpha_{12}+\mu_3}{\alpha_{12}})(\frac{\beta_2\beta_3 x_9}{\beta_5(\mu_5+\gamma_2)})+\frac{\beta_4 l_3(\alpha_{12}+\mu_2+\delta_1)}{\beta_5\alpha_{21}}$$
$$+(\frac{\beta_2 x_9}{\mu_5+\gamma_2})(\frac{\beta_1 x_8 k_2(\alpha_{12}+\mu_2+\delta_1)}{\alpha_{12}\beta_5 x_9})+\frac{\gamma_2\beta_2 x_9 k_2(\alpha_{12}+\mu_2+\delta_1)}{\alpha_{12}\alpha_{21}(\mu_5+\gamma_2)}+\frac{\delta_1 l_3(\alpha_{12}+\mu_2+\delta_1)}{\alpha_{12}\alpha_{21}}$$

Substituting the values of v and w in equation (3) and (4) we get

$$a = \frac{P_1 - P_2}{Q_1 - Q_2}$$

where

$$P_1 = \beta_5 l_7 k_1 l \left(\frac{\mu_7 \alpha_{21} (\mu_5 + \gamma_2) + \beta_2 \beta_4 \gamma_2 x_9 x_{10} + \alpha_{21} \beta_2 \beta_3 x_9 x_{10}}{\beta_5 x_{10} \alpha_{21} (\mu_5 + \gamma_2)} \right)$$
$$+ \beta_5 l_7 k_1 \left(\frac{\beta_4 x_{10} l_3 (\mu_5 + \gamma_2)(\alpha_{12} + \mu_2 + \delta_1)}{\beta_5 x_{10} \alpha_{21} (\mu_5 + \gamma_2)} \right) + \frac{\beta_1 \beta_2 x_8 k_2 (\alpha_{12} + \mu_2 + \delta_1)}{\alpha_{12} (\mu_4 + \gamma_1)}$$
$$+ \frac{\beta_1 \beta_2 x_9 \alpha_{12} \gamma_1 k_2 (\alpha_{12} + \mu_2 + \delta_1)}{\alpha_{12} \mu_1 (\mu_4 + \gamma_1)(\alpha_{12} + \alpha_{21} + \mu_1)} + \frac{\beta_1^2 x_8 \delta_1 (\alpha_{12} + \mu_1)}{\alpha_{12} \mu_1 (\alpha_{12} + \alpha_{21} + \mu_1)}$$

and

$$P_2 = \left(\frac{\beta_2 \beta_3 x_9}{\mu_5 + \gamma_2} + \frac{\beta_4 l_3 (\alpha_{12} + \mu_2 + \delta_1)}{\alpha_{21}} + \frac{\beta_2 \beta_4 x_9 \gamma_2}{\alpha_{21} (\mu_5 + \gamma_2)} \right) l_7 k_1$$
$$+ \frac{\beta_2^2 x_9 (\mu_7 k_1 \alpha_{12} + \beta_1 x_8 \delta_1)}{\alpha_{12} \beta_2 x_9 (\mu_4 + \gamma_1)} + \frac{\beta_1 \beta_2 x_9 \gamma_1 \delta_1}{\mu_1 (\mu_4 + \gamma_1)(\alpha_{12} + \alpha_{21} + \mu_1)}$$
$$+ \frac{\beta_1^2 x_8 k_2 (\alpha_{12} + \mu_1)(\alpha_{12} + \mu_2 + \delta_1)}{\alpha_{12} \mu_1 (\alpha_{12} + \alpha_{21} + \mu_1)}$$

and

$$b = \frac{\alpha_{12} \gamma_1 \lambda_1 k_3}{\mu_1 (Q_1 - Q_2)(\mu_4 + \gamma_1)(\alpha_{21} + \mu_1)(\alpha_{12} + \alpha_{21} + \mu_1)}$$

By using equations of (5), it can be shown by direct calculation that k_3 is strictly positive. Thus, b is nonzero, and so Theorem 2 of Appendix B (van den Driessche &Watmough, 2002) can be used to distinguish between a forward or backward bifurcation.

Now the sign of a, denoted by $Sgn(a)$ can be expressed as

$$Sgn(a) = Sgn((P_1 - P_2)(Q_1 - Q_2))$$

Since we have already observed that $b \neq 0$ then the stability of the model can be explained with respect to the sign of a. Now by Theorem 2 of Appendix B (van den Driessche &Watmough, 2002) if $a < 0$, then there are locally asymptotically stable endemic equilibria near x_0 for $0 < \theta < \delta$ where $\delta > 0$ and if $a > 0$, then there are unstable endemic equilibria near x_0 for $-\delta < \theta < 0$ where $\delta > 0$.

Numerical Simulations and Discussions for the Model of HIV Transmission

Estimation of Parameters Used in the Model

To illustrate the various theoretical results already discussed, the model is simulated using parameter values/ranges shown in Table 1. Choice of numerical values for the model's parameter values is based upon

published data on the transmission dynamics of HIV in one of the major cities, Delhi, India. All population sizes are considered here in thousands. Since AIDS is a sexually transmitted disease, we restrict our analysis to the population that is age 15 or older.

The life expectancy of male after 15 years of age is 55.6 years (so that $\mu_1 = \mu_4 = \frac{1}{55.6} = 0.0178$ per year) and the life expectancy of female after 15 years of age is 58.8 years (so that $\mu_6 = \frac{1}{58.8} = 0.017$ per year) (Census of India 2001, 2006). The average male age at marriage at Delhi in India is 23.1 years (so that $\gamma_1 = \gamma_2 = \frac{1}{23.1} = 0.0433$ per year) (Census of India 2001, 2006). The population size is assumed equivalent to the population size at DFE.

Table 1: Description and estimation of parameters for the HIV transmission model

Parameter	Description	Estimated value/range
λ_1	Recruitment rate of susceptible single males into the community (in thousands)	102.5258/year
λ_2	Recruitment rate of susceptible FSWs into the community (in thousands)	0.595/year
α_{12}	Rate at which faithful husbands become unfaithful	$\alpha_{12} \in [0,1.2]$/year
α_{21}	Rate at which unfaithful husbands become faithful	$\alpha_{21} \in [0,0.5]$/year
μ_1	Death rate of M_{1SS}, M_{2SS}	0.0178/year
μ_2	Death rate of M_{1IS}, M_{2IS}	0.0857/year
μ_3	Death rate of M_{1II}, M_{2II}	0.0857/year
μ_4	Death rate of M_S	0.0178/year
μ_5	Death rate of M_I	0.0857/year
μ_6	Death rate of F_S^S	0.017/year
μ_7	Death rate of F_I^S	0.0857/year
γ_1	Rate at which M_S gets married	0.0433/year
γ_2	Rate at which M_I gets married	0.0433/year
c_1	Husband-wife unprotected sexual contact rate	$c_1 \in [0.1,0.5]$/year
c_2	FSW-male unprotected sexual contact rate	$c_2 \in [0.1,1.5]$/year
β_{01}	Male to female transmission probability per unprotected sexual contact	0.00105/year
β_{02}	Female to male transmission probability per unprotected sexual contact	0.00155/year
β_1	Transmission rate at which new infection goes to M_{2SS} from F_I^S	$\beta_{02}c_2$ /year
β_2	Transmission rate at which new infection goes to M_S from F_I^S	$\beta_{02}c_2$ /year
β_3	Transmission rate at which new infection goes to F_S^S from M_I	$\beta_{01}c_2$ /year
β_4	Transmission rate at which new infection goes to F_S^S from M_{2IS}	$\beta_{01}c_2$ /year
β_5	Transmission rate at which new infection goes to F_S^S from M_{2II}	$\beta_{01}c_2$ /year
δ_1	The rate at which infected husband infects wife	$\beta_{01}c_1$ /year

Since the population size of single unmarried males and FSWs in thousands are 3042 and 35 (AIDS/HIV in Delhi, 2005), respectively then we have $\lambda_1 = M_S(\mu_4 + \gamma_1)$ and $\lambda_2 = F_S^S \mu_6$. Thus, new recruitment of susceptibles into the community are $\lambda_1 = 102.5258$ and $\lambda_2 = 0.595$ per year for males and FSWs, respectively. The incubation period is between 8-12 years (Rao, 2003). Furthermore, for this population, the expected lifespan after diagnosis with AIDS is 20 months i.e., 1.67 years (Gumel et al, 2006) (so that $\mu_2 = \mu_3 = \mu_5 = \mu_7 = \frac{1}{(10+1.667)} = 0.0857$ per year).

The rate of HIV transmission from FSWs to clients is 0.0011-0.002 per unprotected sexual contact (Gisselquist & Correa, 2006). Here, we take the average (i.e., $\beta_{02}=0.00155$). The rate of HIV transmission from male to female is 0.0005-0.0016 per unprotected sexual contact (Johnson et al 2006). Here, we take the average (i.e., $\beta_{01}=0.00105$) as well. In Delhi the average number of client contact of FSWs 1440 per year (Census of India 2001, 2006) (so that $\beta_i=\beta_{02}c_2$ per year for $i=1,2$ and $\beta_i=\beta_{01}c_2$ per year for $i=3,4,5$ where $0.1<c_2<1.5$). We consider the average number of unprotected sexual contact between husband and wife in Delhi is c_1 (so that $\delta_1=\beta_{01}c_1$ where $0.1<c_1<0.5$, say) and we have also assumed the ranges of how many faithful husbands become unfaithful as well as how many unfaithful husbands become faithful per thousand per year in the subject to their sexual relationship (so that $\alpha_{12}\in[0,1.2]$ and $\alpha_{21}\in[0,0.5]$ per year).

The size of the heterosexual community in Delhi is approximately 9351 (age 15+) (Census of India 2001, 2006) where susceptible males and females are 5201 and 4115 according to (Census of India 2001, 2006) and susceptible FSWs are 35 according to (AIDS/HIV in Delhi, 2005). According to the census of India 2001, the percentage of married males and females in Delhi is 37.67% and 35.56% (Census of India 2001, 2006). The susceptible unmarried males are 3206 and susceptible married couples are 3206 where we consider 5% is unfaithful couple. HIV infected males, females and FSWs are 16.830, 8.896 and 2.334 respectively in Delhi (Census of India 2001, 2006; AIDS/HIV in Delhi, 2005; Rao & Kakehashi, 2004). It is assumed that the total number of HIV infected faithful and unfaithful couples in Delhi in 2001 is zero (so that the initial values of M_{1H} and M_{2H} are zero).

Some Important Diagrams for the Model

In this section, we show different plots for the model for various parameter sets discussed in the previous section.

Figure 1 shows solutions to the DFE of the model as FSW-male coital contact rate, the rate at which faithful husband becomes unfaithful and the rate at which unfaithful husband becomes faithful per thousand per year are considered here to be less (i.e., $c_2=0.2,\alpha_{12}=0.05$ and $\alpha_{21}=0.5$) than the real situation of Delhi. This gives a basic reproduction number $R_0=0.6368$. It shows that the disease dies out.

Figure 2 delineates the same solution graph as Figure 5.1 where log scale is used along Y-axis.

Figure 3 depicts the solutions limiting to the EE of the model as FSW-male coital contact rate per thousand per year is taken to be more than that assumed in Figure 5.1 (i.e., $c_2=0.3$). The rate at which faithful husbands become unfaithful and the rate at which unfaithful husbands become faithful per thousand per year are chosen arbitrarily (i.e., $\alpha_{12}=0.5$ and $\alpha_{21}=0.005$) since no data is available. It shows that $R_0=10.9369$ and the disease persists, limiting to the EEP.

Figure 4 depicts the combined effect of the rate of change in faithful husband becomes unfaithful (α_{12}) and the rate of change in unfaithful husband becomes faithful (α_{21}) on the basic reproduction number R_0. This contour plot shows a marked increase in R_0 with increasing (α_{12}) as well as decreasing (α_{21}).

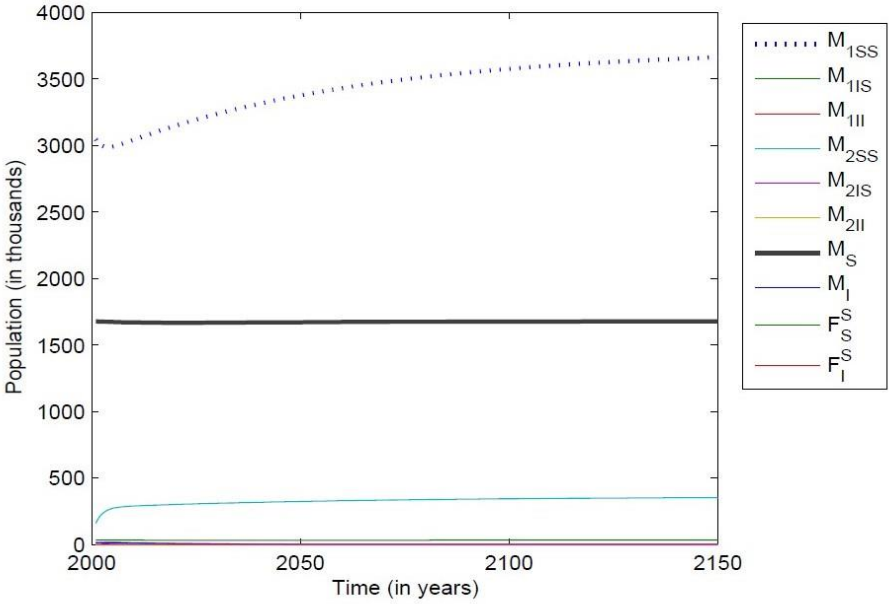


Figure 1. Trends of HIV, AIDS and susceptible population in DFE. The figure is drawn with $c_1 = 0.3, c_2 = 0.2, \alpha_{12} = 0.05$ and $\alpha_{21} = 0.5$ and all other parameters are as in Table 1.

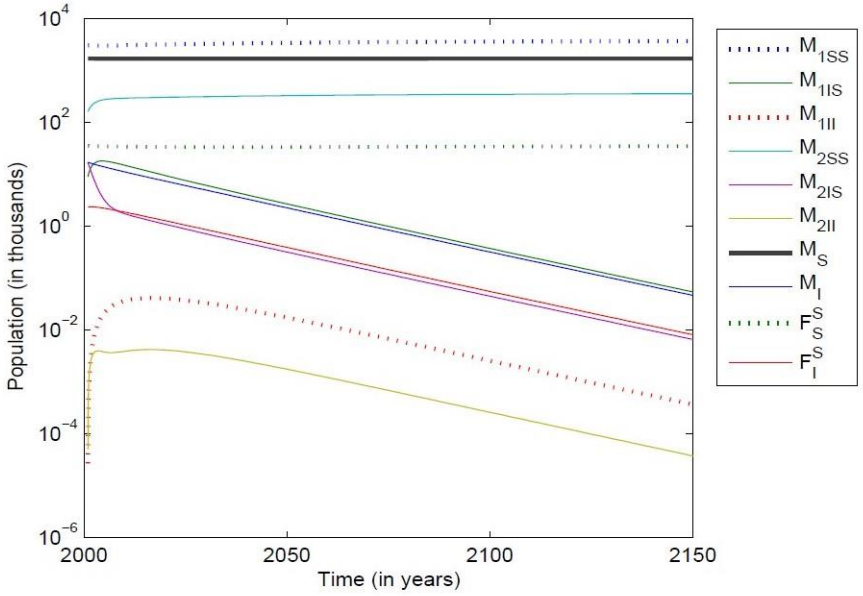


Figure 2. Trends of HIV, AIDS and susceptible population in DFE where log scale is used along Y-axis. The figure is drawn with $c_1 = 0.3, c_2 = 0.2, \alpha_{12} = 0.05$ and $\alpha_{21} = 0.5$ and all other parameters are as in Table 1.

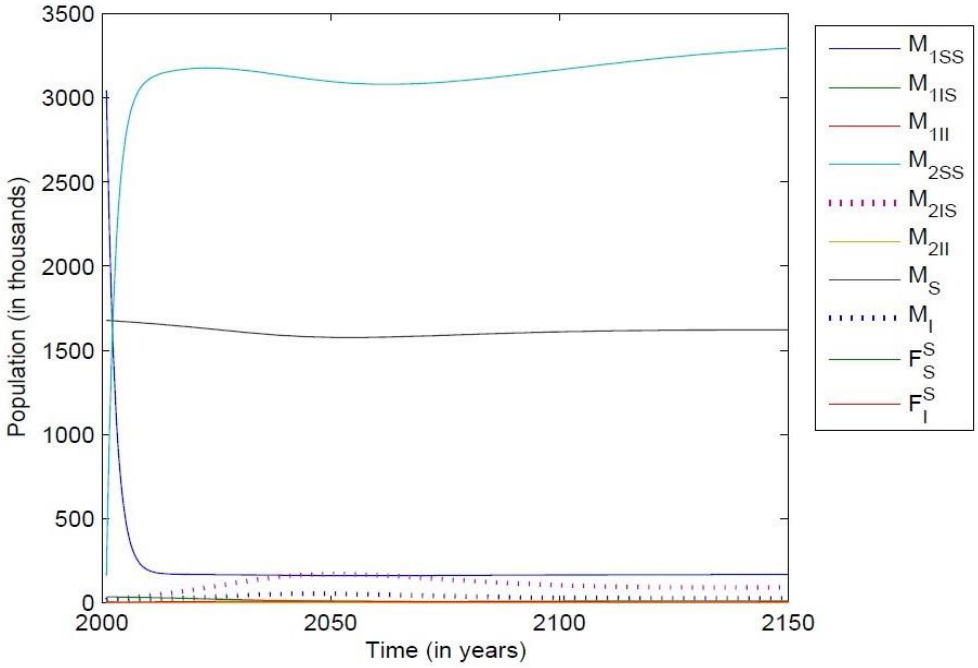


Figure 3. Trends of HIV, AIDS and susceptible population in EE. The figure is drawn with $c_1 = 0.3, c_2 = 0.3, \alpha_{12} = 0.5$ and $\alpha_{21} = 0.005$ and all other parameters are as in Table 1.

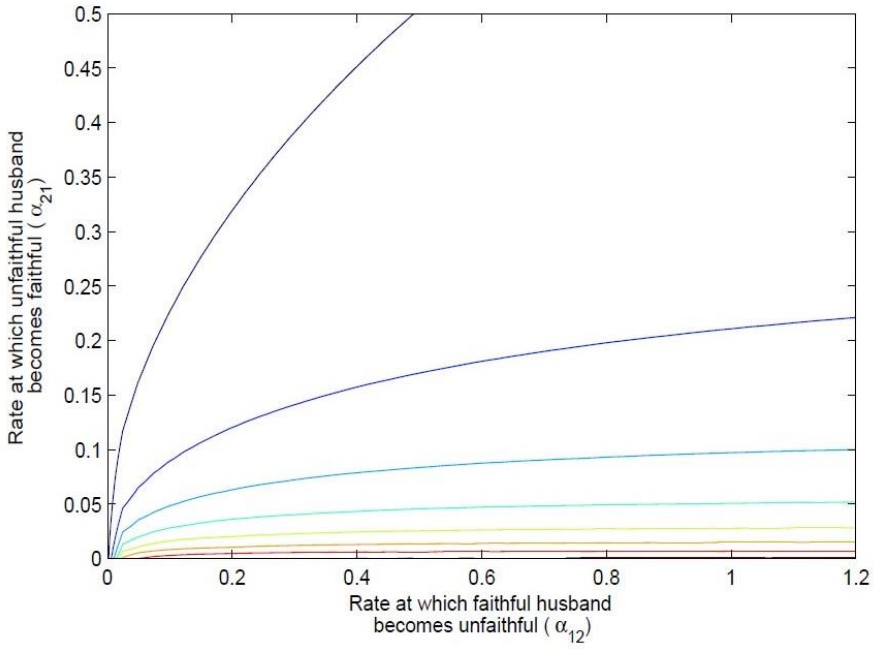


Figure 4. Contour plot of R_0 as a function of the rate at which faithful husband becomes unfaithful (α_{12}) and the rate at which unfaithful husband becomes faithful α_{21}. The figure is drawn using $c_1 = 0.3, c_2 = 1.440$ and other parameters are as in Table 1. The higher curves correspond to lower values of R_0.

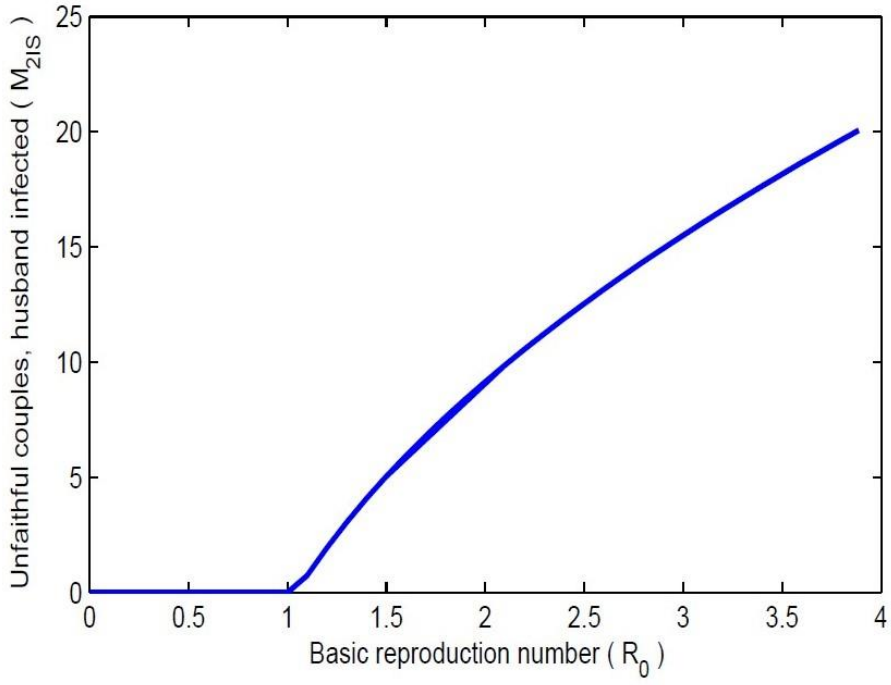


Figure 5. Bifurcation in the $(R_0(c_2), M_{2IS}(c_2))$−plane. The vertical axis measures the number of unfaithful couples where husbands are infected at equilibrium for different values of R_0.

Furthermore, in Figure 5, the bifurcation diagram for the model is represented using parameter values $c_1 = 0.3, c_2 \in [0.1, 1.5], \alpha_{21} = 0.5, \alpha_{12} = 0.075$ and other parameters are as in Table 1, which shows that the disease-free and endemic equilibria exchange stability when the basic reproduction number R_0 is 1. We note that, as c_2 is varied, a forward bifurcation occurs rather than a backward bifurcation. Also, note that $a = -1.7745 \times 10^{-5}$ (i.e., negative). Thus, for $R_0(c_2) < 1$, the DFE is stable whereas for $R_0(c_2) > 1$, the DFE is unstable and the EEP is stable.

Conclusion

In our model, the potential impact of the presence of unfaithful husbands in sense of sexual relationship with high-risk core group of people (i.e. FSWs) is assessed in growing the spread and the persistency of AIDS epidemic in the community. Numerical simulations are carried out using reasonable sets of parameter values to assess the impact of unprotected coital contact rates between males and FSWs and the rate of change at which faithful husbands become unfaithful. We show that the unprotected sexual relationship among single males, unfaithful husbands and the core group of FSWs is the major factor in sustaining HIV/AIDS levels in the community.

This model of HIV transmission has asymptotically stable disease-free equilibria whenever the basic

reproduction number is less than one. When this number is greater than one, there is a unique endemic equilibrium. The model shows that there is a possibility of a population collapse if all the parameter values remain constant (i.e., no initiatives are taken for changing the behavioural parameters). This model can contribute to the planning of preventive procedures in case of FSW-driven sexual behaviour in India. Behavioural parameters can also help public health planning. For example, lowering the values of parameters such the rate at which faithful husbands become unfaithful (α_1) and FSW-male unprotected sexual contact rate (α_2) would be helpful for controlling the AIDS epidemic. Overall, this study shows that the HIV/AIDS epidemic would not occur in a heterosexual community, such as the Indian community if proper steps (for example, condom promotion for FSWs, advertisement for AIDS awareness etc.) are taken by government and non-government organizations and are implemented effectively.

Acknowledgements

The author would like to thank Prof. Connell McCluskey from Wilfrid Laurier University, Ontario, Canada for his guidance and help while doing this research work.

References

AIDS/HIV in DELHI. (2005). Meeting the Challenge, Delhi State AIDS Control Society, Government of Delhi, Population Foundation of India and Population Reference Bureau, New Delhi, India.

Census of India 2001 (2006), Report of the technical group on population projections constituted by the national commission on population.

Diekmann, O., Heesterbeek, J.A.P. & Metz, J.S.J. (1990). On the definition and the computation of the basic reproduction number ratio R0 in models for infectious diseases in heterogeneous populations, *J.Math.Bio*. 28, 365-382.

Dorabjee, J., and Samson, L. (2000) A multi-centre rapid assessment of injecting drug use in India, *International Journal of Drug Policy* 11, 99-112.

Eicher, A. D., Crofts, N., Benjamin, S., Deutschmann, P. & Rodger, A. J. (2000). A certain fate: spread of HIV among young injecting drug users in Manipur, northeast India, *AIDS care- Psychological and Socio-Medical Aspects of AIDS* 12, 497-504.

Gangakhedkar, R. R., Bentley, M. E., Divekar, A.D., Gadkari, D., Mehendale, S. M., Shepherd, M. E., Bollinger, R.C. & Quinn, T. C. (1997). Spread of HIV infection in married monogamous women in India, *Journal of the American Medical Association* 278 2090-2092.

George, S., Jacob, M., John, T. J., Jain, M. K., Nathan, N., Rao, P. S. S., Richard, J. & Antonisamy, B. (1997). A case-control analysis of risk factors in HIV transmission in South India, *Journal of Acquired Immune Deficiency Syndromes and Human Retrovirology* 14, 290-293.

Gisselquist, D. & Correa, M. (2006). How much does heterosexual commercial sex contribute to India's HIV epidemic?, *International Journal of STD and AIDS* 17: 736-742.

Gumel, A.B., McCluskey, Connell C. & van den Driessche, P. (2006). Mathematical study of a Staged-Progression HIV Model with Imperfect Vaccine, *Bulletin of Mathematical Biology* 68: 2105-2128.

Hethcote, H. W. (2000). The mathematics of infectious disease, *SIAM Rev*. 42, 599-653.

Johnson, L., Dorrington, R. & Matthew. (2006). An uncertainty analysis and sensitivity analysis of the ASSA2002 AIDS and Demographic model, *Centre for Actuarial Research working paper*.

Rahman, K. A. (2023). Modelling the spread of HIV/AIDS in India focusing commercial sex worker, *International Journal of Modeling and Optimization* (Accepted).

Rao, A. S. R. S. & Kakehashi, M. (2004) A combination of differential equations and convolution in understanding the spread of an epidemic, *Sadhana* Vol. 29, Part 3, pp. 305-313.

Rao, A. S. R. S. (2003). Mathematical modelling of AIDS epidemic in India, *Current Science*, Vol.84, No.9.

Roy, M. A. & May, R.M. (1991). *Infectious diseases of Humans*, Oxford University Press, Oxford.

Shannon et. al. (2015). Global epidemiology of HIV among female sex workers: influence of structural determinants, *Lancet* 385: 55–71 http://dx.doi.org/10.1016/S0140-6736(14)60931-4

Van den Driessche, P. & Watmough, J. (2002) Reproduction numbers and sub- threshold endemic equilibria for compartmental models of disease transmission", *Elsevier (Math. Biosci.)*.

World Health Organization (WHO) and Joint United Nations Program on AIDS (UNAIDS), Report on the global AIDS epidemic, (2006)

Wiggins, S. (1990) *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, Springer-Verlag, Berlin.

Welding 3D Printed Structures for Composite Sacrificial Tooling

Eric Kerr-Anderson, Kellie Hardecopf, Alex Hilo, Regan Harvey, Tasha Kemna, Dominic Perez, Matt Ficker, Kyle Gerold, Matt Wooden, Aidan Dungy, Brennon Coit

Winona State University, USA

Abstract: 3D printed parts offer the ability to generate dimensioned, complex objects with minimal machining touch time and skill, but they are typically very weak and limited in size. Strong and light composite parts require tooling to be created for the fabric to lay on while the resin is curing, but tooling can be quite expensive during the prototyping phase or for low part quantity runs. This study examined the techniques required to weld smaller 3D printed parts together to form large 3D printed tools that could be used as a sacrificial tool for a composite part. In this method, the 3D printed structure would remain inside the part and provide support and dimensional reference during the composite curing process. Friction, hot extrusion, and hot contact welding methods were examined using lap shear joints in both tensile and flexural test methods to determine effective joinery style and overlap lengths to achieve normal 3D printed properties. The results of this study demonstrated how multiple 3D printers could be used to create cost-effective rapid prototyping sacrificial tooling and low part quantity runs for composite structures by welding smaller 3D printed structures into a larger single 3D printed part.

Keywords: Sacrificial Tooling, Composite Tooling, 3D Printing, Plastic Welding

Citation: Kerr-Anderson, E., Hardecopf, K., Hilo, A., Harvey, R., Kemna, T., Perez, D., Ficker, M., Gerold, K., Wooden, M., Dungy, A., Coit, B. (2023). Welding 3D Printed Structures for Composite Sacrificial Tooling. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023-- International Conference on Life Sciences, Engineering and Technology* (pp. 55-66), Denver, CO, USA. ISTES Organization.

Introduction

Rapid prototyping represents a unique set of competing interests, but the ultimate goal is to get a part into a potential customer's hands as quickly as possible. The ability to quickly eliminate potential design options or make iterative improvements to the design before committing to the creation of expensive tooling is a very useful design tool. When evaluating manufacturing methods for rapid prototyping of composite parts, it is important to consider equipment cost, required operator skill, lead time of machining, effective detail, and nearness to final commercial product.

Plastic welding is a technique that is becoming more ubiquitous amongst the 3D printing community (France, 2013; Horvath & Cameron, 2020). There are three main 3D printing welding techniques that have been successfully demonstrated: the use of a hot soldering iron to smooth a ridge line or excess material together, the

use of a handheld rotary device to heat 2.85 mm filament and substrates with friction, and the use of a 3D pen to extrude additional material into the weld joint (Horvath & Cameron, 2020). Soldering irons can be used with a variety of tips to provide smoothing operations, hole opening, channel creation, or the removal of excess material. 3D printed designs utilizing welds may either print a ridge line to act as the excess weld material, or a chamfer is added to the weld joint allowing for printer filament to be placed and welded into the joint. Friction welding relies on material spinning at high rpm (~2000 rpm) to generate enough friction to locally heat and melt the 2 sides of the joint as well as the filament. In this case a 2.85 mm filament is cut and clamped as a tool in the spindle to provide a stiffer polymer rod for rotation. Friction welding will mix the polymer from both side walls and can result in a molten weld bead as seen in MIG and TIG applications (Maheshwari et al., 2018). There is no need for high temperature heat bands with the use of friction welding, which allows it to be used for all thermoplastic materials. 3D pens are handheld 3D printers that perform similarly to high temperature, precise glue guns. 3D pen extruder technology allows the same type/fill/color of material to be used for welding that was used to 3D print the base structures with precise temperature and feed rate control similar to a MIG welding system for steel (Horvath & Cameron, 2020).

Traditionally, composite parts are manufactured using wood molds, clay molds, flat glass tabletops, and steel tools that each are covered with a non-stick coating and a vacuum is typically used to assist in the molding process (Ammen, 1979; Callister & Rethwisch, n.d.; Kluz, 1981). Ultimately the process selected uses some means to hold a fabric infused with resin or a molten charge of plastic in a shape until it cures and/or cools down to form a structural part. The creation of flat panels is typically the easiest shape to manufacture, which is one reason why they are used for testing properties. Those properties are often packaged into a material card for Finite Element Analysis to virtually test a non-flat composite part as a fast-fail prototyping iterative cycle (Barbero, 2013; Gay, 2014; Agarwal et al., 2017). Another alternative is to simulate the performance using flat or pultruded assemblies that are equivalent to the structural performance of the final conformal part. 3D printing offers many advantages in generating realistic facsimiles of a final design to determine appropriate aesthetics and assembly fit with minimal training, touch time, and part cost. Fused deposition 3D printing has an inherent design flaw of a weak z-direction due to the stacking nature of FDM as shown in Figure 1 (Smyth, 2017; Garret et al., 2017; Tokotuu & Aranda, 2021).

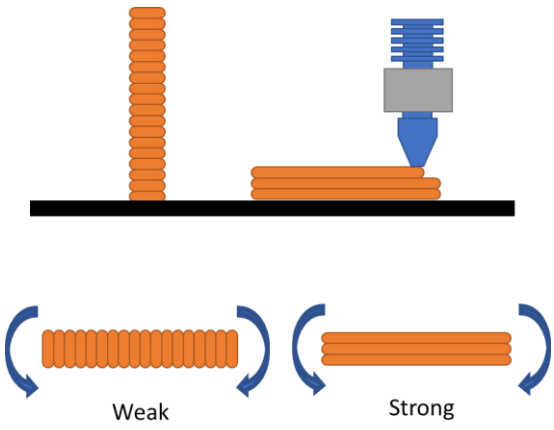


Figure 1: Anisotropic Properties of 3D Printed Parts.

This weakness has been mitigated by using short carbon fiber filled filament, co-extruding continuous fiber, or by utilizing SLA printers.

Sacrificial tooling is a very old process used to create a desired object preform first in a material that is easier to machine or fabricate prior to destroying the preform in the process of creating the same object in a different material. Investment casting involves using a wax preform that is surrounded by a ceramic slurry that is dried and heated in a furnace in which the ceramic hardens, and the wax preform burns/melts to create a cavity for metal pouring. The ceramic is water soluble which allows the metal part to be recovered easily after casting and provides a high detail that allows its significant use in the jewelry industry. Sand casting is another method that is used to pour high temperature cast iron into a preform of sand that is broken up after the pour is complete to recover parts (Ammen, 1979; Callister & Rethwisch, n.d.). Several 3D printers allow for water soluble support material to be printed in tandem with the print material to assist in complex geometry to be generated with easy post clean-up. For resin based composite processing methods, soluble supports may dissolve prior to resin cure if incompatible with the resin system. Most fabric based composite prototypes will utilize some form of foam or balsa core that can be easily shaped as sacrificial tooling, though anything that can hold resin-soaked fabric in place long enough for the resin to cure would provide adequate sacrificial tooling (Gay, 2014; Agarwal et al., 2017; Truong, 2020; Vaidya, 2011; Wick-Joliet et al., 2021). While hardwire cloth, saran wrap, and duct tape can be a quick stand-in for proper tooling, the precision of such tooling can be challenging. As parts become more complicated, the requirement of trial and error, tooling, equipment, expertise, and time increases dramatically.

The intent of this study was to add to the body of knowledge pertaining to the length of 3D printed weld joints needed to obtain welds as strong as the 3D printed parts for assemblies. As previously discussed, the strong plane is the X/Y plane. If a part is intentionally designed to be manufactured for use via 3D printing, it may be beneficial to break the part into several smaller parts that can take advantage of the print plane strength prior to assembly and welding as shown below in Figure 2.

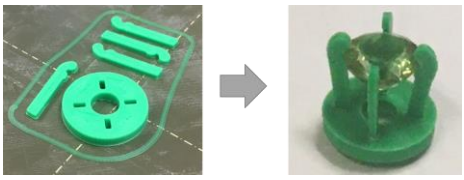


Figure 2: 3D printed bezel assembly with weld below

3D printing has been used to create sacrificial preforms that allow for carbon fiber fabric to be applied to the surface of the part for strength and aesthetics with minimal equipment. Big composite parts require big tools, and anything larger than 8-10 inches is too big to print on most commercial 3D printers. While it is ideal to print one solid part at scale, the equipment needed to do so is expensive, can be experimental, and will take a longer time to print. In many cases, several standard printers could cost the same as one large printer. By splitting the larger part into several small parts, the job can be dispersed on several machines printed at the same time as shown in

Figure 3.

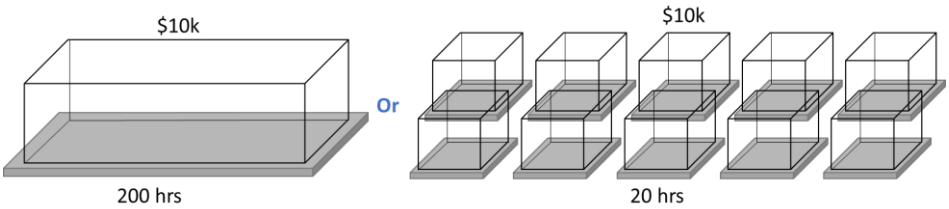


Figure 3: Comparison of 1 large 3D printer to multiple standard 3D printers

There are ways to section a large part into several smaller parts with a set lap joint to provide alignment and weld placement as shown below in Figure 4.

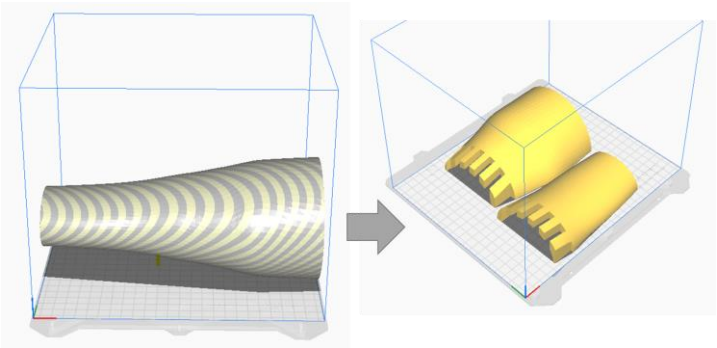


Figure 4: Parts too large for a printer need to be scaled down or partitioned

The challenge with printing several smaller parts and reassembling them revolves around understanding the tolerancing of the machines that are used to ensure slip fit, and alignment drift as multiple parts are assembled.

Method

Tensile Lap Shear Testing

In year 1 of this project tensile lap shear testing was conducted in two rounds; experimental techniques and strength assessment. Parts were first modelled and printed in PLA to replicate an ISO 1A tensile bar with a half lap gage length of 30 mm as shown below in Figure 5.

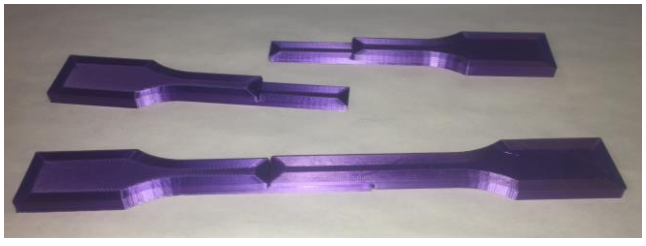


Figure 5: 3D printed single lap shear joints

Parts were printed using a layer height of 0.15 mm, wall count of 8, top/bottom layer count of 6 with 20% infill.

After practice and experimentation, several welds were created by four students using 3D printing pens, friction welding, and hot-pressing techniques with a soldering iron as shown in Figure 6.

Figure 6: (a) 3D printing extrusion pens, (b) Friction welding with a rotary tool, (c) soldering iron

A multi-technique approach used a 3D printing extrusion pen to create a weld by heating the nozzle tip prior to plunging it into the weld gap between parts and extruding PLA into the gap while moving the pen followed by a smoothing and compressing of the weld bead line with a soldering iron. The second round of testing focused on the different combinations of using soldering iron with or without additional filament placed on top of the weld joint and the use of a 3D pen extrusion plunged into the weld joint. Each of the categories had 5 specimens analyzed. Tensile lap shear specimens were clamped in an Instron 68TM-50 load frame, and pulled in tension to failure at a rate of 1 mm/min.

Flexural Lap Weld Testing

In year 2 of this project flexural testing was conducted on 3D printed PLA parts to determine structural weld dimensions on a 1.25” x 4.8” x 0.125” specimen. Each grouping had 5 specimens with unique spacing, length, and placement. The spacing was selected to cleanly divide the width of the specimen into 5, 4, and 3 lap fingers.

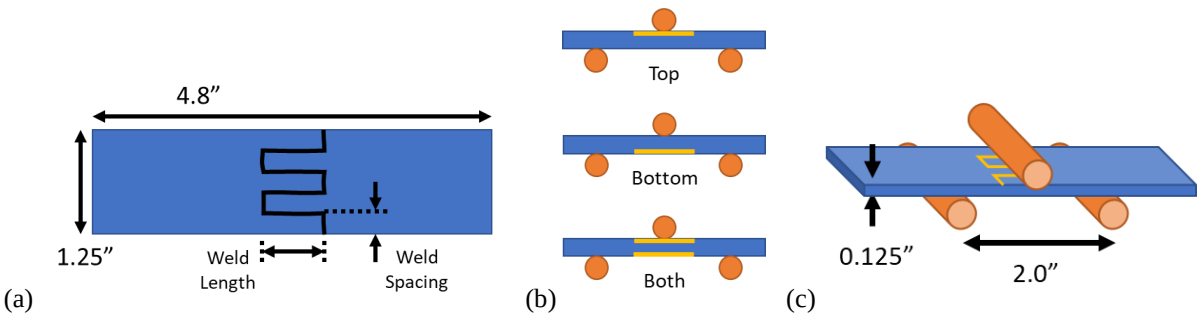


Figure 7: (a) Part Dimensions (b) Position of Weld (c) 3-pt Flexural Setup

A total of 135 specimens were welded and tested consistent with the experiment design outlined in Table 1.

Table 1: Experimental design for flexural weld strength analysis

		Spacing		
		0.25"	0.3125"	0.4167"
Weld Length	0.25"	Top	Top	Top
		Bottom	Bottom	Bottom
		Both	Both	Both
	0.50"	Top	Top	Top
		Bottom	Bottom	Bottom
		Both	Both	Both
	0.75"	Top	Top	Top
		Bottom	Bottom	Bottom
		Both	Both	Both

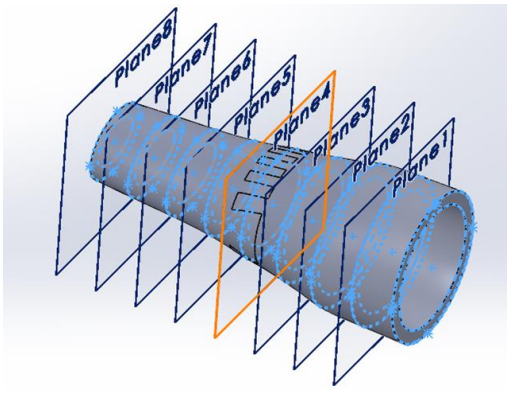
Specimens were plunge welded with a 3D printing pen extruding PLA filament followed by a smoothing operation with a soldering iron. If both sides were to be welded, the process was repeated on the reverse side. Specimens were tested with a 3-pt flexural fixture in an Instron load frame as shown below in Figure 8.

Figure 8: 3-pt flexural testing of weld joint

Span was set at 16:1 and the specimens with welds on one side only were placed with the weld facing up or down as specified by the order of testing.

Sacrificial Tooling Proof of Concept

After the flexural testing was analyzed, the optimized weld was cut into a scaled replica of a student volunteer arm. A rough approximation was made by placing rubber bands at 1” spacing to determine the major and minor axis of an ellipse at each rubber band using a caliper. Offset planes, a lofted extrusion, and a 0.040” thick cut in Solidworks were used to create the desired parts, as shown below in Figure 9.

(a)  (b) 

(c) 

Figure 9: (a) measuring dimensions at 1" increment, (b) CAD file creation (c) Welding 3D printed parts

After welding, the sacrificial tool was placed inside a braided carbon fiber sock in a filament winding machine to work epoxy resin into the fabric while rotating. The part was allowed to cure and the excess carbon was trimmed as shown in Figure 10.

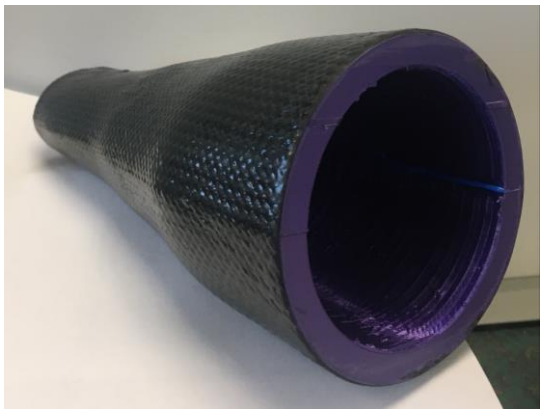
(a)  (b) 

Figure 10: (a) Rotational epoxy molding, (b) Trimmed final part with sacrificial tooling

Results

Tensile Lap Shear Testing

The first round of testing used several different techniques. The friction welding with a rotary device was difficult to prevent the weld from walking without a significant groove to follow and generated a significant amount of debris. The first attempt at 3D pen extrusion was a surface weld with minimal penetration. In an attempt to heat just the mated surfaces, a braided copper wire was fanned out and clamped between the two pieces to be heated from the outside using the copper to conduct heat into the weld zone. The goal of this testing was to achieve a weld strength greater than 225 lbf. The results are shown below in Figure 11.

The copper wire and friction welding was abandoned because the use of the 3D pen and soldering iron was much

easier and showed the most promise for stronger welds. One specimen broke outside of the weld zone; welded by plunging the pen tip into the weld and forcing hot material deeper into the weld joint with a soldering iron (SI) used to press remaining material into the weld and smooth the weld bead. Based on the results of the first round, the second round was setup to explore various combinations of 3D pen plunging, adding additional PLA filament, and soldering iron smoothing. The results are shown below in Figure 12.

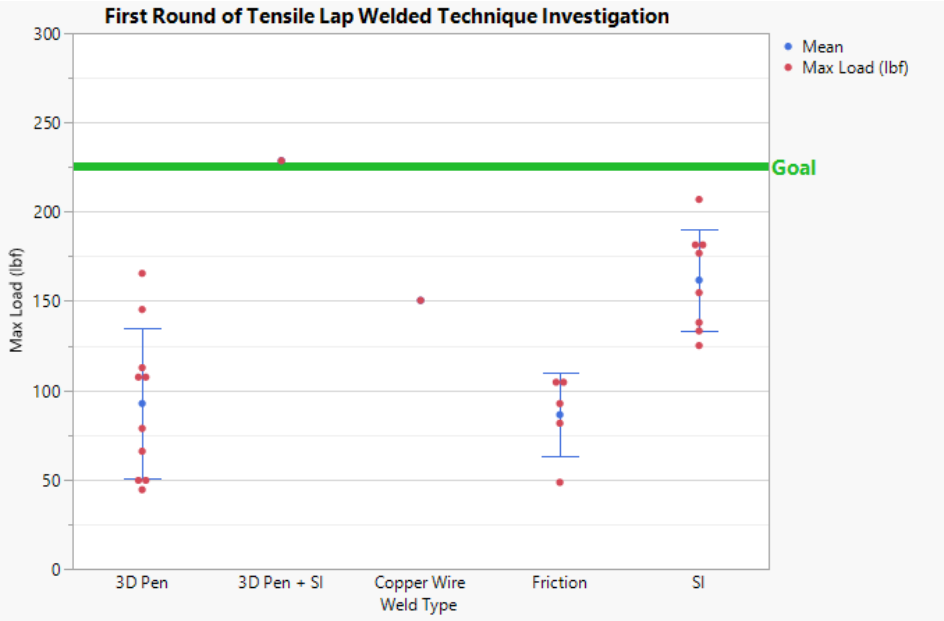


Figure 11: First round of tensile lap testing

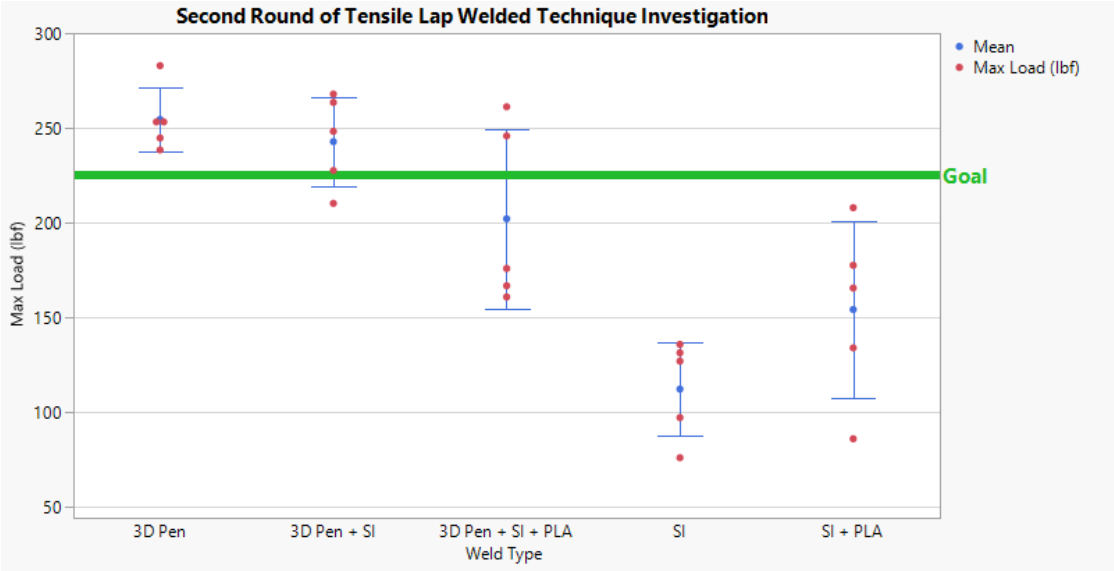


Figure 12: Second round of welding techniques

Plunging with the 3D extrusion pen was the most successful weld type and using a soldering iron to smooth the weld provided clean and smooth surfaces.

Flexural Lap Weld Testing

Flexural welding examined the spacing between weld lines, the length of the weld lines, and whether the weld was on the tensile side (bottom) or compressive side (top). The dotted line represents the baseline data obtained from conducting flexural tests on rectangular specimens with no cuts or welds; anything above this line is successful. The results of the testing are shown below in Figure 13.

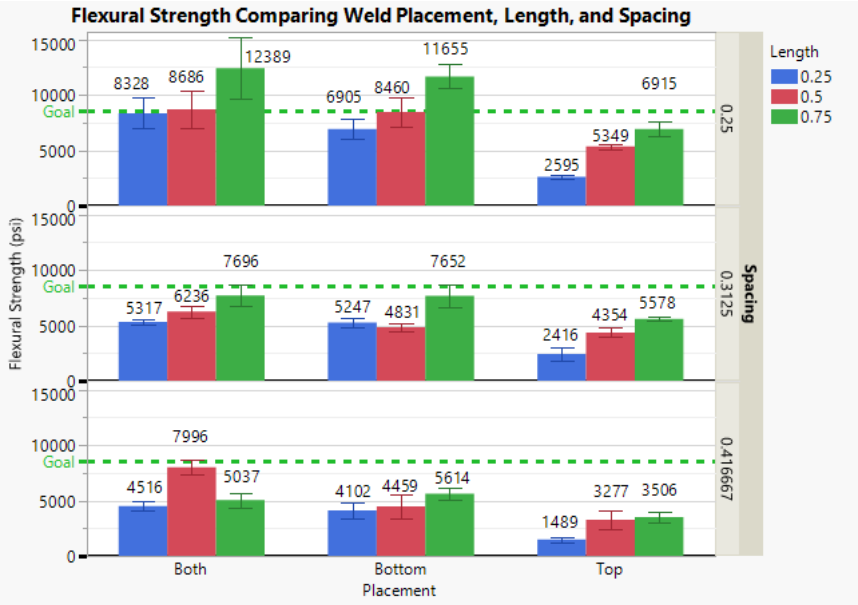


Figure 13: Flexural testing of Weld joints

It was clear that the specimens with welds placed on either the bottom or both sides performed better than the welds placed on the top of the weld joint. The lack of a weld on the compressive side will result in the two weldments compressing on each other, whereas, the lack of a weld on the tensile side will immediately initiate crack growth and bending. This could present a challenge if the interior of a welded joint is not accessible for welding. The only welds that achieved higher strengths than goal were the specimens with 0.25” spacing, 0.75” length, and a weld on the tensile side of the imposed flexural strain.

Discussion

It was quite surprising how easy it was to learn to create strong welded joints; many had no prior welding experience and were able to make strong joints with less than 2 hours of practice. This is a technique that can easily be adapted to many situations and would allow for new design concepts when creating parts with the intention of 3D printing as the manufacturing method. The ability to print all of the structural members in the print plane to be assembled and welded post printing eliminates much of the failure risk associated with slender vertical sections. 3D printing extrusion pens have temperature and speed control with the ability to use the same 1.75 mm material as that of the substrate part. This technique also takes advantage of the weld being compared

to a filled section making it easier to obtain equivalent properties. While most stress in a flexural application is witnessed on the top and bottom of an imposed curve, the strength of the laps can easily be increased with an increased wall count in the slicer without adding too much time or material. Care should be taken to conduct welding and smoothing operations in a well-ventilated area.

The major challenges of this technique gaining widespread use lie in the post processing of a CAD file prior to printing and the calibration of the cut width for parting lines. Not all welded joints need to be structural joints, and a preform for composite hand layup may not even need solid surfaces. There is a lack of easy to interface and use partitioning tools that would generate the complicated cuts required for the techniques examined to be usable by a wider audience. There also needs to be some guidance in terms of how to maintain dimensional tolerance as welded parts stack on one another possibly requiring the creation of welding jigs. It is also not clear how dimensioning is used in slicing g-code in terms of the edge overflow of parts. It was observed that if parts are printed on a bed interlocked, there will be a very large gap between parts. The same parts printed separate from each other will have a small gap or require filing and sanding to obtain a clearance fit. This is possibly printer and slicer dependent and therefore would be different for all setups, but it did cause additional work to clean joints of excess material.

Conclusion

3D printed parts offer the ability to generate dimensioned, complex objects with minimal machining touch time and skill, but they are typically very weak and limited in size. Strong and light composite parts require tooling to be created for the fabric to lay on while the resin is curing, but tooling can be quite expensive during the prototyping phase or for low part quantity runs. This study examined the techniques required to weld smaller 3D printed parts together to form large 3D printed tools that could be used as a sacrificial tool for a composite part. In this method, the 3D printed structure would remain inside the part and provide support and dimensional reference during the composite curing process.

It was determined that the easiest technique to create strong welded bonds between PLA structures was to use a 3D extrusion pen to plunge and extrude PLA into the weld joint followed by a smoothing operation with a soldering iron. It was determined for the printing parameters used that a lap weld joint with a spacing less than 0.25” and a length in excess of 0.75” with the weld placement on the tensile side of the flexural load would be as strong or stronger than a standard 3D printed part.

Sacrificial tooling was successfully created to generate a replica of a human arm by dimensioning, creating a virtual representation, partitioning it into 4 parts, and welding those parts together. A carbon fiber epoxy composite skin was added to the tool as proof of concept. This technique not only could be used for complex surface geometry, but also to create complex internal channels for fluid transfer, wiring, or internal mechanisms.

Recommendations

More work needs to be done on easy-to-use partitioning interfaces in CAD or slicer packages to create effective interlocking weld joints.

Acknowledgements

This work would not have been possible without support from WSU Foundation via the Early-Year Research and Creative Mentoring program. The information presented was compiled over the course of 2 school years working with 2 different sets of students.

References

France, A. K. (2013). Make: 3D Printing: The Essential Guide to 3D Printers. United States: Make Community,

Horvath, J., Cameron, R. (2020). Mastering 3D Printing: A Guide to Modeling, Printing, and Prototyping. Germany: Apress.

Maheshwari, S., Siddiquee, A. N., Srivastava, M., Kundra, T., Rathee, S. (2018). Friction Based Additive Manufacturing Technologies: Principles for Building in Solid State, Benefits, Limitations, and Applications. United Kingdom: CRC Press.

Ammen, C. W. (1979). The Complete Handbook of Sand Casting. United Kingdom: McGraw-Hill Education.

Callister, W. D., Rethwisch, D. G. (n.d.). Materials Science and Engineering: An Introduction. United Kingdom: John Wiley & Sons, Limited.

Kluz, J. (1981). Moldmaking and Die Cast Dies for Metalworking Trainees: Machine Tool Operators, Machinists, Toolmakers, Diemakers, Moldmakers, Special Machine Builders. United States: National Tooling & Machining Association.

Barbero, E. J. (2013). Finite Element Analysis of Composite Materials Using AbaqusTM. United Kingdom: Taylor & Francis.

Gay, D. (2014). Composite Materials: Design and Applications, Third Edition. United States: CRC Press.

Agarwal, B. D., Broutman, L. J., Chandrashekhara, K. (2017). Analysis and Performance of Fiber Composites. United Kingdom: Wiley.

Smyth, C. T. (2017). Functional Design for 3D Printing: Designing 3d Printed Things for Everyday Use - 3rd Edition. United States: Clifford Smyth.

Garret, B., Redwood, B., Schöffer, F. (2017). The 3D Printing Handbook: Technologies, Design and Applications. Netherlands: 3D Hubs B. V.

Tokotuu, N., Aranda, S. (2021). 3D Printing Failures: 2022 Edition: How to Diagnose and Repair ALL Desktop 3D Printing Issues. (n.p.): Independently Published.

Truong, Q. (2020). Composite Architecture: Building and Design with Carbon Fiber and FRPs. Germany: Walter de Gruyter GmbH.

Vaidya, U. (2011). Composites for Automotive, Truck and Mass Transit: Materials, Design, Manufacturing. United States: DEStech Publications.

Wick-Joliet, R., Tschamper, M., Kontic, R., & Penner, D. (2021). Water-soluble sacrificial 3D printed molds for fast prototyping in ceramic injection molding. *Additive Manufacturing*, *48*, 1-8.

Predicting Boolean Satisfiability Using a Graph Neural Network

Mahfuza Farooque
Pennsylvania State University, USA

Arya Keni
Pennsylvania State University, USA https://orcid.org/0000-0001-6252-0261

Suman Saha
Pennsylvania State University, USA

Abstract: Boolean satisfiability problem (SAT) solver plays an important role in both hardware and software verification fields. On the other hand, machine learning and deep learning become widely used techniques in every field of our modern life. In our research, we implement a deep learning algorithm, called GNN (Graph Neural Network) with a well-known SAT-Solver algorithm, called the DPLL (Davis Putnam Logemann Loveland) algorithm to predict the assignment of Boolean variables of SAT problem. We show similar features between GNN and the DPLL algorithm and explain why the GNN with the DPLL algorithm is a better neural network compared to other neural networks for finding efficiently the variable assignments of an SAT problem. Moreover, we show that the GNN with the DPLL algorithm improves the accuracy of predicting the Boolean variable assignments of an SAT problem for a large dataset whether the existing research has used graph neural networks (GNNs) for SAT solving for small datasets.

Keywords: Graph Neural Networks, DPLL, SAT Solvers, Neural Networks, Propositional Logic

Citation: Farooque, M., Keni, A., & Saha, S. (2023). Predicting Boolean Satisfiability Using a Graph Neural Network. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023-- International Conference on Life Sciences, Engineering and Technology* (pp. 67-80), Denver, CO, USA. ISTES Organization.

Introduction

Boolean satisfiability (or SAT problem) plays a key role in Computer Science (CS) and in our many real-life applications. The most well-known algorithm for SAT problems is DPLL, and people are trying to apply various kinds of Machine learning algorithms for optimization problems. Many other methods exist to operate on Boolean logical statements, relying on conditioning methods which DPLL is a part of, where essentially a variable that is least interlinked to the others is given a concrete Boolean value, and the statement is proceeded to solve accordingly, with switches for making different variable values concrete accordingly to arrive to a solvable conclusion, such as: Resolution, Binary Search, Conditioning, and etc.

We investigated all Machine Learning (ML) algorithms on DPLL and found that some specific ML algorithms show more efficient results. Neural Networks (NNs) are an important component in analytical solving and heuristic determination of propositional logical statements in current and future methodologies of such statements. Furthermore, applying Neural-Networks (NNs) to determine literal selection gives us an insight into Formal Hardware-Verification processes. Typically involving Neural Networks within the context of binary classification is highly intuitive, but there are multiple challenges when a solver of procedural iterations is involved, such as the DPLL SAT solver. NNs inherently try to model the output based on a particular constraint, which has their own drawbacks and advantages depending on their architectures. The typical architecture for solving CNF statements is a GNN, due to a GNN being naturally compliant with a CNF as in (Manoel VM Franca, 2013).

Inspiration is taken from works done in (Md. Kamrul Islam, 2020), where the focus lies in understanding the mathematics of DPLL logic and where there is similarity in terms of algorithmic predictability with layers of conventional GNN. Additionally, in (Wilson Hsu, 2023) there is a relevant discussion on the limitations of procedural logic utilized for logical determinism, and the involvement of evolved decision making in it, hinting at the SAT solving problem; and (Wenxi Wang, 2022), where similar ideas of recombinant GNN with DPLL based SAT solving regimes, under different architectural and propositional conditions was explored. This is the basis of procedural, and iterative (or computationally intelligent) solution driven systems. Neural Networks (NNs) are an important component in analytical solving and heuristic determination of propositional logical statements in current and future methodologies of such statements. There are many devised architectures that predict solutions for given propositional statements as a large dataset (20000 to 100000 problems) and successfully categorize it's SAT when the SAT-Problem is able to be solved otherwise UNSAT.

In addition to this key aspect we will be studying, propositional statements can also be generated with the aid of specific NNs that act as the proposed dataset to solve for. In this analogy on such NN mechanics, we will have a look at different architectures of NNs, generation techniques, types of logic generated by choice, and their different paradigms. This is a key insight into improving the efficiency of SAT solving ability of NNs by proposing a new model structure for statement generation, solving approach and categorization. This work is the first step towards designing, implementing, and testing a Transformer Neural Network that is capable of handling the generation and solving of First Order Propositional Logic, and can be modified for Higher Order Logic, in a parallel fashion.

Understanding the current standards for these systems, such as NeuroSAT and an exploration into other possibilities of approach that are non-conventional. In NeuroSAT (Wanf and Deng, 2020), one can see that the single bit supervision employed with a modification of a GNN works well to about 70% of test cases, but has limitations at short statement and "k" value domains (with the CNF conjunctions and variables per conjunction being low for a high rate of success). The importance here lies in devising a system that relies on certain principles from NeuroSAT, but can improve on its "long term memory".

Methodology

The process that entails the Neural Network guided DPLL, and pure NNs themselves involve many optimization and estimation domains. In this section, we describe first the DPLL algorithm and then we will describe graphical Neural Network.

DPLL Algorithm

The abstract mathematical logic that entails the solving parameters for any or all of the proposed NNs entail the standard DPLL (Davis-Putnam Logemann-Loveland) rules, when encountering one of the samples, namely Decide (if the statement abides by the CNF (Conjunctive Normal Form), a form of representation of the logical statement), Propagate, which propagates the literal of model of the statement to the proposed model, Fail, which categorizes to UNSAT if the propagation fails, and Backtrack, which uses the logical inferences to solve the statement otherwise. We will see the abstract DPLL mechanism below (Vijay D. Silva, 2012).

Abstract DPLL Rules

The DPLL rules follow as such, where C is an instance of n clauses of CNF conforming models from φ, and L denotes a sample literal space conforming to the CNF. Here, L^d denotes an annotated literal, $\Delta||\varphi \Rightarrow \Delta'||\varphi$ denotes a state transition from $\Delta||\varphi$ to $\Delta'||\varphi$ after applying a DPLL rule on $\Delta||\varphi$.

Decide

$\Delta||\varphi \Rightarrow \Delta, L^d||\ \varphi$ Which translates as if $L \notin \Delta$, $L^{\perp} \notin \Delta$ but $L \in C$ then Δ is extended to Δ, L^d. Here, we annotated the literal.

Propagate

$\Delta\ ||\ \varphi, C \vee L \Rightarrow \Delta, L\ ||\ \varphi, C \vee L$ when $\Delta \models \neg C$, $L \notin \Delta$, $L^{\perp} \notin \Delta$. Which translates as if Δ is unsatisfiable with the clause C and literal L or $\neg L$ is not present in Δ, to satisfy the clause $C \vee L$, Δ is extended with literal L.

Fail

$\Delta||\varphi, C \Rightarrow$ UNSAT when $\Delta \models \neg C$, Which translates as if Δ is unsatisfiable with C, and there is no decision literal in Δ then Δ is unsatisfiable for the CNF.

Backtrack

$\Delta_1, L^d, \Delta_2 \parallel \varphi, C \Rightarrow \Delta_1, L^{\perp} \parallel \varphi, C$ Which translates as if $\Delta_1, \Delta_2, L \models$ is not satisfiable with C, there is no decision literal in Δ_2 then it goes back to L^d and changes it to $\neg L$ and proceeds to the next state by applying other rules of DPLL.

Essentially, the algorithm procedurally eliminates possibilities of one or the other outcomes by traversing a split set of the CNF (deciding) as in the previous example, while deciding on each possible step, backtracking for a fail classification, propagating the current prediction forward for a successful solution.

At each stage, the CNF statement is assigned within sub-divided clauses, a truth value, and then a truth value within it for each variable in a subclause. Each possibility is explored to verify if a correct or any solution can be conclusively obtained by simple propositional logical operations. If it is not, then that option of node (containing the possibility of assignment) is terminated, if that is false, and there may be a solution at each step, the node is progressed into the next mathematical step, until there is one final node at the last layer of the n-nary tree. The key reason for it being a generalized solution to the DPLL is its extrapolation into all possible CNF state assignments, and solutions with general logical rules only; exploration of which takes exponential runtime.

For a procedural run of how the DPLL mechanism, one can study the following mathematical logic that a computer imitates classically:

Example 1:

Let φ_1 : 1 ∨ ¬2 ∨ ¬3, ¬2 ∨ 3, ¬3 ∨ ¬4 ∨ 5, 5 ∨ 6, ¬6 ∨ ¬1

Δ||1 ∨ ¬2 ∨ ¬3, ¬2 ∨ 3, ¬3 ∨ ¬4 ∨ ¬5, 5 ∨ 6, ¬6 ∨ ¬1 (Decide)
$\neg 6^d$||1 ∨ ¬2¬3, ¬2 ∨ 3, ¬3 ∨ ¬4¬5, 5 ∨ 6, ¬6 ∨ ¬1 (Unit Propagation)
$\neg 6^d$, 5||1 ∨ ¬2 ∨ 3, ¬2 ∨ 3, ¬3 ∨ ¬4 ∨ ¬5, 5 ∨ 6, ¬6 ∨ ¬1 (Decide)
$\neg 6^d$, 5, 2^d||1∨¬2∨¬3, ¬2∨¬3, ¬2∨3, ¬3∨¬4∨¬5, 5∨6, ¬6∨¬1 (Unit Propagation)
$\neg 6^d$, 5, 2^d, 3||1∨¬2∨¬3, ¬2∨3, ¬3∨¬4∨¬5, 5∨6, ¬6∨¬1 (Unit Propagation)
$\neg 6^d$, 5, 2^d, 3, 1||1∨¬2∨¬3, ¬2∨3, ¬3∨¬4∨¬5, 5∨6, ¬6∨¬1 (Unit Propagation)
$\neg 6^d$, 5, 2^d, 3, 1, ¬4||1 ∨ ¬2 ∨ ¬3, ¬2 ∨ 3, ¬3 ∨ ¬4 ∨ ¬5, 5 ∨ 6, ¬6 ∨ ¬1 (Model Found)

After applying abstract DPLL step-by-step on φ_1, we see that there is a model Δ: $\neg 6^d$, 5, 2^d, 3, 1, ¬4 that satisfies φ_1.

Example 2:

Let φ_2 : p ∨ q ∨ r, p, ¬q ∨ r, ¬r ∨ ¬q, q ∨ r, g ∨ ¬r

Δ||p ∨ q ∨ r, p, ¬q ∨ r, ¬r ∨ ¬q, q ∨ r, q ∨ ¬r (Unit Propagation)
p||p ∨ q ∨ r, p, ¬q ∨ r, ¬r ∨ ¬q, q ∨ r, q ∨ ¬r (Decide)

p, q^d||p ∨ q ∨ r, p, ¬q ∨ r, ¬r ∨ ¬q, q ∨ r, q ∨ ¬r (Unit Propagation)

p, q^d, r||p ∨ q ∨ r, p, ¬q ∨ r, ¬r ∨ ¬q, q ∨ r, q ∨ ¬r (Back Propagation)

p, q^d||p ∨ q ∨ r, p, ¬q ∨ r, ¬r ∨ ¬q, q ∨ r, q ∨ ¬r (Unit Propagation)

p, ¬q, r||p ∨ q ∨ r, p, ¬q ∨ r, ¬r ∨ ¬q, q ∨ r, q ∨ ¬r (FAIL)

After applying abstract DPLL step-by-step on φ_2, we see that there is not any model Δ that satisfies φ_2.

Theory on GNN Mechanisms

To understand the GNN further in a brief manner, the architecture of a basic GNN gives insight into how data is processed in an extensible format given a particular state-space.

From a NN as an overarching method, (or rather an artificial NN or ANN), the GNN extends from the sum of weights and values at each nodes (performed in the ANN iteratively across all layers from input layer as a weighted sum to a final output vector), to a further representation of the same in graph form, but also utilizing common layering practices as in conventional NN's. While an ANN performs a simple task of statically assigning values as per a weighted sum computation for each node depending on its connections, the GNN has layers that compute activation of certain parameters, and null (non-existent) weights of a pooled layer of all the nodes and edges, to connect them in a NN layer by layer format rather than nodes to edges for a connection scheme. In general a NN would process nodes from input to output with non-linear activation processes, and weighted/bias node probabilities, to output a vector of probabilities indicating a certain presence/non-presence of state-space objects. As applications of this methodology, this could range from detection of traffic, to highlighting red colored items in an image, to: verifying whether a certain CNF statement can be reduced to True or False, in a binary fashion (2 valued vector).

A GNN works typically, hence, by utilizing the weights between paths of nodes and edges, connected by their interlinked CNF sub-clause solutions to solve sub-solutions and merge their truth values parallelly, as depicted in Figure 1.

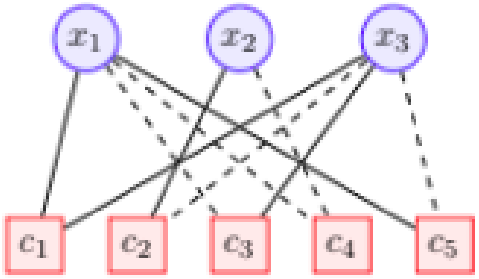


Figure 1: CNF to GNN representation of a statement, for initial vectorization

The relation with the Λ example, and its C_n values (as seen in Figure 1, involving (A ∨ ¬C ∨ B) ∧ (¬B ∨ C)), are

used to understand the connections to be made in the NN architecture as the next step. To make the splicing, using DPLL rules of propagating forward from each chosen literal to form the complete Λ (final set of propositional solutions) and backtracking at each step to find interconnected literals, while parallelly deciding at each step the action to be performed, and whether the partial statement adheres to CNF, and backtracking again to the last solved step if failed are the key actions under DPLL. This process of analyzing relations hence leads to the NN construction procedure, as depicted in Figure 1, for solving the equation (A ∨ ¬C ∨ B) ∧ (¬B ∨ C) in an SAT solver (Aditya Paliwal, 2019), (Wanf and Deng, 2020).

This statement is formed into a graph as it is algorithmically combined by ways of combinatorial logic within each element of the CNF statement, and its conjoined pair(s), to form back the original statement via connection of edges. Choosing the architecture is key to the successful operation of the process, and Figure 3 illustrates a typical NN structure to give an idea of its operational paradigms. The Graphical representation of applying DPLL as a precursor to any NN which uses specific propositionalization in its general solution to determine final un-solvability in NP complexity. The functionality of NeuroSAT is in Figure 1, the complete statement of can be transformed into a NN of either recurrent or graph architecture, solved by DPLL for (A∨¬C∨B)∧(¬B∨C) by NeuroSAT, after the bias of this NNs output is fed as an input. Bayesian probability (literal occurrences in interdependent statements) is utilized in between these NNs, to determine inter-linked weights for more complex statements.

Here NeuroSAT is the benchmark platform to compare NN-related predictions against what this paper explores as platforms utilizing NN, for accuracy, efficacy, and system structure differences. This is strictly concerning NN performance as a DPLL based or inspired SAT solver. NeuroSAT is the currently existing solver with a high accuracy rate (Daniel Selsam, 2019), and utilizing some functions of GNN and TNN, as a hybrid GTN (or Graph Transformer Network). This provides it with high statement length yields with limitations. This is relevant within GTN and NeuroSAT as NeuroSAT employs a GTN with a single bit supervision, as a supervised NN learning process, to solve small lengths (limited by bit error rate and by bit based memory translation, topics out of scope for this paper, but utilized in the paper (Wanf and Deng, 2020)). NeuroSAT hence works differently by using a pure GTN (or NN, or GNN as an extended version of GTN (or vice versa)) benchmark, but uniquely in an architectural standpoint.

Mainly, the DPLL Integration in GNN logically dictates the replacement of the layers of the GNN involving feed-forward and back-propagation algorithms, along with relevant subsidiary methods of input choice by hidden threshold layers (dense compaction), and max pooling as a choice making algorithm. All 4 rules of the DPLL postulate can be utilized instead of pure GNN based algorithmic learning, to hybridize the process of generating a learned outcome by procedural and artificial means.

The four rules of DPLL naturally merge with a GNN, due to the GNN's natural existence in machine learning to perform forward and backward propagation (like most other NNs), and decision making processes with each hidden layer computation.

For further clarity, the DPLL merger in GNN provides parallel computation in lieu of traditional GNN layers performing the same actions, bypassing the need of probabilistic activation and typical learning mechanisms of said layers, in partial satisfaction. This is important because this eliminates any need for the system to adapt to the format and the nuances of the CNF statements and developing a solution inherently, but rather, employing well known algorithms procedurally in the same vein, (and its modifier for further assist on certain functions with the DPLL, for improved ”foresight” in solving long term DPLL models, and longer CNF statements, thusly), and using the NN learning component for other lacking areas of the DPLL, such as labelling classifications or iterative backup of data transmissions through layers (or rather, not losing data over generations of training).

The issue with such a system might be that the use of the DPLL algorithm hinders evolution of the network in certain areas, in context of the ability to adapt within its formation of forward and back propagations, at the least. The key differences from the typical GNN architecture and the modified architecture with DPLL can be seen here, in Figure 2, where DPLL (embedding in GNN) forward and backward propagation is taking over by each unit of recursive and linear I/O of convolution and recurrent GNN net, where the DPLL transformation is decided upon and fed into this mechanism, and is reset upon failure. This decision is performed by the deciding stage of the mathematical process outlined by the first few layers of the GNN with DPLL, mechanized as in Figure 2. Unit propagation may also be an option that is mathematically equivalent for single inferences within DPLL Decision layers. The rest of the mechanism is similar (Loss function, output settings, input graph, and general pooling when embedding into output). Note that there can be any number of repeated GNN layering, which can defect to decision phases upon backtracking into the previous phase of such convolution stage. The same number of successful propagation’s leads to an embedded output of the nodes and edges, which is then evaluated for metric efficacy. Whereas enough backtracks upon unsuccessful solutions may lead to the initial decision phase.

Furthermore, the uniqueness of hybrid behavior is mainly from the convolution and recurrent layers, which is then maximum value-pooled before the state output is binned into a final binary label. Any layers of Convolution to Recurrence can lead to a backtrack upon unsuccessful resolution or propositional methodology of solving, or propagation (forward to the next layer or unit) upon success, while the decision stage propagates the literals forward into the GNN layers. The output that is embedded is usually compared against the mean squared and exponential loss metrics, to compute the binary output to its confidence, and actual binary label itself. For more information on the embedding and loss of the system, refer to the classical GNN (as architecture, and not post-processing, is the key change here). The fail stage specifically acts to verify if there can be no satisfiable solution near the end of each epoch and forward propagation and backward tracking phases after initial decision, to classify an UNSAT and label different metrics of loss and data acquisition for the CNF statement accordingly. In this manner, the UNSAT or SAT prediction can follow, in the final output layer, with a quantified loss, confidence, and other metrics. The output is binary but has an equivalent 2-fold vector of confidences for both solution states, where UNSAT is specifically determined upon a correct application of the ”FAIL” method.
More formally a GNN can be classified as a network representation of a graph. To do that, we are defining a

graph as follows: An undirected graph G of form G=(V, E), with the given Vertex and Edge (V and E, respectively). Where the nodes or vertices are connected to the edges, This follows the property of $E \subseteq V \cdot V$ and $v \in V$. An important graphical theory to highlight is that of: This creates a row vector of some dimension, with a similar feature relation of the edge to the edge vector. A GNN maps each node to a vector space embedding by iteratively updating the representation of the node based on its neighbors. In this formalism we do not extract edge features. Each node h at vector v and iterative time-step t (formal time stamp of epochs from 1 to a natural "T"): htv is then computed to be updated for machine learning based prediction as: $h_t^v = U_t \cdot (h_{t-1}v \cdot P^{w \in v} M_t(h_t^v, h_t^w, h^{wv}))$ for some updating function of learning rate "U", and sub-vertices per node "w", related through another CNF statement operation of message "M". Note that h^{wv} is a property of G and does not change given a CNF configuration.

In a forward and backward pass for this new hybridized system, the DPLL layer of forward propagation works similarly to that of the well known forward pass method of a neural network, where the weighted sum of vectors of literal values as a prediction is sent to the next layer for further computation. A backward pass works equivalent to backtracking as mentioned in the DPLL theory, in lieu of traditional backward propagation. This method is described in more detail in the GNN method in a later section.

For example, the GNN can represent the statement: $(x_1 \vee x_3) \wedge (x_2 \vee \neg x_3) \wedge (\neg x_1 \vee x_3) \wedge (\neg x_1 \vee \neg x_2) \wedge (x_2 \vee \neg x_3)$, highlighted in Figure 1. The dashes represent the relative conjunctions of one variable or its negation to the other, as a spacing between its k-clause to the relative k-clause in connection to it.

Selecting a literal to its corresponding node in a vector graph of this form, is thus 2 nodes of variables and clauses, (v, c) linked to another pair of v and c. In this manner a CNF can be directly represented as a GNN initial framework. To represent the inputs mathematically, a formula is assigned to the variable that corresponds to a vector of probabilities of selection of said literal in the first DPLL step. This node model can be extrapolated to contain the adjacency matrix of all the node related probabilities and information. The link between each matrix entry can be a vertex, mathematically speaking. Thus, a CNF vector graph can be a bipartite graph as a $n \cdot m$ matrix, where $A = (A^+, A^-)$, and $A^+(i, j)$ is $1x_i \in c_j$ and conversely $A^-(i, j)$ is $1\neg x_i \in c_j$

This is a one-hot representation of vector values as negations or non-negations, such as all possible values of literals that can be taken. False and True are the appropriate assignments, where nodes corresponding to CNF based literal connections can be: $H_0 = (H_0^v, H_0^c)$ for a clause that is of k-variables, with the dimensions H0 $c \in R^{m \cdot k}$. in this manner, the GNN selects the heuristic (A, H_0), solved as per its initial state of the problem statement, as a CNF propositional set.

Hence, we can see the results within a GNN regime of increasing complexity processing in the accuracy of model predictions through GNN and its modified Bayesian moment (through a common mode, which is out of this scope). Thus, we see that the progression of accuracy purely aided by layered neuron design increases with

complexity increase. (Ashish Vaswani, 2017a), (Li and Srikumar, 2019).

Dataset Acquisition

Acquiring a large dataset is a key aspect in testing the robustness of the derived system, and in prediction of values and limitations. Benchmarks, guidelines, and processing rules are the first step in realizing this.

SAT Benchmarks is benchmarks that have a set number of formulae, usually in the CNF format (Conjunctive Normal Form), that serve as testing (and validating, for a ML model of a SAT solver) dataset criteria for the implemented solver, chiefly to gauge its performance. All SAT solver based development and research that is published follows the SAME format for propositional statement encoding, databases, reads, and preprocessing for their implementation purposes, even for all the datasets provided below.

DIMACS (The Center of Discrete Mathematics and Computer Science) has a system of encoding that is universally approved, called DIMACS-CNF which follows a simple and intuitive method that can be automated to decode as per file reads, for sat solver input usage.

Each .cnf file can be read as follows:
1) The header has a “p cnf ‘variable 1’ ‘variable 2’” line, as the first line if the file can be opened. Variable 1 here is the number of variables in the full statement, and variables 2 is the number of sets.
2) Each line is ended by the “0” integer, marking an endline, and is delimited, with each character spaced by a whitespace “ ”
3) Each line denotes a set, and the set has spaced integers, with each integer denoting a certain variable, with a negative integer denoting the negation of that variable
4) For example, for the statement (x OR y OR NOT z) AND (NOT y OR z) is denoted as: p cnf 3 2 1 2 -3 0 -2 3 0 Where there are 2 sets: (x OR y OR NOT z) ; (NOT y OR z), and 3 variables: x,y,z. Within this, x=1,y=2,z=3, and NOT x=-1, NOT y=-2, NOT z=-3. Each space here can be thought of as an implicit OR, except when preceding the endline of a 0.
5) These statements can be scaled practically upto 6 variables, and 1000 sets, within a statement. Though within most conventional SAT solvers, 3 variables and 10 to 500 (typically, sometimes 800 to 1000) sets are focused on to avoid exponential memory drainage and backlog.

This forms a total of 50000+ SAT statements to categorize in training, testing and validation.

Results

The results of the NNs and the DPLL cover the following regions of architecture, and its detailed overview of the results and their implications for each situation suggest a direction for the current findings. We shall focus on GNN only, since the results of the TNN and RNN are out of scope for discussion of this paper, and will follow in

a cost-benefit analysis style evaluation in later issues of the work.

Performance of GNN

The Graph Neural Network or GNN is a network comprising of a graph-based node-to-edge relationship, which is ideal for SAT-solving capabilities from a graph theory perspective since each n-CNF statement can be represented as a graph of Boolean variables constituting the CNF statement interlinked within the CNF form itself. The structure of the GNN follows the norms in Figure 2.

Within this Figure, the typical graphical structure input in the mathematical sense, is processed through ”N” nonlinear layers that typically process in the specified format of the Node to Edge pre-processing stages (as weighted sums, or augmentations of each node pair connected by its edge only). This is then utilized to a condensed output stage of a vector that is involved in certain computations of losses and errors to attune to based on validated test data and its labels. This is further used in the classification stage of data to use certain stochastic models (any of preference, out of scope of paper study as this affects certain accuracy and decision capabilities of the system too) to cast a final predictive label within a set of possible constrained ones.

A typical GNN has the architecture as in Figure 2, where the layers allow for multiple layers of fine-tuning predictions within sub-graphs that are acyclic.

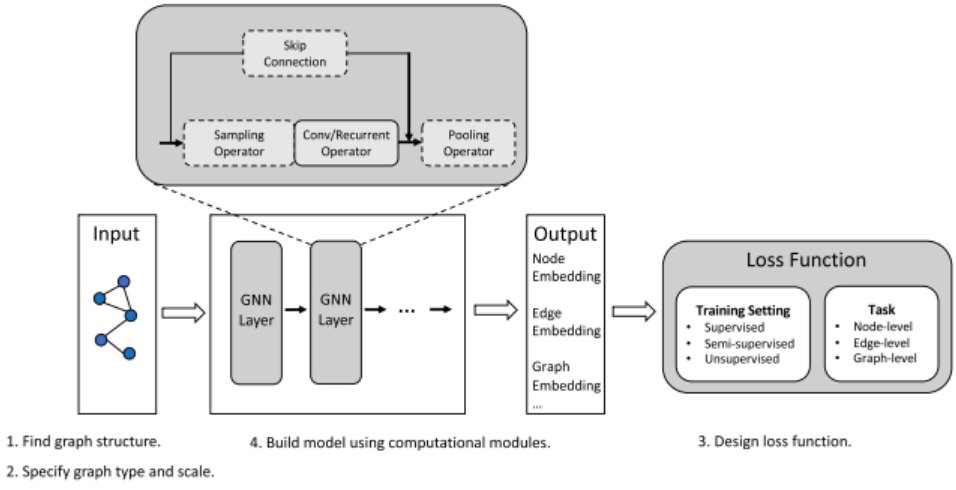


Figure 2: Condensed GNN

The data within these layers is propagated by form of solving parts of the graph with logical connections, much like the bipartite graph n partial solutions of nodes and edges in clusters, and the condensed equivalent solution is passed onto the next layer for further condensing within the given propagation based computational limitations of handling n-variables at a time. This limits the condense-able capabilities of each network, and more so for larger graph nodes and proportionally larger edges in number. But, the data usually is condensed to a 10 to 100 factor reduction, depending on the solutions resolved within each time-step of the network. This aids in the final

layers solving the residual errors/predictions for a final classification. This is achieved by condensing the above 2 GNN architectures into one that follows literal processing parallelly, as in Figure 2.

A similar extrapolation can be made into the domain of representation of logical operators into a bipartite graph, where the exploration by propagating to a new layer from root to leaf(moving in a layer), deciding on branch switching, and moving back from root to node by backtracking the error of solution (moving out a layer), and then ultimately marking all branches as UNSAT or F, except one which is the solution is an ideal example.

Performance of GNN with DPLL

Utilizing the same GNN as above and modifying with DPLL as a layer before graph pre-processing, we can see the increase in accuracy by about 5% at the least. This suggests that the predicted analytical measure (binary cross entropy, modified) of the DPLL method enhancing accuracy as a metric protocol across 5000+ graphs is verified. In reality, about 4.7% of the increase is dedicated to 80% of the data and the rest has a 5% increase. These statistics are via MSE and weight metrics. The metric turnover of the new model, with this layered enhancement, is shown here, for the standard deviation and the accuracy in general as well, results to 66.8% boosted accuracy as a weighted mean with a 0.06% standard deviation in accuracy confidence The details are direct to derive for the same. The modified GNN to accommodate for the DPLL outputs in a binary sense of True or False has to be acquired through the following funnel like GNN architecture with DPLL at the 1x1 end of the hidden/output layer.

This enabled processing with most features intact and derivations at a filter-similar rate from the graph processes to the DPLL processes. This abstraction is necessary for the improved accuracy of the system overall. This process, also called the funneling process, channels the nodes and edges into a finer prediction in terms of bounds of possible accuracies to a higher value and lower range of values. The DPLL has limited flexibility of inputs, hence this method has the added deemed benefit of improving the performance and run time functions exponentially. DPLL also relies on recursive behavior to process CNF statements (clause by clause), so algorithmically reducing the convergence to the unity case (self- inflection of identity) also aids in model creation.

The current standard by NeuroSAT of SAT solving capabilities is comparatively the best performance at small to medium range statements in length (Alex Sherstinsky, 2020), while the GNN with DPLL performs within half a standard deviation, but for ultra-large statements included. The ranges of statements and hence complexity within accuracy ranges widely, but the general trend of best statement complexity to range to accuracy optimum leans in favor of the GNN with the DPLL subroutine as a natural hybrid machine learning method. GNN in theoretical norms, practiced norms for larger statements, and the transformer hybrid version of it perform at a reliable rate of accuracy to be compared in context of future work in optimization and scope enhancement.

In a more detailed overview of the performance metrics of the GNN and the GNN with DPLL, we can

investigate that the table in 4, shows that there is a marked increase in 5% to 10% depending on the type of statement solved, for the same (all) dataset training for 100 iterations. Comparison to the NeuroSAT regime for the same metrics and aspect markers (such as the UNSAT, SAT categories), is also within order of performance (comparable within 1 to 2 standards of deviation to accuracy percentages given above). The performance is near comparable to the NeuroSAT for the UNSAT accuracy, SAT accuracy and the overall accuracy for a much higher number of statements, higher statement length on average, and a higher number of iterations of training, in proportion to the increased complexity. The progression of SAT to UNSAT to overall solvability is also within order to the NeuroSAT benchmark as in (Henryk Michalewski, 2019). We can thus show that there is a marked change in performance for the datasets used, as described in the dataset section, for the GNN to the GNN added with DPLL models. Their performance when compared to NeuroSAT is markedly different under different norms as well, which leads to further interesting studies for the domain of what limitations the UNSAT and SAT statements may have under their utilization paradigm

Table of Accuracy to Size Dynamics for all studied Models

Model	Dataset	Statement Size	Accuracy - Mean (%)
GNN	All	5000	84.01
GNN with DPLL	All	5000	89.21
NeuroSAT	All	5000	75
GNN	All	10000	78.25
GNN with DPLL	All	10000	83.67
NeuroSAT	All	10000	70
GNN	All	15000	73.13
GNN with DPLL	All	15000	77.77
NeuroSAT	All	15000	65

Figure 3: Exact statement size comparison of GNN, GNN with DPLL, and NeuroSAT.

To mitigate that, a test on the same statement size reveals the following mean accuracy on solved SAT or UNSAT statements, highlighted in table 4. We can see a marked increase within 2.5% to 7.5% on a standard plane, of a pure accuracy value (as a binary cross entropy comparison to the labels and the predictions). This suggests a high confidence score in the predictions reported. The pure GNN can be seen to still have a reduced accuracy within 1 standard deviation, which is expected compared to a novel model such as NeuroSAT. Reducing the statement size to its minimum capacity of 5000 may aid in increasing the accuracy for all models, on account of reducing the potential maximum value of perceived error the loss metric can record.

Conclusion

From the analysis of each of the NN's of interest, we can see the clear upward trend of accuracy with

complexity. The key points to note here are that Neural Networks devised are exactly so, since relying on only the layers to accurately predict for any level of complexity leads to accuracy stagnation by any metric (typically MSE, or mean squared error). Hence, a DPLL Algorithm (Davis-Putnam-Logemann-Loveland) is utilized to fine-tune the predictions of the pure NN and increase the accuracy by 9.5%, as an aggregate, depending on the exact configuration of the set algorithm within associations of intermediary layers of the NN flowing data into the DPLL input. (Al., 2019).

The DPLL takes in a matrix of the n-CNF (Conjunctive Normal form for n conjoined variables for Boolean AND-ing) problem statement and gives a binary output, hence the addition of a DPLL may reduce temporal complexity in all domains for all NN's. There is further speculation of utilizing different models of Bayesian Moment Matching (or BMM) (4 orders, gamma, delta, alpha, and lambda, that employ slightly different governing functions for learning within DPLL procedures) to update node weights within the DPLL algorithm to provide a further to be explored boost in accuracy for all NN's, which can be a future cause for exploration. (Sherstinsky, 2020)

Acknowledgements

Alumni of Pennsylvania State University, Master's of Engineering (then student) Mehul Mukherjee aided in the implementation in part of the GNN in python, during May to August of 2022.

References

Aditya Paliwal, Sarah Loos Et. Al. (2019). "Graphical Representations for Higher-Order Logic and Theorem Proving".

Al., Aditya Paliwal Et. (2019). "Graphical Representations for Higher-Order Logic and Theorem Proving".

Ashish Vaswani, Et. Al. (2017a). "https://proceedings.neurips.cc/paper/2017"..

Benedikt Bunz, Matthew Lamm (2017). "Graph Neural Networks and Boolean Satisfiability".

Daniel Selsam, et. Al (2019). "LEARNING A SAT SOLVER FROM SINGLE-BIT SUPERVISION".

Hsu, Wilson (2015). "Infinite Mixture Modeling of Streaming Data with Online Bayesian Moment Matching".

Li, Tao and Vivek Srikumar (2019). "Augmenting Neural Networks with First-order Logic".

Luis C. Lamb, Et. Al. (2021). "Graph Neural Networks Meet Neural-Symbolic Computing: A Survey and Perspective".

Manoel VM Franca Gerson Zaverucha, Artur S. d'Avila Garcez (2013). "Fast relational learning using bottom clause propositionalization with artificial neural networks".

Richard Evans, David Saxton, David Amos and Pushmeet Kohli (2018a). "Can Neural Networks Understand Logical Entailment?"

Sebastian Jaszczur Michal Luszczyk, Henryk Michalewski (2019). "Neural Heuristics for SAT Solving". In: ICLR 2019.

Sherstinsky, Alex (2020). “Fundamentals of Recurrent Neural Network (RNN) and Long-Short Term Memory (LSTM) Network”.

Vijay D. Silva Leopold Haller, Daniel Kroening (2012). “Satisfiability Solvers are Static Analysers”.

Wanf, Mingzhe and Jia Deng (2020). “Learning to Prove Theorems by Learning to Generate Theorems”. In: NeurIPS 2020.

Wenxi Wang, Yang Hu, Mohit Tiwari (2022). “NeuroComb: Improving SAT Solving with Graph Neural Networks”.

The Influence of Cow-Dung-Fed Loam, Clay, and Sand Samples on Electrical Generation of Microbial Fuel Cell

Jezreel Rhodni A. Banagan
Philippine Science High School – Caraga Region Campus, Philippines, https://orcid.org/0009-0004-1300-5385

Bianca Germaine M. Manatad
Philippine Science High School – Caraga Region Campus, Philippines, https://orcid.org/0009-0001-6867-9713

Elmer Jon D. Mupas
Philippine Science High School – Caraga Region Campus, Philippines, https://orcid.org/0009-0004-2996-4548

Patrick D. Cerna
Philippine Science High School – Caraga Region Campus, Philippines, https://orcid.org/0000-0002-2554-2098

Abstract: Studies have already been conducted on microbial fuel cells, and there have been published studies that have proven the capability of MFCs to produce electrical energy from the metabolic activity of microbes. Although studies on this promising technology have been validated for large-scale purposes, published research has yet to address the problems associated with the technology such as the low power and current density. Thus, the study aims to assess different soil samples through physical analysis and evaluate the different types of soil-to-compost mixtures in microbial fuel cells to produce electricity. The soil sample's physical properties were tested using Soil Quality Index (SQI) methods. Analysis of the energy yield of varying compositions of cow manure - loam, cow manure - sand, and cow manure - clay was conducted. The mixture of cow manure and clay was found to have the highest energy yield out of all trials employed. The results revealed that 75% cow manure, and 25% clay peaked about two times more than the other mixtures. The results obtained show that the setup could be promising in terms of solving the low power yield and in-energy production due to clay being porous, which contributes effectively to the process of electric-current conduction.

Keywords: Microbial Fuel Cell, Cow-Dung, Soil, Electricity Generation

Citation: Banagan, J.R.A., Manatad, B.G.M., Mupas, E.J.D., & Cerna, P.D. (2023). The Influence of Cow-Dung-Fed Loam, Clay, and Sand Samples on Electrical Generation of Microbial Fuel Cell. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023-- International Conference on Life Sciences, Engineering and Technology* (pp. 81-91), Denver, CO, USA. ISTES Organization.

Introduction

Background of the Study

Researchers found microbial fuel cell technology to be the mechanism that can utilize biomass energy and decrease methane production by making the methane gas lose energy (Razmjoo, 2021). Although many studies have established the microbial fuel cell as a promising technique that can produce electrical energy from virtually any type of biodegradable material, no published research has addressed the main obstacles it faces which include low power and current density (Khudzari, 2018). The aforementioned ideas about microbial fuel cells and energy crisis motivated the researchers to examine possible solutions and find alternative ways to produce electricity through the use of different types of soil-to-compost mixtures in a microbial fuel cell. Specifically, the study will address the question, "How to produce electricity using microbial fuel cells paired with mixtures of cow manure, clay, loam, and sand?" To help answer the main question, three sub-questions were framed to elicit the needed data:

- Is there a significant difference between the electricity generation of the different soil-to-compost mixtures (clay and cow manure, loam and cow manure, sand and cow manure)?
- Is there a significant difference between control and experimental setups?
- What is the bacterial composition of the most effective soil-to-compost mixture in terms of electricity generation?

The first question aims to determine the difference between the electricity generation of different soil-to-compost mixtures. Then, the second question will substantiate the difference between control and experimental set-ups. Lastly, the third question will tally the bacterial composition of the most effective soil-to-compost mixture in terms of electricity generation. The frameworks of Fosso-Kankeu, E., et al. (2015) and Parkash, A., et al. (2015) will be the most essential in analyzing results and creating methods for this study. Results will help illuminate alternative ways in producing energy and if such practice will still be valuable in the future.

Objectives of the Study

The main objective of this research is to find an alternative source of energy using different soil types and using cow-dung through microbial fuel cells and reduce carbon dioxide and greenhouse gas emissions. Specifically, it aims to;

- Determine the physical and chemical qualities of the different soil samples collected.

a. Determine the color, soil structure, and porosity of the collected loam, clay, and sand samples.

b. Determine the pH level of the collected loam, clay, and sand samples.

- Determine the voltage generation between different soil-to-compost mixtures (clay and cow manure, loam and cow manure, sand and cow manure).
- Determine the significant difference across treatments.

Significance of the Study

Source of Clean and Renewable Energy

The Philippines has an opportunity to harness corporate and public support, to set an example for its regional counterparts, and to chart a bold path toward a renewable energy future. The results of this study aim to benefit communities in cow-dung, loam, clay, and sand with the provision of an alternative source of energy through microbial fuels as its byproduct.

Future Researchers

This study is also deemed significant to future researchers as this study can contribute and provide relevant insights and information and address any research gaps needed for their respective studies relative to the results hereof.

The Department of Science and Technology

Moreover, the data and information gathered will help the Department of Science and Technology also gain more information about the bacterial composition of cow-dung, clay, loam, and sand samples and how it can influence electricity generation, thus paving the way for future research projects and studies.

Scope and Limitations

The study has 13 different treatments, 4 for each soil-to-compost mixture. The bacterial testing for the sample that will yield the most energy will be conducted in the Philippine Science High School – Caraga Region Campus Science Laboratory in Ampayon, Butuan City. This study is limited to the use of high-activity electrode materials like carbon, which is costly but can expedite the oxygen reduction rate of the cathode in the microbial fuel cell.

Method

Selection of Sampling Area

Soil Sampling Area

Soil samples of the study were collected from Masao, Butuan City, Agusan del Norte.

Cow-Dung Sampling Area

Cow feces sample used in the study was collected from Langihan Public Market, Butuan City. This area was chosen since fresh markets have fecal load and is easily accessible to the researchers.

Preparation of Materials and Equipment

Assembly of Personal Protective Equipment

The researchers wore personal protective equipment as it reduces exposure to harmful chemicals and organic matter, a risk associated with the sampling and experimentation part of the study.

Equipment of Sample Handling

For the collection of soil samples and cow feces, the researchers needed to obtain the following materials: soil probe for extracting small soil cores, clean plastic bucket for moving soil samples, permanent markers for labeling soil samples, sample bags for testing the collected soil samples, soil thermometer for measuring soil temperature, and gloves for protecting the hands when handling the soil samples.

Materials for Experimentation

The microbial fuel cell in this study will be a two-chambered device as it is more convenient in comparison to a single-chamber microbial fuel cell. For the anode and cathode compartments, the researchers utilized a plastic cylinder container with a volume of 1000 mL each.

In selecting the anode and cathode material, the following are the characteristics the researchers took into consideration: inexpensive, highly conductive, and non-corrosive, which is why aluminum mesh is selected. Several studies chose iron and copper because they are good conductors.

The microbial fuel cell also needs the salt bridge to separate the 500 mL water containing dissolved oxygen in the cathode from the anode. The research study used a twisted one-meter cotton rope for the salt bridge.

Collection of Soil Samples

The researchers collected soil samples from the three randomly selected sub-sites of Masao, Butuan City, wherein a total of 15 kg of soil samples were collected. The different soil sample temperatures were also recorded.

Analysis of the Physical and Chemical Qualities of Soil Samples Collected

Due to the lack of laboratories available, the researchers opted to self-conduct a physical soil analysis, and since an established standard grading system for the determination of the physical quality of the soil, that assesses the quality of soil, does not exist (Gelaw et al, 2015). The researchers have examined the widely used Soil Quality Index (SQI) methods and have developed a qualitative physical analysis test with some modifications based on the methods from previous research deemed as appropriate for the study (Mukherjee & Lal, 2014).

The physical analysis on the quality of soil samples collected have been carried out at the Philippine Science High School- Caraga Region Campus, wherein the physical and the chemical analysis measured the following soil properties:

- *pH Levels*
- *Structure and Color*
- *Porosity and Permeability*

Soil pH Level

Soil pH indicates the level of the soil's acidity or alkalinity, with the scale ranging from 0 to 14 units. To determine the pH level, the researchers used a pH test strip and the presence of yellow to green indicates the soil sample is either clay, loam, or soil.

The proponents used the Luster Leaf Soil Test Kits to conduct pH level tests on soil samples.

Structure and Porosity/Permeability

The structure of the soil sample is the physical formation of the soil during the time it was collected for sampling. The porosity/permeability is associated with the structure of the soil. The structure will be based solely on observation. The researchers used Soil Structure and Porosity Descriptive Observations and PSQI for Soil Structure and Porosity grading system by Soil Nutrient Management for Maui County of the College of Tropical Agriculture and Human Resources (2007).

Collection of Cow Feces

A total of 20 kg of cow dung, as a source of microorganisms for the anode compartment, was gathered for the experiment.

Experimental Setup

The steps to create a microbial fuel cell involve creating a salt bridge, drilling holes in plastic containers, forming aluminum electrodes, connecting copper wires to the electrodes, placing the electrodes in compartments, measuring voltage, adding a sample mixture and water to the cathode, and covering the salt bridge and electrodes with water and mixture.
After determining the energy yield of one sample mixture, the anode compartment will be replaced with another setup with a different sample mixture inside it. The salt bridge will also be replaced after every sample mixture.

Observation of Power Yield

Researchers watched how well the microbial fuel cell worked as they decided on the best mix of materials for the anodic chamber. The parameter that was used to assess the capabilities of the fuel cell only includes voltage generation.

Results

Physical and Chemical Qualities of Soil Samples

Different physical properties of soil, including its color, structure and porosity, and pH level were obtained to ensure that the soil samples were consistent.

Color, Structure, Porosity

Researchers used widely used Soil Quality Index (SQI) methods to make a qualitative physical and chemical analysis test with some changes based on methods from previous research that were thought to be appropriate for the study (Mukherjee & Lal, 2014).

Loam had a dark brown color, sand had a light brown color, and clay had a yellowish-brown color. The darker color implies a higher concentration of humus or degraded organic materials.

pH LEVEL

Table 1 shows that the pH level of loam is the lowest. The clay pH level of 6.5 is reasonable as it holds plenty of moisture.

Silica, a material with a pH of 7, is the most common component of pure sand. However, pure silica is rarely seen outside of laboratories. Thus, the sand pH level of 7.5 is fitting.

Table 1. The Results of the Soil pH Test.

Soil Types	1st Trial	2nd Trial	3rd Trial	Average Results of the 3 Trials
Loam	6.0 pH	6.0 pH	5.5 pH	6 pH
Sand	7.5 pH	7.5 pH	7 pH	7.5 pH
Clay	5.5 pH	6.5 pH	6.5 pH	6.5 pH

Voltage Generation Between Different Soil-to-Compost Mixtures

The researchers conducted thirty-nine separate treatments placed at the anode chamber of the microbial fuel cell. The researchers did five treatments for each type of soil, each tested three times, and one treatment for 100% cow manure, also tested three times.

Figure 1 shows the trend of the average voltage yield based on different mixtures in the anode compartment of the microbial fuel cell.

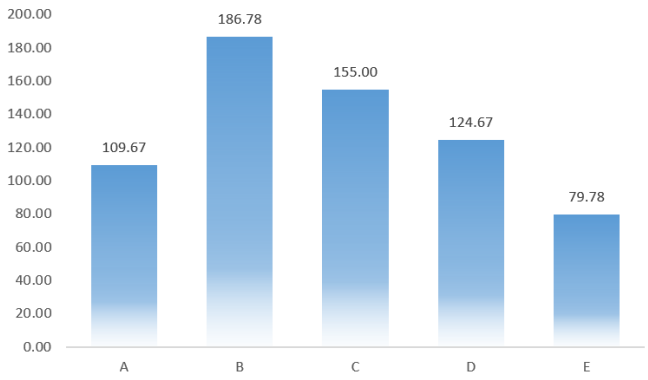


Figure 1. Bar Graph of Voltage Yield Trends Across Different Treatments

The average voltage generation for treatment A which is the mixture of 100% cow manure and 0% soil is 109.67mV. The average voltage generation for treatment E which is the mixture of 0% cow manure and 100% soil is 79.78 mV.

Treatment C, 50% soil and 50% cow manure has the second highest yield amounting to about 155mV. Treatment D is 75% soil and 25% cow manure treatment, with 124.67mV. Lastly, the average voltage generation for treatment B, which is 25% soil sample; 75% Cow Manure is 186.78mV. Treatment B was found to have the highest averages out of five treatments.

Difference across Treatments

The average voltage generation for the 100% cow manure mixture is 109.67 mV. It is important for researchers to determine the yield of this treatment since it is evident in previous literature that cow manure is an efficient renewable source of energy.

For the clay-to-cow manure mixtures, the highest voltage generation is by 25% clay and 75% cow manure mixture. The lowest among all mixtures is the 100% clay and 0% cow manure. All values are more than 109.67mV which suggests that mixing clay and cow manure is more efficient than clay alone or cow manure alone.

For the loam-to-cow manure mixtures, the highest voltage generation is by 25% loam and 75% cow manure mixture. The lowest among all mixtures is the 100% loam and 0% cow manure. All values are more than 109.67mV which suggests that mixing loam and cow manure is more efficient than loam alone or cow manure alone.

For the sand-to-cow manure mixtures, the highest voltage generation is by the 25% sand and 75% cow manure mixture. The lowest among all mixtures is the 100% sand and 0% cow manure. All values are more than 109.67mV which suggests that mixing sand and cow manure is more efficient than sand alone or cow manure alone.

Overall, the highest average voltage generation across all thirty-nine treatments, as seen in **Figure 2** is 25% clay and 75% cow manure mixture - 211.67mV.

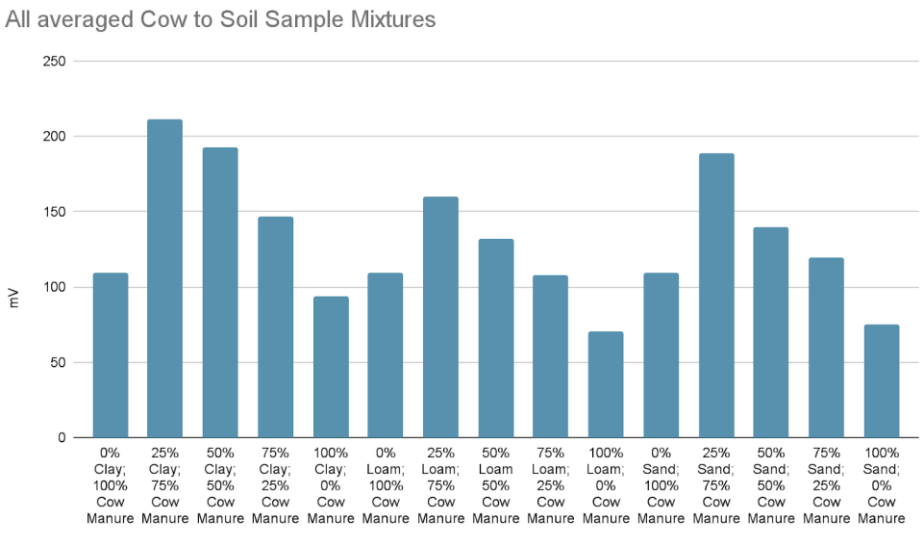


Figure 2. Graph of Different Soil-to-Cow Manure Mixtures

Discussion

Statistical Analysis on the Data Collected

Figure 3 below tells us that there is an interaction between the ratio of the different types of soil used and cow manure. This tells us that the different soil types and its corresponding ratio are important factors to the voltage generation of the microbial fuel cell. It is show in the graph that the optimal power produced is in the second ratio of clay which is 25% clay and 75% cow manure (R2).

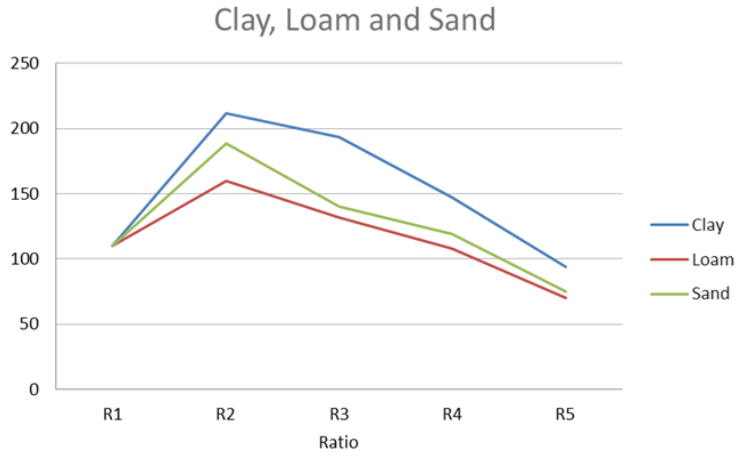


Figure 3. Line Graph of Different Soil-to-Cow Manure mixture

Table 2 below shows the different interactions between the different soil types and its corresponding ratio to cow manure. 100% Cow Manure to 0% soil type is the first ratio for every treatment which explains why the mean score is equal at 109.67 mV.

Table 2. P-value Analysis of the Data Collected.

Soil Type	Ratio	Mean	Interpretation p-value	Remarks
Clay	1	109.67	p<0.01	Significant
	2	211.67		
	3	193.00		
	4	147.00		
	5	94.00		
Loam	1	109.67		
	2	160.00		
	3	132.00		
	4	107.67		
	5	70.33		
Sand	1	109.67		
	2	188.67		
	3	140.00		
	4	119.33		
	5	75.00		

Table 2 and 3 show that the results are statistically significant since the p-value under the interaction of treatment and ratio is <0.01. It indicates strong evidence against the null hypothesis, as there is less than 1% probability the null is correct (and the results are random). This means that the amount of power generated is dependent soil type and the ratio applied. As previously shown in **Figure 2**, maximum power is generated at clay and ratio 2.

Table 3. Treatment Ratio Analysis of the Data Collected

Dependent Variable: Response

Source	Type III Sum of Squares	df	Mean Square	F	P-value
Corrected Model	75259.244(a)	14	5375.660	1502.514	.000
Intercept	774342.422	1	774342.422	216431.112	.000
Treatments	9742.978	2	4871.489	1361.596	.000
Ratio	61253.467	4	15313.367	4280.134	.000
Treatments * Ratio	**4262.800**	**8**	**532.850**	**148.933**	**.000**
Error	107.333	30	3.578		
Total	849709.000	45			
Corrected Total	75366.578	44			

R Squared = .999 (Adjusted R Squared = .998)

Conclusion

The pressing issue of global climate change needs to be addressed as it has exposed the vulnerability of economies, human health, and ecosystems. This study has shown that microbial fuel cells, commonly used for wastewater treatments, hold considerable potential for generating clean electricity, which could help address the effects of global climate change, as it primarily uses microbial metabolism. Moreover, since the study utilizes cow manure, it contributes to the reduction of methane emissions, a greenhouse gas.

The results revealed that the mixture of 75% cow manure, and 25% clay soil in the anode compartment of the MFC has the highest energy yield. Many studies prior to this have justified the results of the favorable energy yield from the clay-cow manure mixture as clay is highly conductive. The results of various test trials also provided information that only cow manure mixtures have comparably lower yields than when it is combined with soil samples. In summary, the results obtained show that MFC should be pursued as it utilizes microbes for energy production and produces clean energy, which is in line with United Nations Sustainable Development Goals.

Recommendations

With the potential of this technology, further research should be conducted on the microbial components to characterize and understand the extent to improve the technology fully.

Acknowledgements

This paper and the research behind it would not have been possible without the continuous support of their research teacher and adviser, Mrs. Michelle Fernando, Mrs. Sherry P. Ramayla, Ms. Deborah Gwen Gilot, Mr. David Paul Jinayon, and Mr. Patrick Cerna. Their enthusiasm, knowledge, and patience have been the researchers' inspiration which allowed them to keep track of all the activities required to complete the final draft of this paper.

The researchers thank Mr. Gilbert Alerta and Mr. Erle Mark Estrella for their assistance with the methodology and for sharing their wisdom with the researchers throughout the research. The researchers would also like to thank their classmates, batch mates, and schoolmates who have given their comments and suggestions that contributed significantly to the construction of the paper. They would like to let their family know how grateful they are for the love and guidance they have given the researchers. They are the ultimate source of inspiration.

Most importantly, the researchers would like to thank the Almighty, who has been there through thick and thin.

References

Fosso-Kankeu, Elvis & Marx, Sanette & Waanders, F. & Jacobs, Visagie. (2015). Impact of soil type on electricity generation from a Microbial Fuel Cell.

Gelaw, A., Singh, B., & Lal, R. (2015). Soil Quality Indices for Evaluating Smallholder Agricultural Land Uses in Northern Ethiopia. *Sustainability*, *7*(3), 2322–2337. https://doi.org/10.3390/su7032322

Md. Khudzari, J., Kurian, J., Tartakovsky, B., & Raghavan, G. S. V. (2018). Bibliometric analysis of Global Research Trends on Microbial Fuel Cells using scopus database. *Biochemical Engineering Journal*, *136*, 51–60. https://doi.org/10.1016/j.bej.2018.05.002

Mukherjee, A., & Lal, R. (2014). Comparison of Soil Quality Index Using Three Methods. *PLoS ONE*, *9*(8), e105981. https://doi.org/10.1371/journal.pone.0105981

Razmjoo, A., Gakenia Kaigutha, L., Vaziri Rad, M., Marzband, M., Davarpanah, A., & Denai, M. (2021). A Technical analysis investigating energy sustainability utilizing reliable renewable energy sources to reduce CO2 emissions in a high potential area. *Renewable Energy*, *164*, 46–57. https://doi.org/10.1016/j.renene.2020.09.042

HYDROLINE: Hydropower in a Pipeline

Mariella Jeanne Dellosa
Philippine Science High School - Caraga Region Campus, Philippines, https://orcid.org/0009-0008-4516-2253

Pete Justin Dagaraga
Philippine Science High School - Caraga Region Campus, Philippines, https://orcid.org/0009-0004-8600-6389

Gaudenis Joshua Plaza
Philippine Science High School - Caraga Region Campus, Philippines, https://orcid.org/0009-0003-2183-7977

Patrick Cerna
Department of Science and Technology, PSHS-CRC, https://orcid.org/0000-0002-2554-2098

Abstract: The hydro dam is believed to be a clean energy source, yet evidence suggests it has brought damage to the environment and nearby communities. This issue could be mitigated by in-conduit hydropower (ICH), a technology rarely tackled in the literature. As such, the proponents of this study created an ICH system prototype consisting of a hybrid Savonius-Darrieus turbine inside a 4-inch PVC pipe tee. The device was tested at the Philippine Science High School - Caraga Region Campus (PSHS-CRC). Throughout a 5-minute operation time, the device generated an average of 234 V. At the first minute, the average value amounted to 330 V. Nonetheless, it then decreased to 210 V due to mechanical complications. Despite the difficulties encountered, the device generated a maximum voltage of 348 V and received positive ratings from a teacher, plumber, and electrician of the PSHS-CRC. However, these results were obtained only when wooden strips—components unoriginally part of the system's design—were added to the turbine. Despite requiring improvements in its design, the device still proved its potential with its high voltage output. Further study on the ICH system will significantly contribute to the development of cleaner and safer hydropower technology.

Keywords: Renewable Energy, In-Conduit Hydropower, Hybrid Savonius-Darrieus Turbine, Water Distribution Network, Pipeline System.

Citation: Dellosa, M. J., Dagaraga, P. J., Plaza, G. J., & Cerna, P. (2023). HYDROLINE: Hydropower in a Pipeline. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023-- International Conference on Life Sciences, Engineering and Technology* (pp. 92-129), Denver, CO, USA. ISTES Organization.

Introduction

Background

Hydropower is generally known to be one of the cleanest ways to produce electricity due to its renewable nature. Such a generalization has led to the initiation of numerous hydropower projects in various countries, especially in China (Li et al., 2018). Nonetheless, researchers have begun questioning its resulting environmental, social, and cultural impacts (Tajziehchi et al., 2013; Zarfl et al., 2019). For instance, research shows that the construction of a large hydropower plant (LHP) disrupts fish life cycles and marginalizes fishermen who rely on fishing resources for their subsistence (Alho et al., 2015; da Costa Doria et al., 2018; Winemiller et al., 2016). Even studies claim that LHPs emit more greenhouse gases (GHGs) than what is generally estimated (Fearnside & Pueyo, 2012; Kemenes et al., 2016). The construction of these projects has also caused negative socio-cultural impacts, displacing millions of people who subsequently are insufficiently compensated during resettlement (Moran et al., 2018; Stickler et al., 2013; Van Cleef, 2016). Concerningly, most hydro dam budgets underestimate the costs of such consequences (Ansar et al., 2014). The awareness of these issues escalated, which led to an increase in dam removals worldwide (O'Connor et al., 2015).

LHPs are becoming more recognized as an unsafe means of generating electricity. Because of this, the support for small hydropower plant (SHP) development has increased (Couto & Olden, 2018). The SHP consists of the same fundamental characteristics comprised in an LHP. The only major difference between the two is their size and power generation output (Premalatha et al., 2014). Many studies claim that SHPs do not cause any environmental and social complications and, as such, are a clean source of energy (Nautiyal et al., 2011; Sipahutar et al., 2013). However, considering its ratio to the power generated, the adverse impact of the SHP is no less than that of the LHP (Premalatha et al., 2014). In fact, per kWh generated, the hazards of an SHP can exceed the hazards of an LHP (Bakken et al., 2012; Kibler & Tullos, 2013; Pascale et al., 2011). A reason for this issue is that the smaller the dam's capacity, the more GHGs are emitted (Prakash & Bhat, 2012). Moreover, SHPs are perceived to decrease the abundance of fish populations as much as LHPs (Fung et al., 2019). Unfortunately, the technology will not remain cost-competitive for long since the price of wind energy—another source of renewable energy—is already lower than that of hydropower (da Silva et al., 2016).

Interestingly, it has yet to be taken into much thought that hydropower can still be harnessed without causing the issues discussed above. A prime instance of this is the utilization of in-conduit hydropower (ICH) in water supply systems (WSSs). ICH generation is a process in which the kinetic energy of in-pipe water flow is converted into electrical energy. WSS conduits have an untapped potential for decreasing grid electricity consumption and providing renewable energy to water agencies (Sari et al., 2018). Existing studies claim that ICH systems do not interfere with the surrounding environment nor require much civil work to be installed, operated, and maintained (Loots et al., 2014; Mbele & Kusakana, 2017). Unfortunately, there needs to be more in-depth research regarding the development of ICH, especially concerning its design and simulation. Most ICH studies solely evaluate existing ICH pilot projects or provide possible sites for their installation. Real-world

applications of the technology hardly exist in the hydropower industry. The lack of its exploitation may be caused by insufficient exposure in the market (Sari et al., 2018).

In contribution to ICH research, the proponents of this project designed a small and simple ICH turbine that can be easily installed and operated in residential water distribution pipelines. This is to make its real-world application a more feasible process to achieve. The turbine is able to function without the resulting environmental and socio-cultural problems that both LHPs and SHPs currently create. The results of the turbine's operations shall help determine the device's potential compared to the current hydropower projects being implemented today. Overall, this paper shall contribute to the technology's recognition in the hydropower industry.

Objectives of the Study

The main objective of this study is to engineer a prototype of a simple and cost-effective ICH system. This system must be able to operate in small pipeline networks, especially those at home. Specifically, the proponents aim to:

1. Design and 3D-print a prototype of an ICH turbine installed in a 4-inch water pipe;
2. Measure and record the turbine's voltage generation in a 5-minute operation test;
3. Evaluate the turbine's voltage generation, functionality, reliability, aesthetics, usability, durability, maintainability, and realizability.

Significance of the Study

ICH technology is capable of generating electricity without interfering with the environment, wildlife, and livelihoods of nearby communities. Hence, the project shall be deemed significant in the field of hydropower generation in mitigating the range of issues caused by numerous hydropower projects. This study provides a relatively ample contribution to the development of ICH generation, considering the scarcity of its real-world applications.

Due to its small size, the proposed device can be used in a variety of locations ranging from farm irrigation conduits to home gutter pipes. The device can also be installed in rural off-grid regions where access to electricity is difficult to find. Notably, this study will also benefit the water distribution network (WDN) itself, exploiting the pipeline's excess water pressure to power the network's electrical equipment (e.g., water pumps). Likewise, this device shall benefit a diverse demographic of users, such as electrical engineers and electricity consumers of the residential, commercial, and industrial sectors.

Scope and Limitations

The primary focus of the study is the design and evaluation of a small ICH turbine installed in a 4-inch water pipe. Since the study is at a prototyping stage, the proponents prioritized the turbine design's simplicity over efficiency. Hence, this paper does not include a thorough optimization of the turbine's dimensional parameters. According to the local WDN engineers, the installation of the device in the network is currently unfeasible. As such, the proponents tested the prototype in the Philippine Science High School - Caraga Region Campus (CRC).

The operation of the prototype was solely conducted with a water hose and a multimeter due to the unavailability of more appropriate equipment. Using the tools available, the researchers were only able to measure the device's voltage generation. To avoid wastage of large amounts of water, the researchers solely operated the device in a single 5-minute trial. Thus, the potential of its application in a real pipeline system was not accurately determined. However, regarding the device's qualitative aspects, the proponents managed to gain feedback from the school plumber and electrician of the PSHS-CRC. It should be noted that much of this feedback—based on the observations made during the experiment—were mere assumptions on the device's potential in real-life applications.

Review of Related Literature

Hydro Dams: The Issue

Hydro dams pose various environmental and socio-cultural issues. The most prominent of such problems are discussed in this literature review. In particular, this section tackles how hydro dams accumulate sediments in reservoirs, emit GHGs in the atmosphere, disturb fish's life cycles, and interfere with the social networks of nearby communities.

The Accumulation of Sediments in the Reservoir

A hydro dam can significantly change the sediment dynamics of its surroundings due to the reservoir's ability to trap a considerable amount of sediments upstream of the dam (Van Manh et al., 2015). According to Kondolf et al. (2014), the amount of sediments trapped in a dam is directly proportional to the reservoir's size. The authors claim that even the Mekong River's largest reservoirs have reached a trapping efficiency of 95% or greater. The trapping of sediments can cause technical, agricultural, and ecological consequences.

Firstly, there is a negative correlation between the number of trapped sediments in the reservoir and the amount of water discharged from the dam (Kameyama et al., 2013). Likewise, the trapping of sediments can reduce the reservoir's capacity and thus lessen the dam's functionality, as hydropower generation is purely dependent on the kinetic energy of flowing water (Agarwal & Kansal, 2017; Egré & Milewski, 2002). Secondly, nutrients

originating from deposited sediments contribute to more than 50% of the production of mineral fertilizers used for agricultural purposes (Manh et al., 2014). As such, the lack of sediments downstream of a hydro dam can reduce the agricultural productivity in the surrounding area (Kondolf et al., 2014). Lastly, the accumulation of sediments also contributes to greenhouse gas emissions. This issue is further discussed in the next section of this paper.

The Emission of Greenhouse Gases

Despite being meant to alleviate climate change as a technology of renewable energy, many hydro dams fail to fulfill the role of reducing GHG emissions. In fact, it is estimated that hydro dams are responsible for 4% or more of the carbon emissions stemming from inland waters (Barros et al., 2011). In constructing the hydro dam reservoir, the terrestrial environment turns into an aerobic and anaerobic decomposition of the organic matter in flooded terrestrial soil (Kumar et al., 2018). This is the primary source of hydro dam GHG emissions, which can even reach the levels of those from fossil fuel power plants (De Faria et al., 2015; Räsänen et al., 2018). Nonetheless, methane (CH4) emissions originating from inland waters (including reservoirs) are hardly considered in global GHG assessments and rarely considered part of the global carbon cycle (Bastviken et al., 2011; Kemenes et al., 2016). This may be due to the overestimation of *carbon sequestration*—a method of mitigating GHG emissions through the storing of atmospheric carbon dioxide (CO2) in geologic formations (Bastviken et al., 2011; Cloy & Smith, 2018; Hutchinson et al., 2007).

Hydro dams installed in areas with high temperatures—notably those in tropical or subtropical zones—can be considered strong anthropogenic hotspots of GHGs (Bansal et al., 2015; Kumar et al., 2021). This is plausibly due to the dynamic nature of the carbon cycle that occurs in hydro dams, which involves two processes: *methanogenesis* and *ebullition*. (Hidrovo et al., 2017). Once organic matter is supplied in deep, anoxic sediment strata, it is oxidized into CO2 through anaerobic respiration (Hidrovo et al., 2017; Lyu et al., 2018; Sobek et al., 2012). In the absence of oxygen (especially due to high temperatures), CO2 is reduced to CH4 through hydrogenotrophic methanogenesis (Lyu et al., 2018). The CH4 is then trapped in gas bubbles via ebullition and is emitted into the atmosphere (Sobek et al., 2012). Thus, GHG emissions will increase whenever uncleared degradable matter (e.g., vegetation) is submerged by a reservoir (Demarty & Bastien, 2011; Räsänen et al., 2018).

Other GHG emissions stem from the transfer of gases prompted by water passing through turbines and spillways, causing degasification (Hidrovo et al., 2017; Kamal et al., 2020). Indirect emissions of GHGs in hydro dams also occur, specifically during the construction phase when the materials and equipment used to build the hydropower plant are being manufactured and transported (Steinhurst et al., 2012). Nonetheless, there is a consensus that it is the lakes and rivers themselves that are the primary sources of GHGs (Raadal et al., 2011). This is probably due to the suggestion that almost half of the total GHG emissions stem from the reservoir (Hidrovo et al., 2017).

The Hindrance to Fish Migration

Not only do hydro dams trap sediments and prevent their release, but they also block fish migrating routes (Ziv et al., 2012). To solve the issue, LHP engineers have designed passageways to let fish travel up and down the dam more easily (McLaughlin et al., 2012). Even so, research suggests that most fish passageways are ineffective and disruptive to the fish's sense of orientation (Kuenzer et al., 2013). Moreover, in the design of fish passageways, solely a limited few of certain fish species are considered (Brown et al., 2013; Silva et al., 2018). Fishes that can pass through the dam are usually limited to those with strong climbing abilities (Baumgartner & Wibowo, 2018). Because of these limitations, upstream and downstream passage efficiencies are, on average, 41.7% and 68.5%, respectively (Noonan et al., 2012). Nonetheless, the efficiency of a fish passageway can be so critically low that the only solution to such an issue would be the removal of the entire hydro dam (Brown et al., 2013). Without effective passageways, many fish would concentrate at the base of the dam during juvenile migration (Loures & Pompeu, 2012).

Usually, the weir itself is thought to be the only barrier to the fish's migration routes. However, there exists another obstacle that does not block the fish physically but ecologically—the reservoir. According to Pelicice et al. (2015), a dam's reservoir serves as a "behavioral" barrier that impedes fish from moving downstream. The raised upstream water levels reduce the water's flow variability, velocity, and turbulence, abnormally altering the water's hydrology (Anderson et al., 2015; Gauld et al., 2013). Water velocities upstream of the dam must be high enough to increase the willingness of fish to enter the fish passageway (Foulds & Lucas, 2013). This is due to the rheophilic behavior of fish that causes them to be attracted to lotic habitats (Pompeu et al., 2012). Fish in the dam also have difficulty moving upstream due to *hydropeaking*—the unsteady release of water caused by the raised physical structure of the dam's reservoir (Person et al., 2014). This substantially increases the velocity of the water downstream, making it more difficult for fish to travel up the dam (Keefer et al., 2011).

Despite these issues having already been taken into account, there still exist several gaps and questions regarding the design and construction of fish passageways. Even the world's largest producer of hydropower—China—has had difficulty in confronting questions about the ecology of water flow (Chen et al., 2016). According to Williams et al. (2012), an ample amount of biological knowledge is required to determine the behavior of fish when they encounter variable water flows, velocities, and turbulence. The authors add that expertise in hydraulic and civil engineering is indispensable to determining the appropriate hydraulic conditions that fish can utilize. Furthermore, having an aptitude for sciences such as physiology, biomechanics, kinematics, and energetics is crucial to possess a sufficient amount of knowledge of fish passage science and engineering (Silva et al., 2018). The hefty requirement for ecological and engineering expertise is plausibly one of the reasons why existing fish passageways are hardly efficient.

The Injustice of Involuntary Resettlement

Another problem that occurs during hydro dam construction is involuntary resettlement. According to Kim

(2015), there are two distinct processes in involuntary resettlement: displacement and resettlement. The author defines displacement as the process in which a community loses assets and resources as a result of the construction of a development project. Resettlement, on the other hand, is defined as the restoration or improvement of the incomes and living standards of those adversely affected by the project's construction; in other words, a method of rehabilitation.

It should be expected that Kim's (2015) definition of resettlement would be implemented by those involved in the LHP designing process. Nonetheless, case studies suggest otherwise. According to a case study series published by the International Displacement Monitoring Centre (2017), many of tens of millions of people tend to become marginalized and impoverished due to being displaced by LHP projects. There were cases in which the injustice of involuntary resettlement became so critical that protests occurred as a consequence. In particular, the Sardar Sarovar Project—a project that aimed to construct multiple dams in the Narmada river—inspired several years of protest, so much so that the World Bank withdrew its financial support for the project's development (Terminski, 2013).

Considering the seriousness of such protests, it is clear that what most hydropower developers lack is the ability to assess the importance of energy justice. According to Sovacool & Dworkin (2015), energy justice is the right of all citizens—regardless of whether or not they are a part of substantially developed economies—to access all energy services. According to Zhao et al. (2020), energy justice includes three subcategories: *recognition*, *procedural*, and *distributional* justice. These components respectively address the "who," "how," and the "what" involved in the social justice of resettlement.

First off, several hydro dam projects do not effectively utilize tracking systems to monitor the implementation of resettlement regulations (Manorom, 2018). According to Kim (2015), the World Bank Group failed to create sufficient documentation of the oversight of several LHP projects during the last two decades. Failing to acknowledge the living conditions of resettlers has led to several other issues, including the violation of modern notions of procedural justice (Sovacool et al., 2016). According to Suhardiman et al. (2014), benefit-sharing programs often lack adequate discussion of the resettler's rights during the development of hydropower projects. Resettlement regulations that do involve consultations with the local migrant communities still fail to give the resettlers control over the resettlement process (Habich, 2015). Often, households are merely compensated by cash or credit for the loss of previously-owned assets; resettlers are, unfortunately, left responsible for finding and purchasing new property (Randell, 2016). Additionally, rural resettlers rarely have the opportunity to gain employment after resettlement and, thus, would have to rely on the little savings they have available (Wilmsen et al., 2011). This then leads to another issue—distributional injustice.

Adhering to distributional justice involves benefit-sharing—the process in which compensation demands are addressed while taking into account the principle of equity and need (De Jonge, 2011). Case studies conducted by Siciliano et al. (2018) suggest that it is rare for hydropower projects to consider the principles of availability, affordability, and intergenerational equity in distributing energy services. Their studies show that the distribution

of such services is usually uneven since it is mostly based on the resettler's geographical location and livelihood options. Qualitative research suggests a divergence between the local and national priorities during the decision-making process of hydropower projects, resulting in the unequal distribution of costs and benefits between urban and rural areas (Siciliano et al., 2015). Competition for natural resources also often ensues between the local livelihoods and the construction and operation of the hydro dam (Yankson et al., 2018). Indigenous people do not have it better because they lose their relation to their ancestral land (Cooke et al., 2017).

In-Conduit Hydropower: The Solution

A hydro dam leaves adverse environmental footprints and injustice to communities requiring involuntary resettlement. However, the energy it principally generates—hydropower—can still be harnessed without the damage it causes. With the development of ICH technology, hydropower can be safely utilized within a WSS—an assemblage of water pipelines and other hydro-mechanical systems that help securely and efficiently store and transport water for its customers. The whole system consists of two main networks: the water transmission network (WTN) and the water distribution network (WDN). The WTN is an open network of large water pipes that transmit water from reservoirs (e.g., springs and wells) to the WDN—a closed-loop network of smaller pipes that directly distribute water to the community (Satish et al., 2021). Figure 1 illustrates a typical WSS scheme of urban areas.

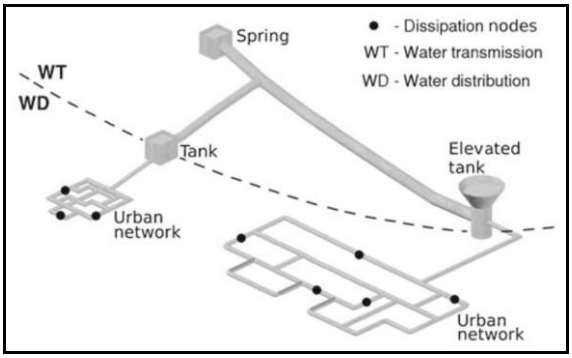


Figure 1. Typical Scheme of the Water Supply System (Carravetta et al., 2012)

The WDN is capable of transporting large amounts of water from one location to another. In spite of this, its effectiveness is hindered by a variety of anomalies, a prominent one being pipe leakages. Pipe leakages result in an unnecessary increase in the expenses of WDN operations; they deteriorate the water's quality, decrease the pipes' flow capacities, and increase the system's energy losses (Colombo & Karney, 2002; Duan et al., 2020). On average, for every percent of the network consisting of pipe leaks, there is a 2% increase in energy costs (Colombo & Karney, 2002; Colombo & Karney, 2005). Globally, water losses from pipe leakages cost a total of 39 billion USD per year. (Liemberger & Wyatt, 2019).

Pipe leakages are usually attributable to high water pressure wearing down pipe walls. In order to alleviate the core problem, pressure management schemes (PMSs) have been implemented to control water pressure from

increasing excessively. PMSs are commonly done by optimizing the settings of pressure-reducing valves (PRVs) readily installed in the pipeline system (Gupta et al., 2017; Ortega-Ballesteros et al., 2022; Samir et al., 2017). Applications of the scheme have already been successful in lessening pipe leakages. For instance, Gupta et al. (2017) were able to decrease leakage rates by 20.64% using a multiobjective genetic algorithm. The case of García-Ávila et al. (2019), on the other hand, involved a 31.65% reduction in pipe leakages. This percentage was surmounted by the 37% achieved by Samir et al. (2017), who ran different leakage scenarios with WaterCAD to determine the aptest quantities of and locations for PRVs. to be installed in the WDN.

In spite of its success in reducing pipe leakages, PRVs. waste a surplus of water pressure that could have been exploited to generate other forms of energy (Mbele & Kusakana, 2017). To control the water pressure while also efficiently recovering the pressure energy, ICH was developed in replacement of PRVs. (Casini, 2015; Porkumaran et al., 2017; Vilanova & Balestieri, 2014). The ICH generator converts the potential and kinetic energy of in-pipe water into mechanical energy, which is then converted into electrical energy with the rotor (Porkumaran et al., 2017). Because ICH can recover energy without fully obstructing the in-pipe water flow, its application makes the maintenance of WDNs achievable without the complete termination of the network's operations (Abdullah et al., 2021).

There are two main types of ICH systems: *internal* and *external* (Casini, 2015; Mbele & Kusakana, 2017). According to Smith (2016, as cited in Mbele & Kusakana, 2017), an internal ICH system comprises a runner fully contained inside an already-installed pipeline section. Out of the two systems, the internal ICH system is the most suitable for water energy recovery due to its compactness. This system can generate from 5-10 W to 100 kW depending on the size of its application.

On the contrary, according to Division (2016, as cited in Mbele & Kusakana, 2017), the runner of an external ICH system is installed in a conduit section that bypasses the main pipeline system. Since the turbine's runner is independent of the size of the WDN's main pipes, it allows more design flexibility compared to internal ICH turbines. However, its assembly requires a large amount of space, making it unideal to be installed in existing WDN infrastructure.

External and internal ICH systems are discussed in the following sections of this paper. In particular, the pump-as-turbine (PAT) and the vertical-axis turbine (VAT) respectively serve as the specific examples of the external and internal ICH systems discussed. This review also tackles the types of VAT in terms of the hydrodynamic forces involved. However, as specified in the *Scope and Limitations*, this paper does not include a thorough analysis of turbine optimization strategies.

The Pump-as-Turbine

The PAT is an unconventional hydraulic pump that can operate in two modes—*pump mode* and *turbine mode*. In pump mode, the PAT functions as a regular pump that converts electricity to pressure energy. Intuitively, in

turbine mode, the PAT converts pressure energy to electricity. Figure 2 demonstrates the comparison of the PAT in pump mode and turbine mode.

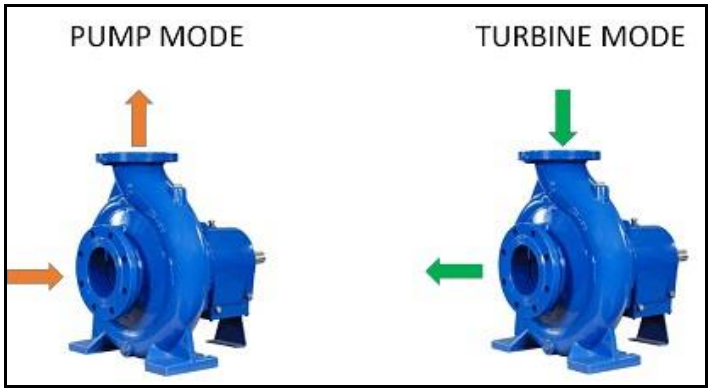


Figure 2. The PAT: Pump vs. Turbine Mode (North Ridge Pumps, n.d.)

According to Chapallaz (1992, as cited in Amelio et al., 2020), the PAT is more economical and technologically simpler than the hydraulic turbine. This is because the PAT does not consist of a flow control system. An illustration of the PAT's typical installation scheme is shown in Figure 3.

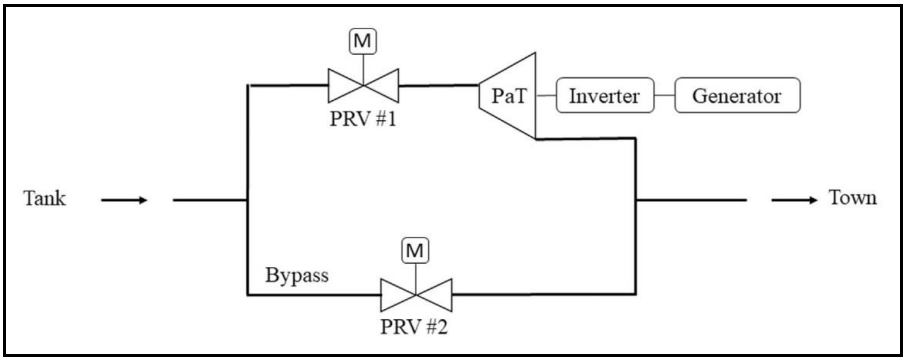


Figure 3. Typical Installation Scheme of a PAT (Stefanizzi et al., 2020).

In conclusion to a thorough review of existing ICH systems, Pérez-Sánchez et al. (2017) suggest that PATs mainly benefit in:

1. Replacing PRVs. in dissipating excessing water flow energy,
2. Efficiently operating between an efficiency value of 0.40 to 0.70,
3. Requiring solely low investment costs, and
4. Consisting of machines that are readily available.

In contrast, a disadvantage of the PAT is that it operates inefficiently below its best efficiency point (Pérez-Sánchez et al., 2017). Current PAT technology has always been slightly less efficient than a regular pump (Liu et

al., 2022). In terms of water pressure control, a PAT is as efficient as a PRV, but only when water consumption rates are high (Lima et al., 2017). Moreover, constant outlet pressure is not possible with a single PAT; the device is unable to produce energy with low water flow rates (Lima et al., 2017).

Despite these drawbacks, investment in PATs remains attractive due to their potential economic and environmental benefits (Binama et al., 2017; Chacón et al., 2021; Stefanizzi et al., 2020). For instance, Stefanizzi et al. (2020) conducted a case study on a PAT installed at the origin of a large WDN located in Southern Italy. It was estimated that the PAT system had an annual energy production of 818k kWh and an annual CO2 reduction of 317 t, along with a total annual revenue of around 215k USD. Chacón et al. (2021) have also done a similar study, one involving a smaller application of a PAT system in an agricultural farm. From the system's 2443-hour operation time during the 2019 irrigation season (May to September), the authors found that the annual savings amounted to 2.4k USD and the annual CO2 reduction amounted to 8.4 t. Figure 4 is a graphic summary of the system's monthly economic and environmental savings, considering the theoretical irrigation time in April.

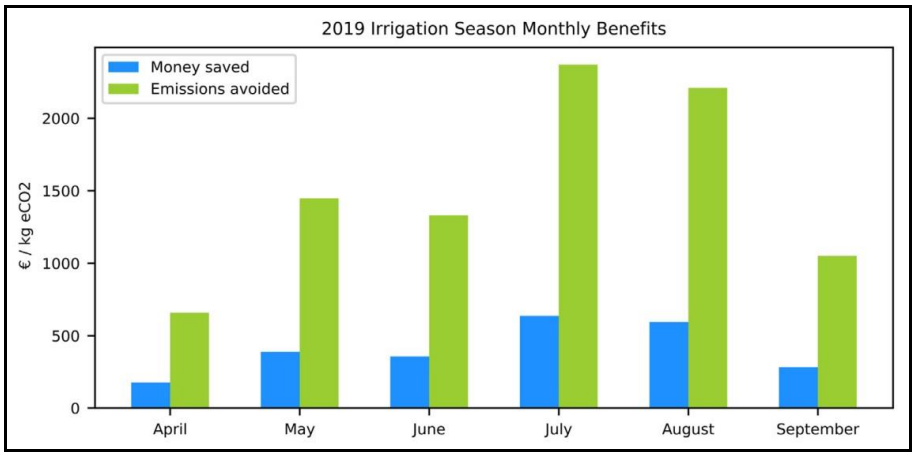


Figure 4. Monthly Economic and Annual Savings of the PAT (Chacón et al., 2021)

The Vertical-Axis Turbine

The in-conduit VAT is similar to the PAT in its principal function of producing electricity by converting the kinetic and pressure energy of in-pipe water into electrical energy. Although, instead of being installed in a secondary pipeline section, the VAT is completely contained within the WDN's main pipes. The conventional VAT—whether wind-driven or water-driven—consists of a number of blades attached to a vertical shaft. This shaft rotates upon being subjected to a torque (Nm)—a result of fluid passing through the turbine's blades, causing the blades to experience lift or drag forces.

The technology mainly gained traction in the study of wind energy generation due to its omnidirectional and yaw-less design. According to an analysis conducted by Johari et al. (2018), vertical-axis wind turbines (VAWTs) generate power more efficiently and consistently than horizontal-axis wind turbines (HAWTs) in environments where the wind's direction often changes. Even though they were introduced before HAWTs,

VAWTs lost popularity due to the belief that they were unreliable for generating energy on a large scale (Bhutta et al., 2012). However, VATs are apt for shallow water channels with varying water velocities and shallow streams with limited water flow rates (Vermaak et al., 2014). Hence, the technology is more popular in the field of hydrokinetic energy generation, particularly in river applications (Behrouzi et al., 2016).

Vertical-axis hydrokinetic turbines (VAHTs) generate a greater amount of power than VAWTs. The density of a fluid directly affects the theoretical amount of power that is available for extraction. According to Maldar et al. (2020a), the theoretical power available (Pavail) in Watts (W) can be acquired with the equation:

$$P_{avail} = \frac{1}{2} \times \rho \times A \times v^3 \quad (1$$

where is the fluid density (kg/m3), A is the turbine blades' cross-sectional area (m2), and v is the incoming velocity—the velocity of the fluid that passes through the turbine (m/s).

Since water is approximately 800 times denser than air, the power density of a VAHT is considerably higher than that of a VAWT. To illustrate, the power density of a wind turbine with a wind flow velocity of 14 m/s is equivalent to that of a hydrokinetic turbine (HKT) operating with an exceptionally low stream velocity of 1.5 m/s (Maldar et al., 2020b). A comparison between the power density of a wind turbine and an HKT is shown in Figure 5.

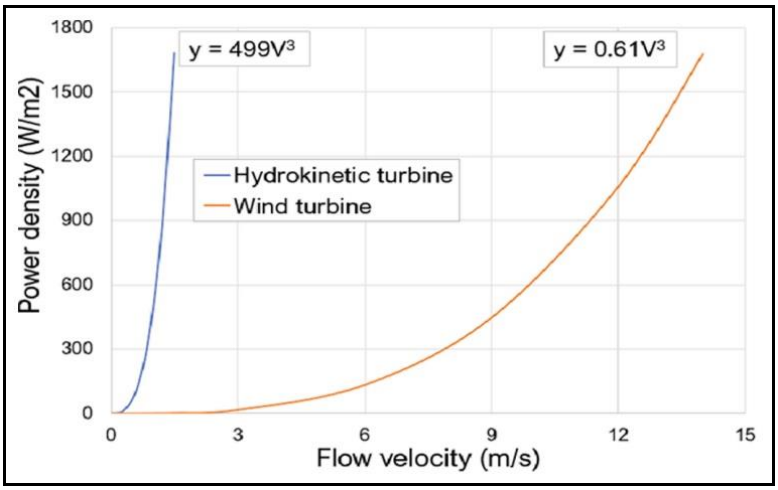


Figure 5. Wind vs. Hydrokinetic Turbine Power Density (Maldar et al., 2020b)

In respect to the hydrodynamic forces experienced by its blades, the VAT is classified into two main types. These types are the *Savonius* and *Darrieus* turbines. The former is mainly run by drag forces, while the latter is primarily driven by lift forces.

The Savonius Turbine

The conventional Savonius turbine, as displayed in Figure 6, consists of side-by-side hemicylindrical blades,

each facing in the opposite direction. When fluid passes through the S-shaped structure, drag force is exerted on the blades, most of which is experienced by the concave side than the convex side. The rotation of the turbine is driven by the difference in drag forces experienced between the concave (advancing) and convex (returning) blades (see Figure 6).

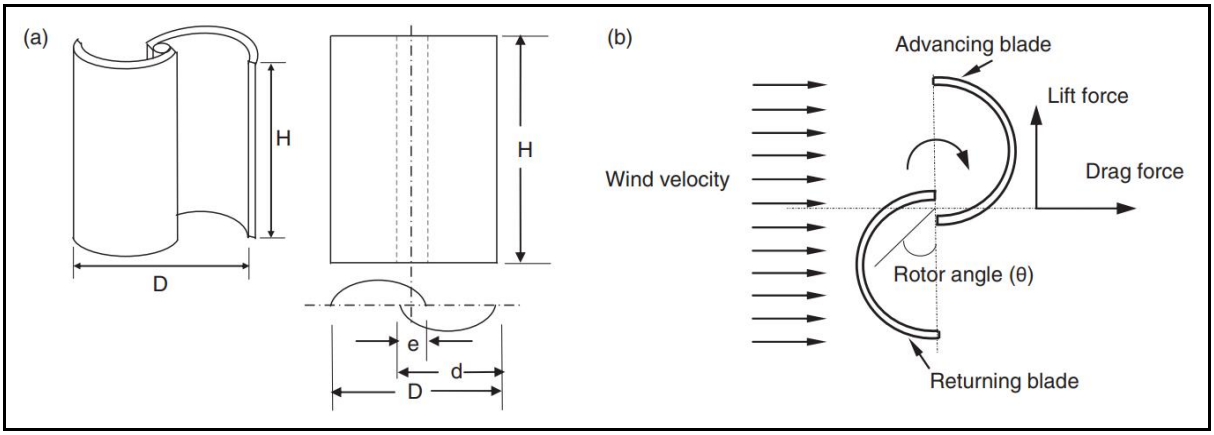


Figure 6. (a) Savonius Rotor and (b) Forces Experienced (Roy & Saha, 2013)

The Savonius turbine is primarily drag-based; the lift force it experiences does not contribute much to its net torque. As such, the tangential speed of the standard Savonius turbine does not exceed the speed of the incoming fluid. To add, it is notorious for having poor efficiency because it relies on drag rather than lift (Maldar et al., 2020a). Nevertheless, it is quite easy to manufacture due to its simplicity and low cost (Dilimulati et al., 2018; Tasneem et al., 2020). It is also well known for its good starting characteristics; the turbine can self-start at considerably low fluid velocities (Kumar & Saini, 2016).

Research on in-pipe Savonius HKTs is currently scarce. Nonetheless, there have been studies conducted on HKTs' river, tidal, and ocean-current applications. For instance, due to the Savonius turbine's poor energy conversion efficiency, various optimization strategies have been proposed to solve the problem (Maldar et al., 2020b). Some studies have focused on optimizing specific turbine characteristics, including the number of blades and their geometry (Hamzah et al., 2018; Kumar & Saini, 2016; Talukdar et al., 2018). There have also been studies on the assembly of additional components to improve the turbine's efficiency, one of which is the fluid deflector (Prasetyo et al., 2018; Sakti et al., 2019). Interestingly, there are a few studies that proposed the development of a Savonius turbine consisting of a combined lift-drag (CLD) blade design (Basumatary et al., 2018; Basumatary et al., 2020; Basumatary et al., 2021).

The Darrieus Turbine

Unlike the Savonius turbine, the Darrieus turbine experiences a significant amount of lift force due to its blades' hydrofoil shape. The most common type of Darrieus turbine is the H-rotor. An illustration of this is shown in Figure 7.

Notably, the Darrieus VAWT is well known for its high aerodynamic efficiency (Kumar & Saini, 2016). This is because the turbine is mainly driven by lift force, which, as studies have shown, results in a better aerodynamic performance than drag force (Castelli & Benini, 2011). Inconveniently, the Darrieus turbine is complex in design, which makes it difficult to manufacture and install. Furthermore, it does not perform well at generating starting torque, which the Savonius turbine specifically excels at.

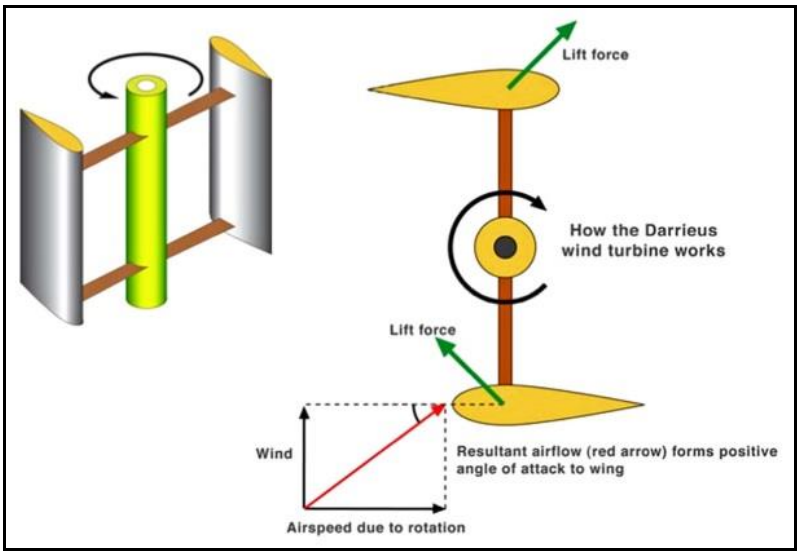


Figure 7. Operation of a Darrieus VAT (Jin et al., 2015)

Similar to the case of in-pipe Savonius HKTs, current research on in-pipe Darrieus HKTs is limited. However, outside WDN applications, there exists a considerable number of studies involving the enhancement of specific turbine parameters, one of the most prominent being the blades' hydrofoil profile (Kumar & Saini, 2017; Mutlu & Çakan, 2018; Saini & Saini, 2018; Kumar & Sarkar, 2022). There have also been a few studies involving the integration of external components such as the duct system (Malipeddi & Chatterjee, 2012; Tunio et al., 2020). Numerous studies like these were performed using the Shear Stress Transport (SST) k-ε turbulence model, a model suggested to be reliable for simulating turbulent flow conditions in computational fluid dynamic (CFD) simulations (Yagmur & Kose, 2021).

The Hybrid Savonius-Darrieus Turbine

Generally, what the Savonius turbine excels at is what the Darrius turbine underperforms. Ditto the opposite case. Likewise, engineers have designed a combination of these turbines' geometric and hydrodynamic characteristics to integrate the Savonius turbine's starting capabilities into the Darrieus turbine's power generation efficiency. As illustrated in Figure 8, a hybrid turbine typically consists of Savonius turbine blades within Darrieus turbine blades.

Pallotta et al. (2020) conducted several laboratory experiments on a certain VAWT model. This was with a range

of different Reynolds numbers. From these experiments, they concluded the following:

1. when tip-speed ratios (TSRs) were lower than unity, the performance of the hybrid turbine was always remarkably higher than that of the Savonius turbine;
2. the power coefficient (Cp) of the turbine was only slightly lower than that of the Darrieus turbine;
3. the hybrid turbine was capable of operating on a larger range of TSRs (0.5 to 4.0) compared with the lone Savonius (0.5 to 1.0) and the lone Darrieus (1.7 to 4.0) turbines.

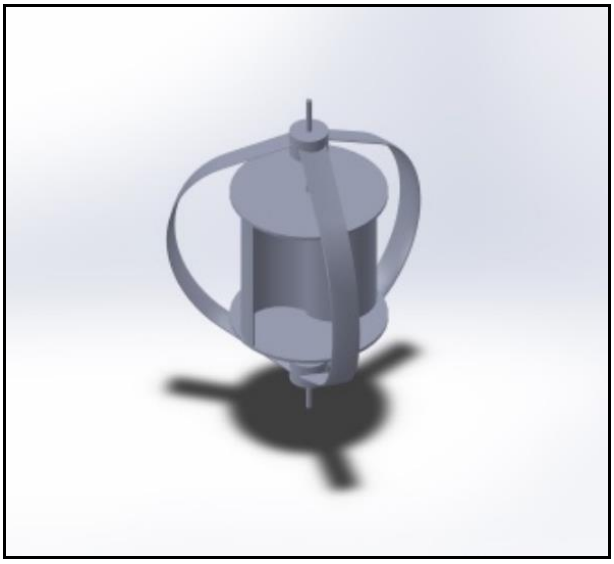


Figure 8. 3D Model of a Hybrid Turbine (Chawla et al., 2015)

Hardly any studies have been carried out on in-pipe hybrid Savonius-Darrieus HKTs. Despite the lack of research in this specific area, there still exists a few studies on the turbine's application outside WDNs. Similar to the case of any VAHT, there has been research on the optimization of the hybrid HKT's dimensional parameters. For instance, experiments and simulations have been performed in order to determine the effects of a range of rotor parameters, including the attachment angle, blade profile, radius ratio, and overlap ratio (Asadi & Hassanzadeh, 2021; Kamal & Saini, 2023; Saini & Saini, 2019).

Conclusion

The proponents aim to design a cost-effective ICH turbine that can be installed in small WDN conduits. Since the flow characteristics of in-pipe water vary throughout the day, the proponents adopted the hybrid Savonius-Darrieus turbine design. This allows the turbine to operate within a large TSR range. In designing the turbine, the proponents prioritized simplicity over a thorough optimization of its dimensional parameters. This is mainly because the project is at a prototyping stage but also because the device is meant to be cost-effective. Thus, a simple hybridization of a two-bladed Darrieus turbine and a two-bladed Savonius turbine was chosen as the design for the study's proposed ICH turbine.

Method

Concerning the operation of the ICH system prototype, the proponents underwent three main phases: the preparation of experimental units, the preparation of the test site and tools, and the experimentation and data collection. The specific tasks of these phases are discussed in this section. The functions of the turbine's main components are also briefly described after the discussion of the research's methodology.

The Process Flow

Preparation of the Experimental Units

The proposed ICH system mainly consists of a turbine, a PVC pipe tee, and a DC motor. The turbine was created using the 3D printer available at the PSHS-CRC Fab Lab. The rest of the components—the PVC pipe tee and the DC motor—were purchased from a local hardware store and from Lazada, respectively. After the procurement of these components, the ICH system was assembled with the assistance of the Caraga State University (CSU) Fab Lab. Revisions to the system's assembly were made with the help of the school plumber and electrician of the PSHS-CRC.

Preparation of the Test Site and Tools

With the assistance of the school plumber and electrician, the testing site and equipment were prepared. The testing tools were prepared in a motorpool at the PSHS-CRC. The location had a readily available water hose that the school plumber set up. On the other hand, the multimeter was borrowed from one of the school's laboratories. Additionally, an evaluation form on the device's qualitative aspects (functionality, reliability, aesthetics, etc.) was prepared to be filled out by the school plumber, the school electrician, and one of the campus's research assistants.

Experimentation and Data Collection

Once the testing site and equipment were fully prepared, the proponents tested the device with the assistance of the school plumber and electrician. After a few pretests, the turbine was tested in a single 5-minute operation period. During the device's operation, the proponents video-recorded the voltage readings of the multimeter. Shortly after the testing was finished, the proponents gathered feedback from the school plumber and electrician on the prototype's functionality, reliability, aesthetics, usability, durability, maintainability, and realizability.

The Process Flowchart

The three main phases are organized in a flowchart shown in Figure 9. The tasks listed at the top-right corner of

the chart correspond to the construction of the ICH system prototype. The top-left side of the flowchart consists of the tasks pertaining to the preparation of the testing site and testing equipment. These two phases were done independently and simultaneously. The processes enumerated at the bottom of the chart correspond to the device's operation and the data collection. These were done after the preparations of the ICH system, testing location, and testing equipment.

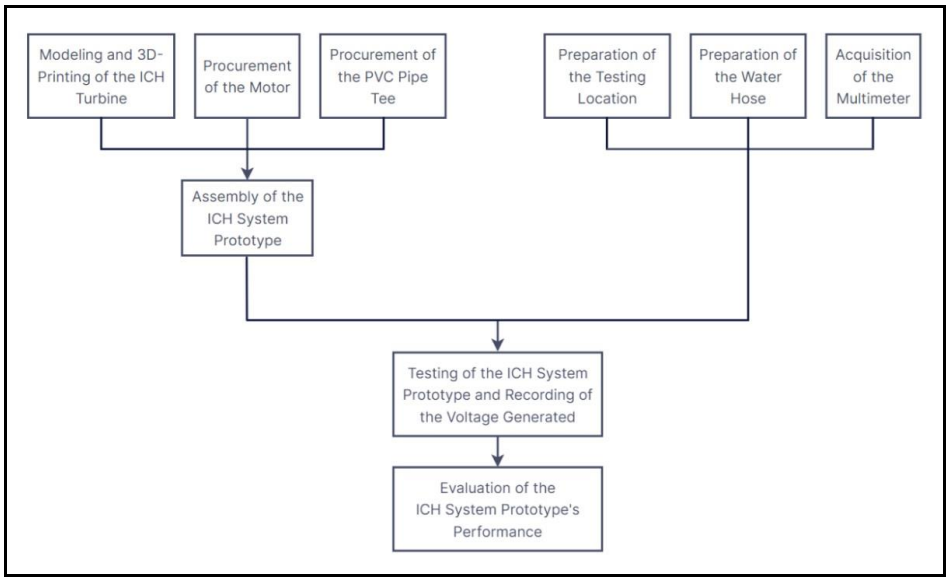


Figure 9. The Process Flowchart

System Components

Aside from the turbine, each component used in this study was either purchased by the proponents or borrowed from the PSHS-CRC laboratories. The PVC pipe tee, metal rod, nuts, washers, and bearings were bought from local hardware stores. The DC motor was purchased online from Lazada. The multimeter was acquired from one of the campus's laboratories, while the water hose was borrowed from the school's motorpool.

The Turbine

The turbine converts the water's kinetic energy into mechanical energy. Its design is a simple hybridization of the Savonius and Darrieus. The outer blades' shape follows the geometry of the NACA 0018. Each of the inner blades consists of a curvature angle of 45°. The whole turbine was fabricated with the assistance of the PSHS-CRC Science Research Assistants (SRA). Figures 10 to 12 show the design of the ICH turbine.

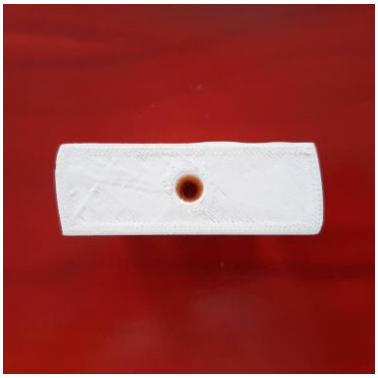


Figure 10. Top View of the ICH Turbine

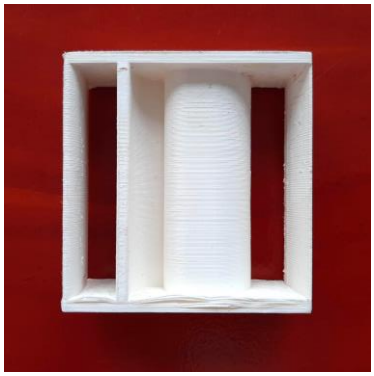


Figure 11. Front View of the ICH Turbine

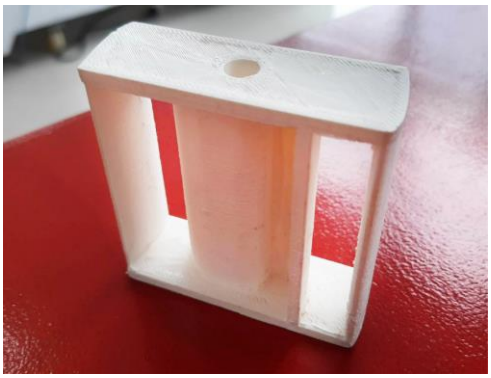


Figure 12. Angled View of the ICH Turbine

The Motor

The motor converts the turbine's mechanical energy into electrical energy. The motor used in this study is a 220V DC motor with a double-row ball bearing. The proponents purchased this component online at Lazada.

The PVC Pipe Tee

The PVC pipe tee houses the turbine of the ICH system. It has a circular opening at the top that allows the motor to easily attach to the turbine via the metal rod. The specific pipe used in this study has a diameter of 4 inches.

The Multimeter

The multimeter can measure different kinds of electrical parameters in adjustable ranges. The proponents used the tool to measure the motor's voltage generation. Its readings were video-recorded during the operation.

The Water Hose

The water hose is a long tube that conveys water from a water source to a particular area. The water hose used in the study was provided by the school. In testing the ICH system prototype, it was used to distribute water from a large water tank to the pipe tee.

The ICH System Prototype

The ICH system prototype generates power by utilizing the kinetic and potential energy of the flowing water to generate electricity. The energy present in the water flow is first converted into mechanical energy via the rotation of the turbine blades, then converted into electrical energy via the rotation of the motor. Figure 12 displays the ICH system prototype.

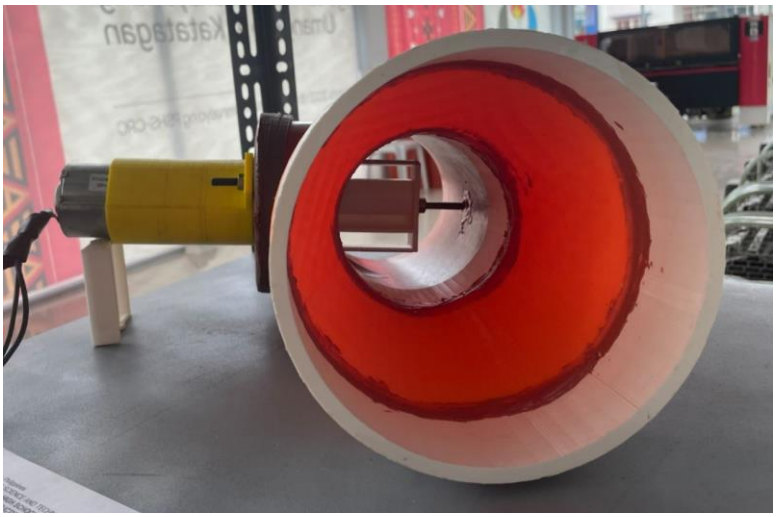


Figure 13. Inner View of the ICH System Prototype

Results and Discussion

The Test Setup

The ICH system prototype was tested at the motorpool of the PSHS-CRC. During the setup, the device was placed down on a wooden plank to allow the operators to hold it down for easier control. The water hose, on the other hand, was connected to a large water pump that served as the water source. The multimeter was placed down at a safe distance from the ICH system, enough to prevent the tool from getting wet by the high-pressure water distributed by the water hose. The motor’s wires were conveniently long enough to connect to the multimeter’s probes. Figures 14 and 15 show the setup of the ICH system and the multimeter, respectively.

Figure 14. The Operation Setup for the ICH System Prototype

Figure 15. The Operation Setup for the Multimeter

After fully setting up the device and testing equipment, the proponents began the pretest. With the school plumber's and electrician's assistance, the pipe tee was held firmly onto the wooden plank, and the water hose's tip was directed at the turbine. The water hose conveyed flowing water fast enough to rotate the turbine at high speeds. During this test, the pace of the turbine's rotation was inconsistent, subsequently requiring a quick repair of the system. This involved refastening the motor and adding wooden strips to the turbine's gaps, ensuring that the turbine rotates consistently. This then allowed the proponents to begin the official 5-minute operation test. During this test, one of the proponents video-recorded the rotation of the turbine, while the other recorded the readings of the multimeter. Screenshots of the video recordings are shown in Figures 16 and 17.

Figure 16. Operation of the ICH System Prototype

Figure 17. Cropped Screenshot of the Multimeter During Testing

One of the campus's teachers was also tasked to observe the whole operation of the ICH system prototype. This teacher, along with the plumber and the electrician, evaluated the device's qualitative aspects after the operation. Their observations, as well as the data collected from the video recordings, were used to assess the prototype's performance.

Voltage Generation

Based on the recordings of the multimeter's readings, the proponents graphed the voltage output generated throughout the 5-minute operation (see Figure 18). In the first minute, the device generated an average of 330 V. However, after this period, one of the turbine's wooden strips was damaged. Despite the impairment, the motor was able to consistently generate an average of approximately 210 V afterward. Throughout the whole operation, the motor's average voltage output amounts to 234 V. Impressively, the highest instantaneous voltage generated during the entire operation was 348 V.

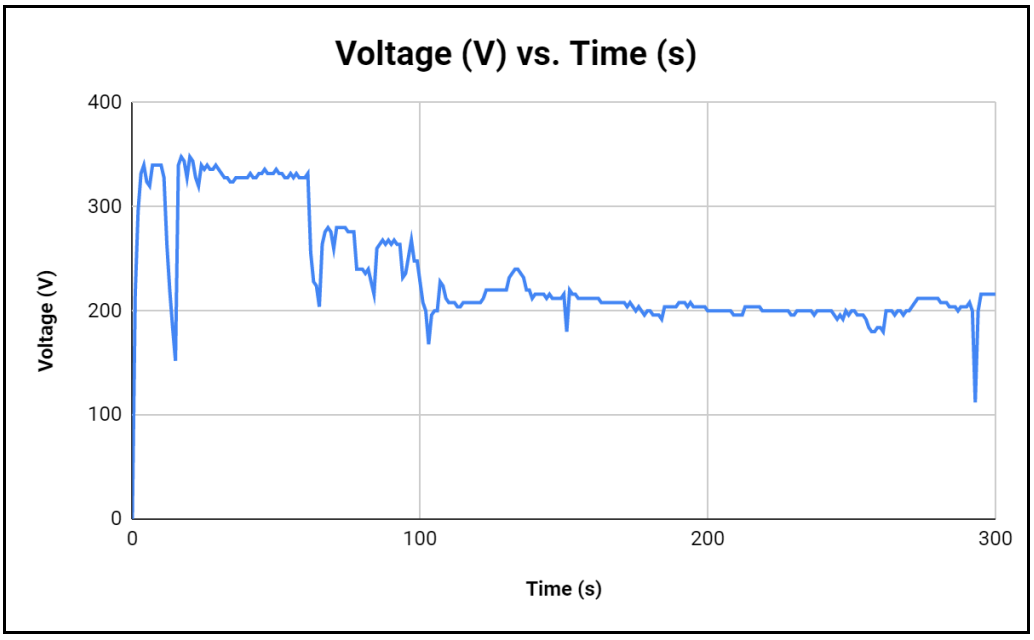


Figure 18. The System's Voltage Output vs. Time

Performance Evaluation

The proponents requested a teacher, plumber, and electrician of the PSHS-CRC to fill out an evaluation form on their observations of the device's operation. Each statement in the form pertains to one of these criteria: functionality, reliability, aesthetics, usability, durability, maintainability, and realizability. These qualitative parameters were evaluated on a 5-point Likert scale, as shown in Table 1.

Table 1. Values of the 5-Point Agree-Disagree Scale

Answer	Value
Strongly Agree	5
Agree	4
Neutral	3
Disagree	2
Strongly Disagree	1

There were at least two statements that were evaluated for each criterion. The proponents first calculated the average scores of each statement, then obtained the average of these values to determine the overall score of each criterion. These scores were evaluated based on the descriptive rating scale shown in Table 2.

Table 2. Descriptive Evaluation Scale for Each Criterion

Evaluation	Range	Range Difference
Strongly Positive	4.61 - 5.00	0.39
Positive	4.11 - 4.60	0.59
Neutral	3.31 - 4.10	0.79
Negative	2.31 - 3.30	0.99
Strongly Negative	1.00 - 2.20	1.20

Table 3 shows an overview of the criteria scores. The average of these values is a score of 4.33, indicating that the device's performance received an overall positive rating. The evaluation of each criterion is discussed in more detail in the subsections of this segment of the paper.

Table 3. Evaluation Scores Given for Each Criterion

Criterion	Score
Functionality	4.67
Reliability	4.67
Aesthetics	4.33
Usability	4.67
Durability	4.00

Maintainability	4.33
Realizability	3.67
Overall Performance	4.33

Functionality

From the proponents' observations, the device was able to generate voltage consistently. However, this was solely after wooden strips were added to the turbine. The proponents then noted that the official turbine design could be modified in this manner for future improvements. Table 4 shows the scores given for the device's functionality. According to the evaluators' assessments, the device will be able to fulfill its purpose of generating power and distributing energy as it operates in a WDN. The overall score of 4.67 indicates that the device's functionality received a strongly positive rating.

Table 4. Evaluation of the ICH System's Functionality

Statement	Rating 1	Rating 2	Rating 3	Average
In terms of power generation, the device will work as intended when integrated into a water distribution network.	5	5	4	4.67
In terms of charging and distributing energy, the device will work as intended when integrated into a water distribution network.	5	5	4	4.67
Overall Score				4.67

Reliability

As seen in the recording of the multimeter readings, the turbine was able to generate a consistent voltage output. This was achieved even after one of the turbine's wooden strips was damaged. Table 5 shows the scores given for the device's reliability. The evaluators, on average, rated the turbine's reliability as 4.67. As such, a strongly positive rating was given for the device's reliability. It should be noted that this assessment considers that the wooden strips were part of the system. Notably, all the raters strongly agreed that the device could compete with existing SHPs. The device's potential in realistic setups was rated lower, albeit high enough to consider that it was rated very positively. The same can be said about the device's consistency in its performance.

Table 5. Evaluation of the ICH System's Reliability

Statement	Rating 1	Rating 2	Rating 3	Average

The device can continue to yield positive results in realistic setups.	5	4	5	4.67
The device's performance was consistent.	5	4	4	4.33
The device can compete against current small hydropower technology.	5	5	5	5.00
Overall Score				4.67

Aesthetics

Prioritizing cost-effectiveness, the proponents adopted a simple turbine design, most of which solely consisted of the essentials for the turbine's functionality. However, without the wooden strips, the turbine failed to rotate at a consistent speed. The proponents subsequently noted that the turbine's initial design lacked components essential for the device's consistent voltage output. Table 6 shows the scores given for the device's aesthetics. The overall score of 4.33 shows that the device's aesthetics obtained a modest positive rating. Based on the responses to the criterion's first and second statements, the proponents concluded that the device did not comprise components that make it unnecessarily more costly or ineffective. Even then, the scores given to the third statement show that there could still be more additions to the device to make it more aesthetically pleasing.

Table 6. Evaluation of the ICH System's Aesthetics

Statement	Rating 1	Rating 2	Rating 3	Average
The device does not consist of parts or components that make it unnecessarily more costly.	4	5	4	4.67
The device does not consist of parts or components that may decrease its performance.	4	4	5	4.33
The device does not require any more parts or components for a better visual look.	4	4	4	4.00
Overall Score				4.33

Usability

The simplicity of the system enables users outside the field of hydropower to understand its functions intuitively. Operating the device does not require deep knowledge of its hydrodynamics, although such knowledge would be useful for its optimization. Table 7 shows the scores given for the device's usability. The device's usability acquired an overall strongly positive rating of 4.67. All the evaluators agreed that implementing the system in a

WDN can be easily accomplished without the need for an adequate amount of hydropower expertise.

Table 7. Evaluation of the ICH System's Usability

Statement	Rating 1	Rating 2	Rating 3	Average
It is feasible to apply the device in a working water distribution network.	4	5	5	4.67
Those not specialized in the field of hydropower can operate the device without much difficulty.	4	5	5	4.67
Overall Score				4.67

Durability

The sprayed water flowed at an extremely high speed and pressure. Likewise, it was expected for the turbine to experience at least a noticeable amount of damage from the water's forceful contact. As anticipated, one of the turbine's wooden strips was damaged in the middle of the official testing phase. In addition, one of the turbine's external blades was damaged by the end of the operation. Fortunately, the rest of the components were left unharmed during the whole experiment. Table 8 shows the scores given for the device's durability. With an overall score of 4.00, the device's durability received a neutral rating. This indicates that the proponents require improvements in making the device more durable for high-speed and high-pressure water flow. Despite the damages made, the overall score for the device's durability is acceptable, considering that the turbine was solely meant to be a 3D-printed prototype.

Table 8. Evaluation of the ICH System's Durability

Statement	Rating 1	Rating 2	Rating 3	Average
The device can continue to yield positive results in realistic setups.	4	4	4	4.00
The device's performance was consistent.	3	4	5	4.00
The device can compete against current small hydropower technology.	4	4	4	4.00
Overall Score				4.00

Maintainability

The proponents believe that the device can be easily maintained due to its detachability. Disassembling and reassembling the components only require using simple tools such as pliers and screwdrivers. Hence, extracting

the device from a pipeline section should not require much skill, although this still depends on the conduit system's complexity. Additionally, many of the device's components—mainly the metal rod and fasteners—can be easily replaced by newly purchased ones. Table 9 shows the scores given for the device's maintainability. The respondents gave an overall positive rating score of 4.33 on the device's maintainability. Accordingly, the proponents could have still improved the device so as to maximize the user's convenience in repairing and maintaining it without causing noticeable impairments.

Table 9. Evaluation of the ICH System's Maintainability

Statement	Rating 1	Rating 2	Rating 3	Average
The device can be easily removed from and reattached to the pipeline system without a significant amount of damage (for maintenance purposes).	4	4	5	4.67
The device can be easily readjusted for maintenance purposes.	4	4	5	4.67
Overall Score				4.67

Realizability

In conceptualizing the device, the proponents aimed to make it potentially applicable in real-world settings, particularly in small pipeline systems such as those at home. Thus, the proponents considered the device's realizability as an important factor to evaluate. Table 10 shows the scores given for the device's realizability. All the evaluators agreed that the mass installation of the device could decently contribute to a home's electrical system. However, most of them were neutral on the device's ability to do so without damage. The device's realizability received a low, neutral rating of 3.67. This suggests that the device requires improvement in its robustness and electricity generation.

Table 10. Evaluation of the ICH System's Realizability

Statement	Rating 1	Rating 2	Rating 3	Average
Multiple installations of the device in an entire home pipeline system will contribute a notable amount of electricity to the home.	4	4	4	4.00
The device can contribute electricity to a home without significant damage.	3	4	3	3.33
Overall Score				3.67

Conclusion

The turbine of the ICH system prototype adopted the hybrid Savonius-Darrieus design. The system was tested at the PSHS-CRC's motorpool. This was done with the assistance of the PSHS-CRC plumber and electrician, along with the supervision of one of the school's teachers. The proponents first conducted a pretest on the device to ensure that it could function as planned. Seeing that the turbine was unable to rotate at a consistent pace, the proponents—with the help of the school plumber and electrician—attached wooden strips to the turbine's gaps to enable it to rotate consistently.

Afterward, the proponents began the official 5-minute operation test. Throughout the whole operation, the device generated an average of 234 V. During the first minute of the test, the motor generated an average of 330 V. However, after this period, one of the turbine's wooden strips was damaged due to the high water speed and pressure. This led to a decrease in the overall voltage generation, subsequently resulting in an average voltage output of 210 V. Despite the difficulties encountered, the device managed to generate a maximum voltage output of 348 V. This provides a glimpse of the device's full potential if the turbine were more robust.

After the official experiment, the teacher, plumber, and electrician evaluated the device's qualitative parameters. This was done using a 5-point agree-disagree scale. The evaluators scored the device's functionality (4.67), reliability (4.67), aesthetics (4.33), usability (4.67), durability (4.00), maintainability (4.33), and realizability (3.67). The device's overall performance was rated with a positive score of 4.33. Accordingly, the device requires improvements in a number of aspects, especially in its durability and realizability.

Regardless, the design and construction of the device were, overall, a success. Should this technology be studied and tested further with a better design and experimental setup, it could effectively harness hydropower at its maximum potential, mitigating the negative impacts resulting from existing large and small hydro dams.

Recommendations

For those interested in improving the methods implemented in this study, the authors suggest following the recommendations below.

1. Apply the device within a working WDN to accurately determine its potential in real-world applications. If this is not feasible, use a water pump that can fill the majority of the pipe's cross-sectional area.
2. Before conducting an official test, thoroughly study and test optimization strategies that can improve the ICH system's performance.
3. Test the device's performance in powering electrical appliances.
4. Measure the device's Cp.
5. Identify the device's effectiveness in different TSRs.

6. Record the in-pipe water's velocity and pressure to accurately identify the turbine's effectiveness based on the water flow conditions.
7. Ensure the robustness of the turbine's material to prevent damage.
8. Operate the device in a longer time frame to identify its longevity.
9. Have more professionals evaluate the device's performance.

Acknowledgements

First and foremost, we would like to thank our Almighty Father for giving us His guidance in creating this study. He gave us the opportunities to put our innovative ideas into reality and blessed us daily with the wisdom needed to achieve this research.

We would also like to thank our parents for their support. To Mr. and Mrs. Dagaraga, Mr. and Mrs. Dellosa, and Mr. and Mrs. Plaza, thank you for providing us with the support and help needed to complete our research project.

Next, we thank Dr. Michelle M. Barbon and Dr. Patrick D. Cerna for guiding us in our research journey. All of this was only possible with their advice and supervision that guided us towards improving our research skills and allowing our creativity to contribute to the development of today's technology.

Moreover, we want to express our gratitude to the Caraga State University Fab Lab team. In the design and assembly of the proposed device, they provided us with their counsel, experience, and knowledge in making the completion of this project possible.

We would also like to extend our thanks to PSHS-CRC Fab Lab, the PSHS-CRC Physics Lab, and Sir Nerry C. Nuñez for accepting our requests that involved making further progress in our study. Without them, specific requirements for this research would have been more costly.

Finally, we would like to show our appreciation to our friends who helped and supported us throughout this study's creation. Despite their busy schedules and heavy workload, they supported us when we needed them.

References

Abdullah, M. F., Jauhari, I., Mohd Sabri, M. F., & Nik Ghazali, N. N. (2021). A Novel Vertical Axis Parallel Turbines System for In-pipe Hydropower Generation: Conceptual Design and Preliminary Experiment. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 1-15. https://doi.org/10.1080/15567036.2021.1880501

Agarwal, S. S., & Kansal, M. L. (2017). Issues of hydropower development in Uttarakhand region of Indian Himalaya. *Water and Energy International*, *59*(11), 52-64. https://www.indianjournals.com/ijor.aspx?target=ijor:wei& volume=59r&issue=11&article=006

Alho, C. J., Reis, R. E., & Aquino, P. P. (2015). Amazonian freshwater habitats experiencing environmental and socioeconomic threats affecting subsistence fisheries. *Ambio*, *44*(5), 412-425. https://doi.org/10.1007/s132 80-014-0610-z

Amelio, M., Barbarelli, S., & Schinello, D. (2020). Review of methods used for selecting pumps as turbines (PATs) and predicting their characteristic curves. *Energies*, *13*(23), 6341. http://doi.org/10.3390/en13236341

Anderson, D., Moggridge, H., Warren, P., & Shucksmith, J. (2015). The impacts of 'run-of-river' hydropower on the physical and ecological condition of rivers. *Water and Environment Journal*, *29*(2), 268-276. https://doi.org/10.1111/wej.12101

Ansar, A., Flyvbjerg, B., Budzier, A., & Lunn, D. (2014). Should we build more large dams? The actual costs of hydropower megaproject development. *Energy policy*, *69*, 43-56. https://doi.org/10.1016/j.enpol.2013.10.069

Asadi, M., & Hassanzadeh, R. (2021). Effects of internal rotor parameters on the performance of a two bladed Darrieus-two bladed Savonius hybrid wind turbine. *Energy Conversion and Management*, *238*, 114109. http://doi.org/ 10.1016/j.enconman.2021.114109

Bakken, T. H., Sundt, H., Ruud, A., & Harby, A. (2012). Development of small versus large hydropower in Norway–comparison of environmental impacts. *Energy Procedia*, *20*, 185-199. https://doi.org/10.1016/j.egypro.2 012.03.019

Bansal, S., CHAKRABORTY, M., Katyal, D., & Garg, J. K. (2015). Methane flux from a subtropical reservoir located in the floodplains of river Yamuna, India. *Applied ecology and environmental research*, *13*(2), 597-613. https://doi.org/10.15666/aeer/1302_597613

Barros, N., Cole, J. J., Tranvik, L. J., Prairie, Y. T., Bastviken, D., Huszar, V. L., ... & Roland, F. (2011). Carbon emission from hydroelectric reservoirs linked to reservoir age and latitude. *Nature Geoscience*, *4*(9), 593-596. https://doi.org/10.1038/ngeo1211

Bastviken, D., Tranvik, L. J., Downing, J. A., Crill, P. M., & Enrich-Prast, A. (2011). Freshwater methane emissions offset the continental carbon sink. *Science*, *331*(6013), 50-50. https://doi.og/10.1126/science.1196808

Basumatary, M., Biswas, A., & Misra, R. D. (2018). CFD analysis of an innovative combined lift and drag (CLD) based modified Savonius water turbine. *Energy Conversion and Management*, *174*, 72-87. http://doi.org/10.1016/j.enconman.2018.08.025

Basumatary, M., Biswas, A., & Misra, R. D. (2020). Detailed hydrodynamic study for performance optimization of a combined lift and drag-based modified Savonius water turbine. *Journal of Energy Resources Technology*, *142*(8), 081301. https://doi.org/10.1115/1.4045924

Basumatary, M., Biswas, A., & Misra, R. D. (2021). Experimental verification of improved performance of Savonius turbine with a combined lift and drag based blade profile for ultra-low head river application.

Sustainable Energy Technologies and Assessments, *44*, 100999. https://doi.org/10.1016 /j.seta.2021.100999

Baumgartner, L. J., & Wibowo, A. (2018). Addressing fish-passage issues at hydropower and irrigation infrastructure projects in Indonesia. *Marine and Freshwater Research*, *69*(12), 1805-1813. https://doi.org/10.1071/mf1808 8

Behrouzi, F., Nakisa, M., Maimun, A., & Ahmed, Y. M. (2016). Global renewable energy and its potential in Malaysia: A review of Hydrokinetic turbine technology. *Renewable and Sustainable Energy Reviews*, *62*, 1270-1281. https://doi/org/10.1016/j.rser.2016.05.020

Bhutta, M. M. A., Hayat, N., Farooq, A. U., Ali, Z., Jamil, S. R., & Hussain, Z. (2012). Vertical axis wind turbine–A review of various configurations and design techniques. *Renewable and Sustainable Energy Reviews*, *16*(4), 1926-1939. https://doi.org/10.1016/j.rser.2011.12.004

Binama, M., Su, W. T., Li, X. B., Li, F. C., Wei, X. Z., & An, S. (2017). Investigation on pump as turbine (PAT) technical aspects for micro hydropower schemes: A state-of-the-art review. *Renewable and Sustainable Energy Reviews*, *79*, 148-179. http://doi.org/10.1016/j.rser.201 7.04.071

Brown, J. J., Limburg, K. E., Waldman, J. R., Stephenson, K., Glenn, E. P., Juanes, F., & Jordaan, A. (2013). Fish and hydropower on the US Atlantic coast: failed fisheries policies from half-way technologies. *Conservation Letters*, *6*(4), 280-286. https://doi.org/10.1111/conl.12000

Carravetta, A., Del Giudice, G., Fecarotta, O., & Ramos, H. M. (2012). Energy production in water distribution networks: A PAT design strategy. *Water resources management*, *26*, 3947-3959. http://doi.org/10.1007/s11269-012- 0114-1

Casini, M. (2015). Harvesting energy from in-pipe hydro systems at urban and building scale. *International Journal of Smart Grid and Clean Energy*, *4*(4), 316-327. http://doi.org/10.12720/sgce.4.4.316-327

Castelli, M. R., & Benini, E. (2011). Comparison between lift and drag-driven VAWT concepts on low-wind site AEO. *World Academy of Science, Engineering and Technology*, 1677-1682. Retrieved from https://doi.org/10.5281/zenodo.1083101

Chacón, M. C., Díaz, J. A. R., Morillo, J. G., & McNabola, A. (2021). Evaluation of the design and performance of a micro hydropower plant in a pressurised irrigation network: Real world application at farm-level in Southern Spain. *Renewable Energy*, *169*, 1106-1120. https://doi.org/10.1016/j.renene.2021.01.084

Chawla, S., Chauhan, A., & Bala, S. (2015, December). Parametric study of hybrid Savonius-Darrieus turbine. In *2015 2nd International Conference on Recent Advances in Engineering & Computational Sciences (RAECS)* (pp. 1-5). IEEE. https://doi.org/10.1109/raecs.2015.7453336

Chen, A., Wu, M., Chen, K. Q., Sun, Z. Y., Shen, C., & Wang, P. Y. (2016). Main issues in research and practice of environmental protection for water conservancy and hydropower projects in China. *Water Science and Engineering*, *9*(4), 312-323. https://doi.org/10.1016/j.wse.2017.01.008

Cloy, J. M., & Smith, K. A. (2018). Greenhouse gas sources and sinks. *Encyclopedia of the Anthropocene*, *2*, 391. https://doi.org/10.1016/B978-0-12-409548-9.09961-9

Colombo, A. F., & Karney, B. W. (2002). Energy and costs of leaky pipes: Toward comprehensive picture. *Journal of Water Resources Planning and Management*, *128*(6), 441-450. http://doi.org/10.1061/(ASCE)0733-9496(2002)128:6(441)

Colombo, A. F., & Karney, B. W. (2005). Impacts of leaks on energy consumption in pumped systems with storage. *Journal of Water Resources Planning and Management*, *131*(2), 146-155. http://doi.org/10.1061/(ASCE)0733-9496(2005)131:2(146)

Cooke, F. M., Nordensvard, J., Saat, G. B., Urban, F., & Siciliano, G. (2017). The limits of social protection: the case of hydropower dams and indigenous peoples' land. *Asia & the Pacific Policy Studies*, *4*(3), 437-450. https://doi. org/10.1002/app5.187

Couto, T. B., & Olden, J. D. (2018). Global proliferation of small hydropower plants–science and policy. *Frontiers in Ecology and the Environment*, *16*(2), 91-100. https://doi.org/10.1002/fee.1746

da Costa Doria, C. R., Athayde, S., Marques, E. E., Lima, M. A. L., Dutka-Gianelli, J., Ruffino, M. L., ... & Isaac, V. N. (2018). The invisibility of fisheries in the process of hydropower development across the Amazon. *Ambio*, *47*(4), 453-465. https://doi.org/10.1007/s13280-017- 0994-7

da Silva, R. C., de Marchi Neto, I., & Seifert, S. S. (2016). Electricity supply security and the future role of renewable energy sources in Brazil. *Renewable and Sustainable Energy Reviews*, *59*, 328-341. https://doi.org/10.1016/j.rser.2016.01.001

De Faria, F. A., Jaramillo, P., Sawakuchi, H. O., Richey, J. E., & Barros, N. (2015). Estimating greenhouse gas emissions from future Amazonian hydroelectric reservoirs. *Environmental Research Letters*, *10*(12), 124019. https://doi.org/10.1088/1748-9326/10/12/124019

De Jonge, B. (2011). What is fair and equitable benefit-sharing?. *Journal of agricultural and environmental ethics*, *24*(2), 127-146. https://doi.org//10.1007/s10806-010-9249-3

Demarty, M., & Bastien, J. (2011). GHG emissions from hydroelectric reservoirs in tropical and equatorial regions: Review of 20 years of CH4 emission measurements. *Energy Policy*, *39*(7), 4197-4206. Retrieved from https://doi.org/10.1016/j.enpol.2011.04.033

Dilimulati, A., Stathopoulos, T., & Paraschivoiu, M. (2018). Wind turbine designs for urban applications: A case study of shrouded diffuser casing for turbines. *Journal of Wind Engineering and Industrial Aerodynamics*, *175*, 179-192. Retrieved from https://doi.org/10.1016/j.jweia.2018.01.003

Duan, H. F., Pan, B., Wang, M., Chen, L., Zheng, F., & Zhang, Y. (2020). State-of-the-art review on the transient flow modeling and utilization for urban water supply system (UWSS) management. *Journal of Water Supply: Research and Technology-Aqua*, *69*(8), 858-893. http://doi.org/10.2166/aqua.2020.048

Egré, D., & Milewski, J. C. (2002). The diversity of hydropower projects. *Energy policy*, *30*(14), 1225-1230. https://doi.org/10.1016/S0301-4215(02)00083- 6

Fearnside, P. M., & Pueyo, S. (2012). Greenhouse-gas emissions from tropical dams. *Nature Climate Change*, *2*(6), 382-384. https://doi.org/10.1038/ncli mate1540

Foulds, W. L., & Lucas, M. C. (2013). Extreme inefficiency of two conventional, technical fishways used by European river lamprey (Lampetra fluviatilis). *Ecological Engineering*, *58*, 423-433. https://doi.org/10.1016/j.ecoleng.20 13.06.038

Fung, Z., Pomun, T., Charles, K. J., & Kirchherr, J. (2019). Mapping the social impacts of small dams: The case of Thailand's Ing River basin. *Ambio*, *48*(2), 180-191. https://doi.org/10.1007/s13280-018-1062-7

García-Ávila, F., Aviles-Anazco, A., Ordonez-Jara, J., Guanuchi-Quezada, C., del Pino, L. F., & Ramos-Fernández, L. (2019). Pressure management for leakage reduction using pressure reducing valves. Case

study in an Andean city. *Alexandria Engineering Journal*, *58*(4), 1313-1326. https://doi.org/10.1016/j.aej.2019.11.003

Gauld, N. R., Campbell, R. N. B., & Lucas, M. C. (2013). Reduced flow impacts salmonid smolt emigration in a river with low-head weirs. *Science of the total environment*, *458*, 435-443. https://doi.org/10.1016/j.scitotenv.2013. 04.063

Gupta, A., Bokde, N., Marathe, D., & Kulat, K. (2017). Leakage reduction in water distribution systems with efficient placement and control of pressure reducing valves using soft computing techniques. *Engineering, Technology & Applied Science Research*, *7*(2), 1528-1534. https://doi.org/10.48084/etasr.1032

Habich, S. (2015). Strategies of Soft Coercion in Chinese Dam Resettlement. *Issues & Studies*, *51*(1). https://doi.org/10.7033/ise.201503_51(1).0006

Hamzah, I., Prasetyo, A., Tjahjana, D. P., & Hadi, S. (2018, February). Effect of blades number to performance of Savonius water turbine in water pipe. In *AIP conference proceedings* (Vol. 1931, No. 1, p. 030046). AIP Publishing LLC. https://doi.org/10.1063/1.5024105

Hutchinson, J. J., Campbell, C. A., & Desjardins, R. L. (2007). Some perspectives on carbon sequestration in agriculture. *Agricultural and forest meteorology*, *142*(2-4), 288-302. https://doi.org/10.1016/j.agrformet.2006. 03.030

Hidrovo, A. B., Uche, J., & Martínez-Gracia, A. (2017). Accounting for GHG net reservoir emissions of hydropower in Ecuador. *Renewable Energy*, *112*, 209-221. https://doi.org/10.1016/j.renene.2017.05.047

International Displacement Monitoring Centre. *Case study series - dam displacement*. IDMC. (2017, April 1). https://www.internal-displacement. org/publications/case-study-series-dam-displacement

Jin, X., Zhao, G., Gao, K., & Ju, W. (2015). Darrieus vertical axis wind turbine: Basic research methods. *Renewable and Sustainable Energy Reviews*, *42*, 212-225. https://doi.org/10.1016/j.rser.2014.10.021

Johari, M. K., Jalil, M., & Shariff, M. F. M. (2018). Comparison of horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). *International Journal of Engineering and Technology*, *7*(4.13), 74-80. Retrieved from https://doi.org/10.14419/ijet.v7i4.13.21333

Kamal, R., Zhu, D. Z., Crossman, J. A., & Leake, A. (2020). Case study of total dissolved gas transfer and degasification in a prototype ski-jump spillway. *Journal of Hydraulic Engineering*, *146*(9), 05020007. https://doi.org/10.1061/(asce)hy.1943-7900.0001801

Kamal, M. M., & Saini, R. P. (2023). Performance investigations of hybrid hydrokinetic turbine rotor with different system and operating parameters. *Energy*, *267*, 126541. https://doi.org/10.1016/j.energy.2022.126541

Kameyama, S., Shimazaki, H., Nohara, S., Sato, T., Fujii, Y., & Kudo, K. (2013). Hydrological and sediment transport simulation to assess the impact of dam construction in the Mekong River main channel. *American Journal of Environmental Sciences*, *9*(3), 247. https://doi.org/10.3844/ajessp.2013.247.258

Keefer, M. L., Peery, C. A., Lee, S. R., Daigle, W. R., Johnson, E. L., & Moser, M. L. (2011). Behaviour of adult Pacific lamprey in near-field flow and fishway design experiments. *Fisheries Management and Ecology*, *18*(3), 177-189. https://doi.org/10.1111/j.1365-2400.2010.00772.x

Kemenes, A., Forsberg, B. R., & Melack, J. M. (2016). Downstream emissions of CH4 and CO2 from hydroelectric reservoirs (Tucuruí, Samuel, and Curuá-Una) in the Amazon basin. *Inland Waters*, *6*(3), 295-302. https://doi.org/10.1080/IW-6.3.980

Kibler, K. M., & Tullos, D. D. (2013). Cumulative biophysical impact of small and large hydropower development in Nu River, China. *Water Resources Research*, *49*(6), 3104-3118. https://doi.org/10.1002/wrcr.20243

Kim, J. Y. (2015, March 4). *World Bank acknowledges shortcomings in resettlement projects, announces action plan to fix problems*. World Bank. Retrieved March 22, 2023, from https://www.worldbank.org/en/news/press -release/2015/03/04/world-bank-shortcomings-resettlement-projects-plan-fix-problems

Kondolf, G. M., Rubin, Z. K., & Minear, J. T. (2014). Dams on the Mekong: Cumulative sediment starvation. *Water Resources Research*, *50*(6), 5158-5169. https://doi.org/10.1002/2013WR014651

Kuenzer, C., Campbell, I., Roch, M., Leinenkugel, P., Tuan, V. Q., & Dech, S. (2013). Understanding the impact of hydropower developments in the context of upstream–downstream relations in the Mekong river basin. *Sustainability science*, *8*(4), 565-584. https://doi.org/10.1007/s11625-012-0195-z

Kumar, A., & Saini, R. P. (2016). Performance parameters of Savonius type hydrokinetic turbine–A Review. *Renewable and Sustainable Energy Reviews*, *64*, 289-310. Retrieved from https://doi.org/10.1016/j.rser.2016.06.005

Kumar, A., & Saini, R. P. (2017). Performance analysis of a Savonius hydrokinetic turbine having twisted blades. *Renewable energy*, *108*, 502-522. https://doi.org/10.1016/j.renene.2017.03.006

Kumar, R., & Sarkar, S. (2022). Effect of design parameters on the performance of helical Darrieus hydrokinetic turbines. *Renewable and Sustainable Energy Reviews*, *162*, 112431. https://doi.org/10.1016/j.rser.2022.112431

Kumar, A., Sharma, M. P., & Yang, T. (2018). Estimation of carbon stock for greenhouse gas emissions from hydropower reservoirs. *Stochastic Environmental Research and Risk Assessment*, *32*(11), 3183-3193. https:// doi.org/10.1007/s00477-018-1608-z

Kumar, A., Yu, Z. G., Klemeš, J. J., & Bokhari, A. (2021). A state-of-the-art review of greenhouse gas emissions from Indian hydropower reservoirs. *Journal of Cleaner Production*, 128806. https://doi.org/10.1016/j.jclepro.2 021.128806

Li, X. Z., Chen, Z. J., Fan, X. C., & Cheng, Z. J. (2018). Hydropower development situation and prospects in China. *Renewable and Sustainable Energy Reviews*, *82*, 232-239. https://doi.org/10.1016/j.rser.2017.08.090

Lima, G. M., Junior, E. L., & Brentan, B. M. (2017). Selection of pumps as turbines substituting pressure reducing valves. *Procedia Engineering*, *186*, 676-683. http://doi.org/10.1016/j.proeng.2017.06.249

Liu, M., Tan, L., & Cao, S. (2022). Performance prediction and geometry optimization for application of pump as turbine: a review. *Frontiers in Energy Research*, *9*, 818118. https://doi.org/10.3389/fenrg.2021.818118

Liemberger, R., & Wyatt, A. (2019). Quantifying the global non-revenue water problem. *Water Supply*, *19*(3), 831-837. https://doi.org/10.2166/ws.2018.1 29

Loots, I., Van Dijk, M., Van Vuuren, S. J., Bhagwan, J. N., & Kurtz, A. (2014). Conduit-hydropower potential in the City of Tshwane water distribution system: A discussion of potential applications, financial and other benefits. *Journal of the South African Institution of Civil Engineering= Joernaal van die Suid-Afrikaanse Instituut van Siviele Ingenieurswese*, *56*(3), 2-13. https://doi.org/10520/EJC161378

Loures, R. C., & Pompeu, P. S. (2012). Temporal variation in fish community in the tailrace at Três Marias hydroelectric dam, São Francisco River, Brazil. *Neotropical Ichthyology*, *10*, 731-740. https://doi.org/10.1590/s1679-6225 2012000400006

Lyu, Z., Shao, N., Akinyemi, T., & Whitman, W. B. (2018). Methanogenesis. *Current Biology*, *28*(13), R727-R732. https://doi.org/10.1016/j.cub.2018.0 5.021

Maldar, N. R., Ng, C. Y., Ean, L. W., Oguz, E., Fitriadhy, A., & Kang, H. S. (2020a). A comparative study on the performance of a horizontal axis ocean current turbine considering deflector and operating depths. *Sustainability*, *12*(8), 3333. Retrieved from https://doi/org/10.3390/su1208 3333

Maldar, N. R., Ng, C. Y., & Oguz, E. (2020b). A review of the optimization studies for Savonius turbine considering hydrokinetic applications. *Energy Conversion and Management*, *226*, 113495. Retrieved from https://doi.org /10.1016/j.enconman.2020.113495

Malipeddi, A. R., & Chatterjee, D. (2012). Influence of duct geometry on the performance of Darrieus hydroturbine. *Renewable Energy*, *43*, 292-300. https://doi.org/10.1016/j.renene.2011.12.008

Manh, N. V., Dung, N. V., Hung, N. N., Merz, B., & Apel, H. (2014). Large-scale suspended sediment transport and sediment deposition in the Mekong Delta. *Hydrology and Earth System Sciences*, *18*(8), 3033-3053. https://doi.org/10.5194/hess-18-3033-2014

Manorom, K. (2018). Hydropower resettlement in the Mekong region. https://hdl.handle.net/10568/96988

Mbele, L., & Kusakana, K. (2017, June). Overview of conduit hydropower in South Africa: Status and applications. In *2017 IEEE PES PowerAfrica* (pp. 385-390). IEEE. https://doi.org/10.1109/PowerAfrica.2017.7991255

McLaughlin, R. L., Smyth, E. R. B., Castro-Santos, T., Jones, M. L., Koops, M. A., Pratt, T. C., & Vélez-Espino, L.-A. (2012). Unintended consequences and trade-offs of fish passage. *Fish and Fisheries*, *14*(4), 580–604. https://doi.org/10.1111/faf.12003

Moran, E. F., Lopez, M. C., Moore, N., Müller, N., & Hyndman, D. W. (2018). Sustainable hydropower in the 21st century. *Proceedings of the National Academy of Sciences*, *115*(47), 11891-11898. https://doi.org/10.1073/pnas. 1809426115

Mutlu, Y., & Çakan, M. (2018). Evaluation of in-pipe turbine performance for turbo solenoid valve system. *Engineering Applications of Computational Fluid Mechanics*, *12*(1), 625-634. https://doi.org/10.1080/19942060.2018. 1506364

Nautiyal, H., Singal, S. K., & Sharma, A. (2011). Small hydropower for sustainable energy development in India. *Renewable and Sustainable Energy Reviews*, *15*(4), 2021-2027. https://doi.org/10.1016/j.rser.2011.01.0 06

Noonan, M. J., Grant, J. W., & Jackson, C. D. (2012). A quantitative assessment of fish passage efficiency. *Fish and Fisheries*, *13*(4), 450-464. https://doi.org/10.1111/j.1467-2979.2011.00445.x

North Ridge Pumps. (n.d.). *North Ridge Pump as Turbine.* North Ridge Pumps. Retrieved March 19, 2023, from https://www.northridgepumps.com/p_153 3_north-ridge-pump-as-turbine

O'Connor, J. E., Duda, J. J., & Grant, G. E. (2015). 1000 dams down and counting. *Science*, *348*(6234), 496-497. https://doi.org/10.1126/science.aaa9204

Ortega-Ballesteros, A., Iturriaga-Bustos, F., Perea-Moreno, A. J., & Muñoz-Rodríguez, D. (2022). Advanced Pressure Management for Sustainable Leakage Reduction and Service Optimization: A Case Study in Central Chile. *Sustainability*, *14*(19), 12463. https://doi.org/10.3390/su1 41912463

Pallotta, A., Pietrogiacomi, D., & Romano, G. P. (2020). HYBRI–A combined Savonius-Darrieus wind turbine: Performances and flow fields. *Energy*, *191*, 116433. https://doi.org/10.1017/jfm.2018.197

Pascale, A., Urmee, T., & Moore, A. (2011). Life cycle assessment of a community hydroelectric power system in rural Thailand. *Renewable Energy*, *36*(11), 2799-2808. https://doi.org/10.1016/j.renene.2011.04.023

Pelicice, F. M., Pompeu, P. S., & Agostinho, A. A. (2015). Large reservoirs as ecological barriers to downstream movements of Neotropical migratory fish. *Fish and Fisheries*, *16*(4), 697-715. https://doi.org/10.1111/faf.12089

Pérez-Sánchez, M., Sánchez-Romero, F. J., Ramos, H. M., & López-Jiménez, P. A. (2017). Energy recovery in existing water networks: Towards greater sustainability. *Water*, *9*(2), 97. http://doi.org/10.3390/w9020097

Person, E., Bieri, M., Peter, A., & Schleiss, A. J. (2014). Mitigation measures for fish habitat improvement in Alpine rivers affected by hydropower operations. *Ecohydrology*, *7*(2), 580-599. https://doi.org/10.1002/eco.1380

Pompeu, P. D. S., Agostinho, A. A., & Pelicice, F. M. (2012). Existing and future challenges: the concept of successful fish passage in South America. *River Research and Applications*, *28*(4), 504-512. https://doi.org/10.1002/rra.15 57

Porkumaran, K., Tharu, R. P., Sukanya, S., Elezabeth, V. V., & Gowtham, N. (2017, March). Micro in-pipe hydro power plant for rural electrification using LabVIEW. In *2017 International conference on innovations in green energy and healthcare technologies (IGEHT)* (pp. 1-5). IEEE. https://doi.o rg/10.1109/IGEHT.2017.8094098

Prakash, R., & Bhat, I. K. (2012). Life cycle greenhouse gas emissions estimation for small hydropower schemes in India. *Energy*, *44*(1), 498-508. https://do i.org/10.1016/j.energy.2012.05.052

Prasetyo, A., Kristiawan, B., Danardono, D., & Hadi, S. (2018, March). The effect of deflector angle in Savonius water turbine with horizontal axis on the power output of water flow in pipe. In *Journal of Physics: Conference Series* (Vol. 979, No. 1, p. 012043). IOP Publishing. https://doi.org/10.108 8/1742-6596/979/1/012043

Premalatha, M., Abbasi, T., & Abbasi, S. A. (2014). A critical view on the eco-friendliness of small hydroelectric installations. *Science of the Total Environment*, *481*, 638-643. https://doi.org/10.1016/j.scitotenv.2013.11.04 7

Raadal, H. L., Gagnon, L., Modahl, I. S., & Hanssen, O. J. (2011). Life cycle greenhouse gas (GHG) emissions from the generation of wind and hydro power. *Renewable and Sustainable Energy Reviews*, *15*(7), 3417-3422. https://doi.org/10.1016/j.rser.2011.05.001

Randell, H. (2016). The short-term impacts of development-induced displacement on wealth and subjective well-being in the Brazilian Amazon. *World development*, *87*, 385-400. https://doi.org/10.1016/j.worlddev.2016.07.005

Räsänen, T. A., Varis, O., Scherer, L., & Kummu, M. (2018). Greenhouse gas emissions of hydropower in the Mekong River Basin. *Environmental Research Letters*, *13*(3), 034030. https://doi.org/10.1088/1748-9326/aaa81 7

Roy, S., & Saha, U. K. (2013). Review of experimental investigations into the design, performance and optimization of the Savonius rotor. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, *227*(4), 528-542. Retrieved from https://doi.org/10.1177/0957650 913480992

Saini, G., & Saini, R. P. (2018, November). Numerical investigation of the effect of blade profile of a Darrieus hydrokinetic turbine. In *2018 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON)* (pp. 1-6). IEEE. http://doi.org/10.1109/ UPCON. 2018.8597073

Saini, G., & Saini, R. P. (2019). A review on technology, configurations, and performance of cross-flow hydrokinetic turbines. *International Journal of Energy Research*, *43*(13), 6639-6679. http://doi.org/10.1002/er.4625

Samir, N., Kansoh, R., Elbarki, W., & Fleifle, A. (2017). Pressure control for minimizing leakage in water distribution systems. *Alexandria Engineering Journal*, *56*(4), 601-612. https://doi.org/10.1016/j.aej.2017.07.008

Sakti, A., Prasetyo, A., Tjahjana, D. P., & Hadi, S. (2019, April). The horizontal axis type of Savonius water turbine in pipe using solidwork simulation. In *AIP Conference Proceedings* (Vol. 2097, No. 1, p. 030042). AIP Publishing LLC. https://doi.org/10.1063/1.5098217

Sari, M. A., Badruzzaman, M., Cherchi, C., Swindle, M., Ajami, N., & Jacangelo, J. G. (2018). Recent innovations and trends in in-conduit hydropower technologies and their applications in water distribution systems. *Journal of environmental management*, *228*, 416-428. https://doi.org/10.1016/j.jen vman.2018.08.078

Satish, D., Doshi, A., & Bade, M. (2021, May). Review on pump as turbine application in water distribution networks for power generation. In *AIP Conference Proceedings* (Vol. 2341, No. 1, p. 030035). AIP Publishing LLC. http://doi.org/10.1063/5.0050115

Siciliano, G., Urban, F., Kim, S., & Lonn, P. D. (2015). Hydropower, social priorities and the rural–urban development divide: The case of large dams in Cambodia. *Energy Policy*, *86*, 273-285. https://doi.org/10.1016/j.enpol. 2015.07.009

Siciliano, G., Urban, F., Tan-Mullins, M., & Mohan, G. (2018). Large dams, energy justice and the divergence between international, national and local developmental needs and priorities in the global South. *Energy research & social science*, *41*, 199-209. https://doi.org/10.1016/j.erss.2018.03.029

Silva, A. T., Lucas, M. C., Castro-Santos, T., Katopodis, C., Baumgartner, L. J., Thiem, J. D., ... & Cooke, S. J. (2018). The future of fish passage science, engineering, and practice. *Fish and Fisheries*, *19*(2), 340-362. https://doi.org/10.1111/faf.12258

Sipahutar, R., Bernas, S. M., & Imanuddin, M. S. (2013). Renewable energy and hydropower utilization tendency worldwide. *Renewable and Sustainable Energy Reviews*, *17*, 213-215. https://doi.org/10.1016/j.rser.2012.09.010

Sovacool, B. K., & Dworkin, M. H. (2015). Energy justice: Conceptual insights and practical applications. *Applied Energy*, *142*, 435-444. https://doi.org/1 0.1016/j.apenergy.2015.01.002

Sovacool, B. K., Heffron, R. J., McCauley, D., & Goldthau, A. (2016). Energy decisions reframed as justice and ethical concerns. *Nature Energy*, *1*(5), 1-6. https://doi.org/10.1038/nenergy.2016.24

Sobek, S., DelSontro, T., Wongfun, N., & Wehrli, B. (2012). Extreme organic carbon burial fuels intense methane bubbling in a temperate reservoir. *Geophysical Research Letters*, *39*(1). https://doi.org/10.1029/2011gl05014 4

Stickler, C. M., Coe, M. T., Costa, M. H., Nepstad, D. C., McGrath, D. G., Dias, L. C., ... & Soares-Filho, B. S. (2013). Dependence of hydropower energy generation on forests in the Amazon Basin at local and regional scales. *Proceedings of the National Academy of Sciences*, *110*(23), 9601-9606. https://doi.org/10.1073/pnas.1215331110

Stefanizzi, M., Capurso, T., Balacco, G., Binetti, M., Camporeale, S. M., & Torresi, M. (2020). Selection, control and techno-economic feasibility of Pumps as Turbines in Water Distribution Networks. *Renewable Energy*, *162*, 1292-1306. http://doi.org/10.1016/j.renene.2020.08.108

Steinhurst, W., Knight, P., & Schultz, M. (2012). Hydropower greenhouse gas emissions. *Conservation Law Foundation*, *24*, 6. https://www.synapse-ene rgy.com/sites/default/files/SynapseReport.2012-02.CLF+PEW.GHG-from-Hydro.10-056.pdf

Suhardiman, D., Wichelns, D., Lebel, L., & Sellamuttu, S. S. (2014). Benefit sharing in Mekong Region hydropower: Whose benefits count?. *Water resources and rural development*, *4*, 3-11. https://doi.org/10.1016/j.wrr.20 14.10.008

Tajziehchi, S., Monavari, S. M., Karbassi, A. R., Shariat, S. M., & Khorasani, N. (2013). *Quantification of Social Impacts of Large Hydropower Dams-a case study of Alborz Dam in Mazandaran Province, Northern Iran.* https://doi.org/10.22059/ijer.2013.615

Talukdar, P. K., Sardar, A., Kulkarni, V., & Saha, U. K. (2018). Parametric analysis of model Savonius hydrokinetic turbines through experimental and computational investigations. *Energy Conversion and Management*, *158*, 36-49. https://doi.org/10.1016/j.enconman.2017.12.011

Tasneem, Z., Al Noman, A., Das, S. K., Saha, D. K., Islam, M. R., Ali, M. F., ... & Alam, F. (2020). An analytical review on the evaluation of wind resource and wind turbine for urban application: Prospect and challenges. *Developments in the Built Environment*, *4*, 100033. Retrieved from https://doi.org/10.1016/j.dibe.2020.100033

Terminski, B. (2013). Development-induced displacement and resettlement: Theoretical frameworks and current challenges. *Development*, *10*, 101. https://doi.org/10.1016/j.erss.2019.101366

Tunio, I. A., Shah, M. A., Hussain, T., Harijan, K., Mirjat, N. H., & Memon, A. H. (2020). Investigation of duct augmented system effect on the overall performance of straight blade Darrieus hydrokinetic turbine. *Renewable Energy*, *153*, 143-154. https://doi.org/10.1016/j.renene.2020.02.012

Van Cleef, A. (2016). Hydropower development and involuntary displacement: Toward a global solution. *Ind. J. Global Legal Stud.*, *23*, 349. https://doi.o rg/10.2979/indjglolegstu.23.1.349

Van Manh, N., Dung, N. V., Hung, N. N., Kummu, M., Merz, B., & Apel, H. (2015). Future sediment dynamics in the Mekong Delta floodplains: Impacts of hydropower development, climate change and sea level rise. *Global and Planetary Change*, *127*, 22-33. https://doi.org/10.1016/j.glopl acha.2015.01.001

Vermaak, H. J., Kusakana, K., & Koko, S. P. (2014). Status of micro-hydrokinetic river technology in rural applications: A review of literature. Renewable and Sustainable Energy Reviews, 29, 625-633. Retrieved from https://doi.org/10.1016/j.rser.2013.08.066

Vilanova, M. R. N., & Balestieri, J. A. P. (2014). Hydropower recovery in water supply systems: Models and case study. *Energy conversion and management*, *84*, 414-426. http://doi.org/10.1016/j.enconman.2014.04.057

Williams, J. G., Armstrong, G., Katopodis, C., Larinier, M., & Travade, F. (2012). Thinking like a fish: a key ingredient for development of effective fish passage facilities at river obstructions. *River Research and Applications*, *28*(4), 407-417. https://doi.org/10.1002/rra.1551

Winemiller, K. O., McIntyre, P. B., Castello, L., Fluet-Chouinard, E., Giarrizzo, T., Nam, S., ... & Sáenz, L. (2016). Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. *Science*, *351*(6269), 128-129. https://doi.org/10.1126/science.aac7082

Wilmsen, B., Webber, M., & Yuefang, D. (2011). Development for whom? Rural to urban resettlement at the Three Gorges Dam, China. *Asian Studies Review*, *35*(1), 21-42. https://doi.org/10.1080/10357823.2011.552707

Yagmur, S., & Kose, F. (2021). Numerical evolution of unsteady wake characteristics of H-type Darrieus Hydrokinetic Turbine for a hydro farm arrangement. *Applied Ocean Research*, *110*, 102582. https://doi.org/10.101 6/j.apor.2021.102582

Yankson, P. W., Asiedu, A. B., Owusu, K., Urban, F., & Siciliano, G. (2018). The livelihood challenges of resettled communities of the Bui dam project in Ghana and the role of Chinese dam-builders. *Development Policy Review*, *36*, O476-O494. https://doi.org/10.1111/dpr.12259

Zarfl, C., Berlekamp, J., He, F., Jähnig, S. C., Darwall, W., & Tockner, K. (2019). Future large hydropower dams impact global freshwater megafauna. *Scientific reports*, *9*(1), 1-10. https://doi.org/10.1038/s41598-019-54980-8

Zhao, X., Wu, L., & Qi, Y. (2020). The energy injustice of hydropower: Development, resettlement, and social exclusion at the Hongjiang and Wanmipo hydropower stations in China. *Energy Research & Social Science*, *62*, 101366. https://doi.org/10.1016/j.erss.2019.101366

Ziv, G., Baran, E., Nam, S., Rodríguez-Iturbe, I., & Levin, S. A. (2012). Trading-off fish biodiversity, food security, and hydropower in the Mekong River Basin. *Proceedings of the National Academy of Sciences*, *109*(15), 5609-5614. https://doi.org/10.1073/pnas.1201423109

BAYAD: A Connection-Adaptable Transaction System for Payments that Centers on Accessibility and the Digital Divide

Edward Molina
Philippine Science High School – Caraga Region Campus, Philippines, https://orcid.org/0009-0005-0039-2803

Hyacinth Atasan
Philippine Science High School – Caraga Region Campus, Philippines, https://orcid.org/0009-0001-6104-5646

Raven Layese
Philippine Science High School – Caraga Region Campus, Philippines, https://orcid.org/0009-0009-2869-0991

Patrick Cerna
Philippine Science High School – Caraga Region Campus, Philippines, https://orcid.org/0000-0002-2554-2098

Abstract: As electronic transaction systems for digital payments become internationally essential, some nations adopt to this technology poorly, like the Philippines. In the Philippines, the implementation of these systems is hindered by lack and unstable internet connection, areas with no service coverage, and the digital divide. To assess these specific problems, a connection adaptable transaction system, BAYAD, is developed with focus on accessibility and the digital divide. The system includes a multi-platform application that works on mobile and desktop, a Short Message Service (SMS) mode of transaction, a Bluetooth and encryption algorithm for offline and local transactions, a device for payments that uses biometrics with two factor authentication, and an algorithm that automatically alternates between different modes of transaction based on the network connection conditions. 63 randomly selected participants were chosen to participate the user acceptance survey. Using the Software Quality ISO 9126 standard based modified Likert survey questionnaire, the respondents strongly agreed that the acceptability factor of the system's functionality, reliability, efficiency, usability, maintainability and portability are significant.

Keywords: Connection-adaptable System, Digital Divide, Electronic Transactions.

Citation: Molina, E., Atasan, H., Layese, R., & Cerna, P. (2023). BAYAD: A Connection-Adaptable Transaction System for Payments that Centers on Accessibility and the Digital Divide. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023-- International Conference on Life Sciences, Engineering and Technology* (pp. 130-144), Denver, CO, USA. ISTES Organization.

Introduction

Electronic transaction systems are the catalyst of a developing nation. These transaction systems are the digital substitutes for physical currency and transaction records. They provide a country with new and innovative businesses, jobs, and services.

In China, QR (Quick Response) Codes, accompanied by a mobile application, are frequently used as a medium of transaction for payments and other offered services. This medium allows a business to operate without human intervention such as in bike rental business where bikes can be left on the streets with a QR Code. This QR Code is then scanned by a mobile device and all the transactions (e.g., payments, time records, and the renter's identification) are handled by this transaction system. This is one of the advantages that can be acquired by other countries that adopt an electronic transaction system.

However, this technology is poorly adapted in some countries, like the Philippines, where it is hindered by unstable internet connection, areas with no network coverage, the country's digital divide, and other factors. The study aims to develop a transaction system, called the BAYAD Transaction System (Bayad is an Approach that Yields Accessibility and Digitalization), to solve these problems.

In the Philippines, an advancement was made by Globe, one of the Philippines' major providers of telecommunication services, that allows its users to transact with its mobile transaction service GCash without requiring an internet connection through its cellular network (Zu et al., 2021). But there are issues since this feature is only available for Globe and TM (Touch Mobile) subscribers, this feature cannot be used in many areas without network coverage, and a lot of people may not have access to smart devices due to the digital divide.

For people who have no access to smart devices, Credit and Debit cards are one of the solutions to the problem. They are inexpensive to produce and often given for free by banks. Automated Teller Machine (ATM) and Point-of-Sale (POS) systems are used to do transactions with these cards. However, similar to physical wallets with bills and coins, they may be frequently lost, forgotten, and left behind at home or at a place.

The BAYAD Transaction System has three components: Bayad Matthew, Bayad Air, and BULSA (Bluetooth Lending Secure Alternative). The first component, Bayad Matthew, is the system's accessible application that runs on multi-platforms: iOS, Android, macOS, Linux, Windows, and the Web. Similar to GCash, Bayad Matthew handles transactions using the internet and also without direct access to the internet using SMS (Short Message Service) by sending encrypted transactions to an SMS Receiver and passing it through the online database. Unlike GCash, which uses the Globe Network to access its transaction services, Bayad Matthew does not limit itself to one network carrier. Since SMS is universal, Bayad Matthew can run on non-smartphone devices allowing more access to people affected by the digital divide.

Still, transactions relying on the Internet or SMS will not work if the area has no network coverage. This study develops BULSA which is a separate component that handles offline transactions using Bluetooth and stores this information on a local database. To validate the authenticity of the transactions, the matching of keys and encryption methods are used. Transactions are short-distance via Bluetooth but accompanied by Bayad Air could operate long- distance transactions.

The last component, Bayad Air, gives alternative access to people who have no smart or non-smart devices. It is the system's hardware component, and it is inspired by the ATM and the POS systems. Instead of Credit and Debit Cards as two-factor authentication, Bayad Air replaces them with biometrics. With Biometrics, like fingerprint authentication, people could transact without bringing or forgetting any physical device. Bayad Air is an adaptive hardware that can be used as a station, like an ATM, for the public to use and as a POS system for merchants to handle payments. Bayad Air, as a station, could also be used to allow long-distanced BULSA transactions by sending the transaction information to Bayad Air machines and can be able to receive that information once the BULSA unique identifications match. This technology could bring creative and innovative business ideas and new ways to transact with other people.

Electronic transaction systems may be better adapted in the Philippines in the future as the network coverage of the country gets wider and more resources are acquired. But, waiting for this progress to arrive would, unfortunately, slow and hinder a country's potential to progress. It may take time for most people and businesses to fully adopt this new way of transaction. Thus, the accessible and adaptable transaction system BAYAD is developed to accelerate this adoption.

Objectives

1. Develop a connection-adaptable transaction system.
1.1 To develop a multi-platform application that works on mobile and desktop.
1.2 To develop an algorithm for offline and peer-to-peer transactions via Bluetooth.
1.3 To develop a transaction method using Short Message Service (SMS) that works on messaging applications.
2. Perform tests on the system and determine effectiveness of technologies used.

Related Works

The number of cashless systems in the world today are increasing. With this, LI (2007) has improved methods and architecture for cashless systems. His invention relates to improving how gaming systems operate wherein the remote host involves a cashless server and the mobile devices are smart cards and cellular phones. Like the Bayad System, a cashless transaction can be enabled even when the mobile device is in the offline state. This happens through at least one working processor.

As more to the gaming industry, Cunningham (2007) was able to incorporate cashless instruments to operate transactions between gaming machines and portable devices. These machines could include slot machines, video poker machines, etc. Usually, we have coins or tokens as awards when we win games. It is being supplemented by ticket dispensers that print ticket vouchers that one could exchange for cash, for example. As technology progresses, other cashless mediums are already being used, such as smart cards. There are also cashless systems like the EZ Pay ticket system. They are found to reduce gaming machine operating costs. Through a logic device, a gaming system comprising a processor responds to the determination of the first authentication of a wireless mobile device offline. It enables a cashless transaction up to a first value from an account associated with the wireless mobile device to the gaming system, and it could also determine a second authentication of the wireless mobile device online, enabling a cashless transaction up to a second greater value this time. The concern here is security. Cashless instruments typically store a cash value that is ultimately redeemable for cash. With this, they can be highly vulnerable to fraud where such cashless instruments or systems are used in relatively simple formats or security architectures.

In 1996, Hogan (1996) started conducting cashless transactions with a system to purchase items and transact relatively monetary value. The invention requires a user's storage device, like a financial card. It works by deducting the amount of the transaction from the balance on the card devices of the system users. In instances where the existing balance associated with the card is unable to cover the price of the transaction, the system has an automatic renewal feature. It automatically increases the balance of the card device by a predetermined amount. It allows the purchase to be made without causing any inconvenience to the card user by increasing the balance. When this happens, the card-issuing bank bills the card user for increments of the predetermined amount.

For the conduct of these types of cashless transactions, such means include: (1) means for receiving a card apparatus containing data representing at least an available fund; (2) means for reading said data from said card apparatus; (3) means responsive to at least said data representing said available fund for automatically increasing said available fund by a predetermined amount without insertion into said terminal of coins or cash and without communication with an external central database for approval; and (4) means for decreasing said available fund by said transaction amount to complete said cashless transaction.

Xie (2016) has come up with a non-contact on-site trading method, a seller device, and a buyer device. This is a method for transactions between buyers and sellers done face-to-face through electronic devices, and more particularly, a non-contact on-site transaction method for completing transactions through near-field communication. According to Xie, the cashless transaction can be further divided into credit transactions between the two parties, third-party credit transactions, and instant transfers (i.e., financial debit cards), where the transaction price will be taken directly from the buyer's account. After deducting, if there is not enough money in the buyer's account, you can't deduct the transaction to complete the transaction. There are three kinds of third-party credit transactions and instant transfers that need to be supported by the intermediary payment agency. However, when an intermediary payment agency provides payment services to intermediaries or uses a

connected value card (closed or open) for debit transactions, the seller's equipment must be connected to a remote management device via the Internet to confirm whether the payment is made.

Accordingly, it is a non-contact on-site method that allows a seller to easily install a high-cost device such as a card reader, a POS system, or a networked device that is easy to communicate with the buyer in the field. and quickly complete cashless transactions. Therefore, the method of the present invention is applied between a seller device, a buyer device, and a payment institution and comprises: (1) the seller device generates a payment statement and records according to a sold item, and transmits the payment bill to the buyer device through near-field wireless communication; the payment bill includes at least one payment amount and account information of the receiving account; (2) the buyer device according to the payment bill transmitting a payment instruction to the payment institution to enable the payment institution to pay an actual amount from a payment account to the collection account; (3) transmitting and confirming the payment information after the payment institution verifies and approves the payment instruction. Providing the buyer device; (4) the buyer device generates a sales account message based on the confirmation payment information and transmits the sales account message to the seller device via near-field wireless communication; and (5) the seller device is based on the sales account The message is written off against the request.

Method

Research Design and Sampling

A descriptive and developmental method was employed for the methodology of this research. The developmental method was used to develop a system that addresses existing issues and achieves specified objectives by innovating on technologies and inventing more efficient ways to apply them. Whereas the descriptive method was used in testing the system by its user-acceptance as well as in discussing effectivity and efficiency in handling hindrances it aims to solve. Manual testing is also a quantitative method used in assessing the success rates of the system's runs and in quantifying the existence of errors for every run-through.

The method of sampling to be used for the user-acceptance feedback will be randomized and done through a random-number generator from the web with correspondence to the assigned numbers of the population which consists of all scholars of the Philippine Science High School campus.

System Overview

The software development methodology used in the study was Incremental Development Model. In this model, the software is designed, developed, and tested incrementally. The Flutter Software Development Kit was used to develop fast and multi-platform applications on mobile and desktop.

BULSA Model

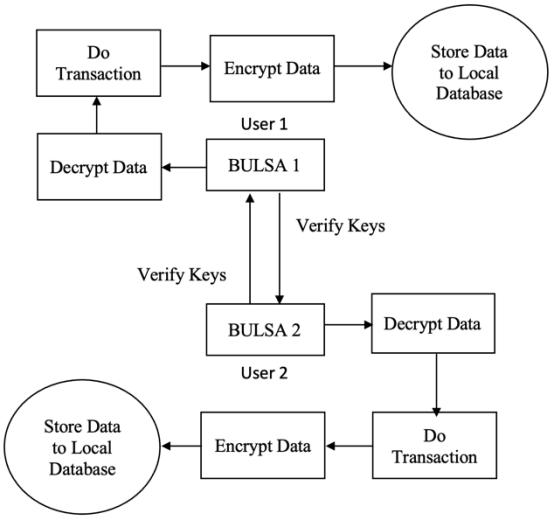


Figure 1. BULSA Transaction Model

Bluetooth Lending Secure Alternative (BULSA) is an offline mode of transaction that uses Bluetooth and Cryptography. Before transaction begins, both BULSA modules would verify and match keys to identify authenticity of both modules. Once verified, the data of one's BULSA is decrypted by the other. After the transaction, the data would be encrypted and stored to the local database.

SMS Transaction Model

Figure 2. SMS Transaction Model

SMS messages are communicated through a SMS Station that act as a receiver and sender of transaction data between the online database and user. Transactions are encrypted and decrypted during the process. The SMS Mode of Transaction would be used when the user's Internet Connection is not available or for transactions using basic phones.

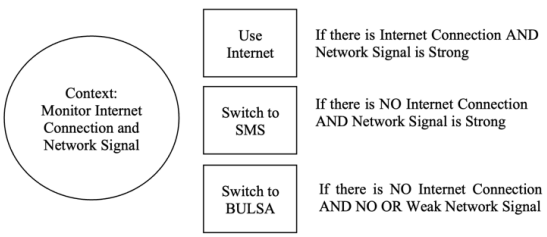


Figure 3. Context Algorithm

Context: Connection Adaptable Model

Context monitors the strength and availability of the Internet Connection and the Network Signal. When conditions are met, it automatically switches the mode of transaction to Internet, SMS, or BULSA. Firstly, it uses Internet when there is a stable internet connection, and the network signal strength is strong. Secondly, it switches to SMS if the internet connection is unstable or unavailable and the network signal strength is still strong. Lastly, it switches to BULSA when both internet connection and network signal are unavailable or weak.

System Design

Figure 4. Bayad Matthew Home Screen on Mobile Phones

Figure 4 shows the home screen of Bayad Matthew. This application is running on a real Android Device and an iPhone 13 virtual device. It shows the necessary functions needed by the user such as send and receive money, BULSA, and a show more button for extra functions.

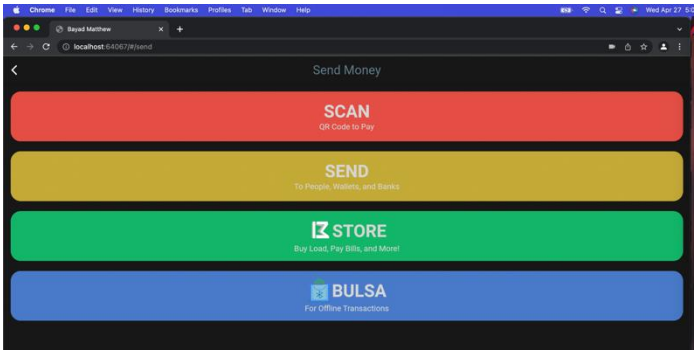


Figure 5. Send Money Options Screen on a Web Browser

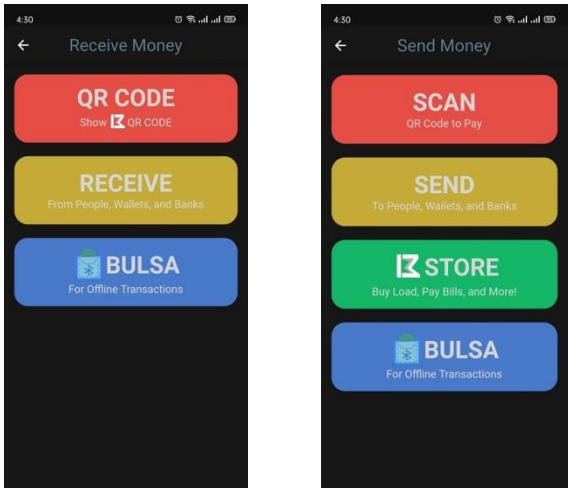


Figure 6. Send and Receive Money Options Screen on Mobile

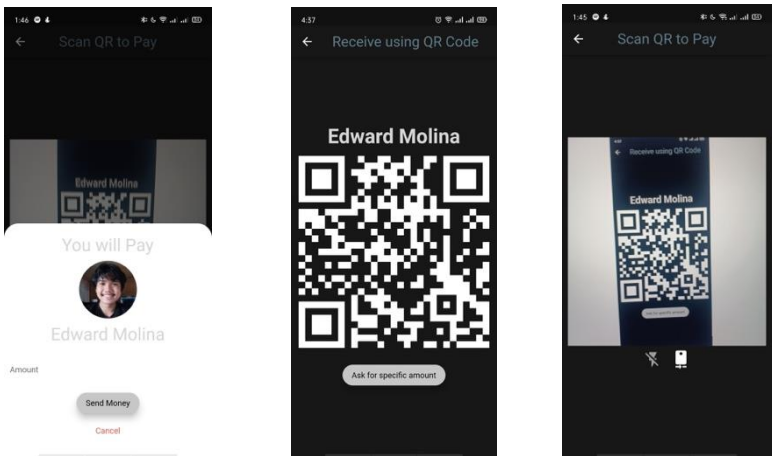


Figure 7. Send and Receive Money using QR Code and Scanner on Mobile

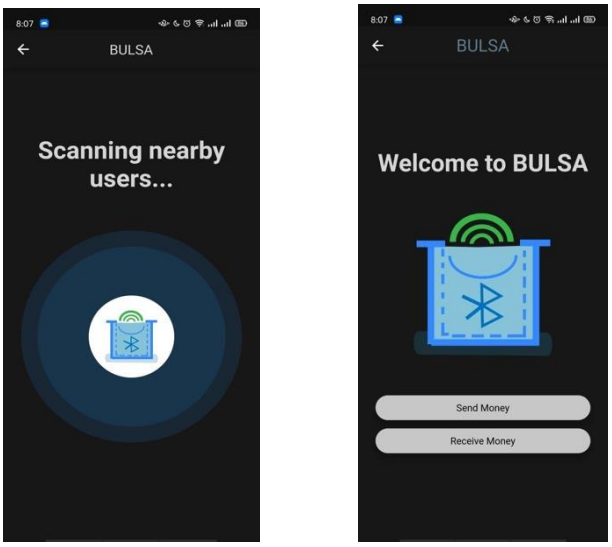


Figure 8. BULSA Scanning and Home Screen on Mobile

Figure 8 shows the BULSA Scanning and Home Screen. In BULSA, the user could choose to send money or receive money. BULSA then scans and detects nearby BULSA users. Once both users are connected, both users could now do their transactions.

Figure 9. Bayad Air Casing

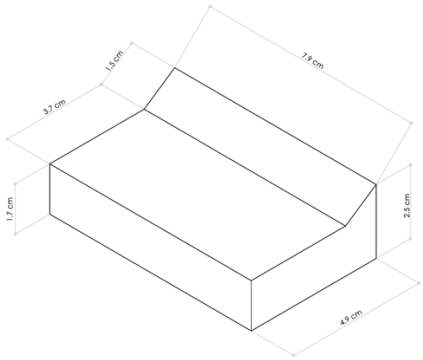


Figure 10. Bayad Air Casing Measurements

Figure 9 shows the Bayad Air 3D Printed Casing without its internals. The measurement of this casing is shown on Figure 10. Bayad Air is a device that uses biometrics accompanied with a two-factor authentication for transactions.

Results

The mobile application was tested manually using various phone models and franchises such as Samsung A50s, Oppo F1s, and Oppo F9. All tests pertaining to the creation of the account (encompassing sign-in and sign-out functions) yielded about a 100 percent success rate. Particularly the error leading to 96 percent success rates for signing-in and signing- out of the user's account was due to issues unrelated to the system itself which was a malfunction causing it to have chronic lags. These errors were nevertheless regarded as system errors as it is the system's aim to have the capacity to compensate for device requirements. Moreover, transactions via the various forms yielded 100 percent success rates (i.e., via the internet, phone number, and QR code), except for SMS that yielded 97 percent with some errors notably due to signal fluctuations. The adaptability by context has also been tested to which it successfully recognized changes and adapted based on internet/signal availability at 100

percent of the trials made. As for its availability cross-platform and across systems, it also yielded a 100 percent success rate.

Table 1. Manual Testing Results

Tests	Number of Trials	Trials Succeeded	Success Rate
Creating an Account for the User	57	56	98.24%
Signing-up	60	60	100%
Signing-out	60	60	100%
Transaction Using Scan QR Code via Internet	100	100	100%
Transaction using Phone Number Via Internet	100	99	99%
Transaction via SMS	88	85	96.59%
Runs on an Android Device	1	1	100%
Runs on an iOS device	1	1	100%
Runs on Web	1	1	100%
Runs on Desktop	1	1	100%

Table 2. User Acceptance of the System

System Acceptability Criteria		**Mean**	**Interpretation**
Functionality			
1)	The system performs sending and receiving of transactions	4.921	Strongly Agree
2)	The system checks and shows the remaining monetary balance of the user	4.873	Strongly Agree
3)	The system can properly identify and scan from images	4.857	Strongly Agree
4)	The system can register accounts	4.778	Strongly Agree
5)	The system can recognize registered accounts with accordance to user profile	4.794	Strongly Agree
6)	The system can perform in various modes of transaction	4.794	Strongly Agree
Reliability			
1)	The system is capable of handling incorrect inputs	4.539	Strongly Agree
2)	The system is free from bugs and runs smoothly without interruption	4.524	Strongly Agree
3)	The system can recover from failure and can resume operation	4.412	Agree
4)	The system can easily find the information I am looking for using the system	4.746	Strongly Agree
5)	The software can recover even after failure	4.524	Strongly Agree
Usability			
1)	The system is easy to use (user-friendly)	4.873	Strongly Agree
2)	User interface of the system is clear and intuitive	4.794	Strongly Agree
3)	Navigation on the different modules is easy	4.746	Strongly Agree
4)	It is available for free download and transferable to other phones, cross platform.	4.778	Strongly Agree
5)	The system can be used even if the users don't have technical experience	4.809	Strongly Agree
Efficiency			

1)	The system responds instantly	4.730	Strongly Agree
2)	The system processes data quickly	4.762	Strongly Agree
3)	The system can generate reports quickly	4.746	Strongly Agree
4)	The system instantly responds to commands of the user	4.809	Strongly Agree
5)	The system precisely organizes information based on criteria or functionality	4.825	Strongly Agree
Maintainability			
1)	Errors can be easily detected by the system	4.460	Agree
2)	The application can be easily modified	4.429	Agree
3)	The application can continue functioning if changes are made	4.619	Strongly Agree
4)	The application can be tested easily	4.746	Strongly Agree
5)	It has an availability of system support	4.651	Strongly Agree
Portability			
1)	The application can be moved to other environments	4.794	Strongly Agree
2)	The application can be deployed easily	4.809	Strongly Agree
3)	The application complies with portability standards	4.778	Strongly Agree
4)	The application can be tested easily	4.794	Strongly Agree
5)	The application has an availability of system support	4.603	Strongly Agree

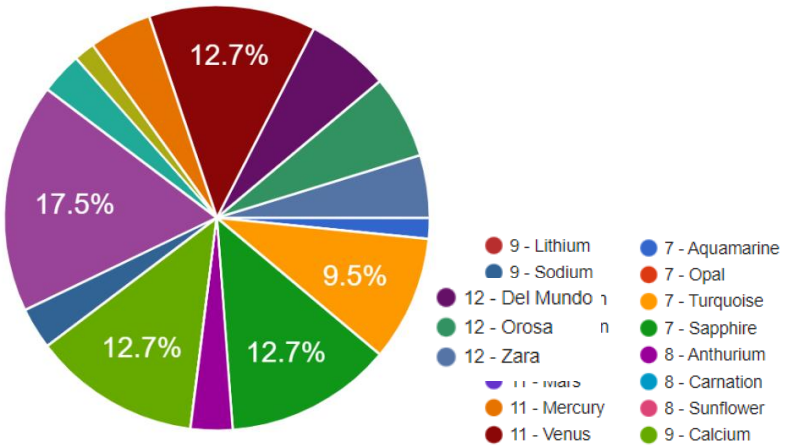


Figure 11. Distribution of Feedback Form Respondents by Section

Discussion

Indicated in Table 2 is the User-Acceptance survey results. The survey was conducted only within the Philippine Science High School-Caraga Region Campus community, particularly the students across different grade levels and sections. The researchers randomized the sample selection using a random number generator, of which each number was designated to a specific person in a grade level. Because of the manner of localization, limited manpower, and time constraints, used in this study is a sample size of only 63 with the sample distribution as follows in Figure 11.

By this, a survey was conducted via a google-form with the purpose of receiving feedback and collecting data. Despite the limited sample size, efforts were dedicated to reaching the maximum number of respondents for the user-acceptance survey, not only for the collection of data but also for constructive feedback which would be beneficial in the system optimization. Nevertheless, for the particular purpose of data collection, only the feedback information from the randomized selection of respondents (that agreed to the use of their responses) were used in this study.

It is guaranteed that data ethics was properly observed in the making of the survey form as well as in the use of the respondent's feedback. The Data Privacy Act was followed and respondents were given the choice to agree or disagree with the use of the information they provided in the feedback form.

Conclusion

A transaction system called BAYAD, an acronym that stands for Bayad is an Approach that Yields Accessibility and Digitalization, was established to provide people access. The system makes the conduct of transactions viable to a broader, more diverse range of people compared to other electronic transactions as the research's main objective is to create a system that improves on the latest available technology and innovative ideas that provide a simple, accessible, private, and secure experience. Transactions made in BAYAD may not be hindered by poor connection or no internet connection. It also does not necessarily require the use of mobile phones. Even people who are not technology-savvy can acquire the service. There are a lot of components that make up the system. It provides users a lot of alternatives for their transactions, whatever the situations they are in, like the scenarios mentioned. The system's major components are (1) Bayad Matthew, (2) Bluetooth Lending Secure Alternative, BULSA for short, and (3) Bayad Air. The first functioning component, Bayad Matthew, is an application created through Flutter. It is also being deployed in mobile, web, and desktop environments. Second, BULSA, a component that uses a software that handles sending, receiving, storing, encrypting, and authenticating transactions offline and locally via Bluetooth. Third, Bayad Air allows users, who have no hardware on hand or prefer to transact without anything to carry, to transact with the use of biometrics. To test the reliability and efficiency of the system, the researchers performed multiple replicated tests on different devices, namely different classifications of smartphones and basic phones, using virtual emulators and physical devices in various

areas. Every functionality of the system's software was also tested and replicated to ensure fewer bugs and glitches are experienced.

Therefore, by identifying the issues of existing cashless transaction systems, alternatives have been innovated to make these systems more efficient. Electronic transaction may become more accessible and available regardless of phone model using this system where SMS can be used when only basic phones are involved, or Bluetooth for when online transactions may not occur. Even for those without phones, biometrics may also be used to compensate. Thus, in this developmental research, an effective connection-adaptable transaction system was achieved.

Recommendations

In line with the results obtained in this developmental research, it is recommended that the scope of the study is broadened such that it includes specified focus and innovations pertaining to database security and other high-level security for BULSA, Bayad Matthew, and Bayad Air. Particularly for the Bayad Air hardware, the use of printed circuit boards is advised to create a wireless connection between components, allowing more ease in handling connections and for a smaller, more portable device. It is further recommended that the software of each platform is optimized and tested to more devices, specified and functional device size is adopted, and a user-acceptance survey that covers a larger variety of more people is conducted.

Notes

First and foremost, we would like to give our deepest thanks to the Almighty Father up above who gave us strength, wisdom, guidance, and the will to keep pushing no matter what the problems and errors were through making our project a reality. Secondly, we would like to thank our families, especially our parents, who helped with the finances, encouraged, and supported us throughout. Thirdly, we would like to express our deepest appreciation to Dr. Patrick D. Cerna, PhD. for supervising our research. Lastly, we extend also our grattitude to Mr. Erle Mark Estrella for assisting us in the fabrication laboratory.

References

Cunningham, I. W. R. (2007, February 27). *US11393283B2 - Methods and architecture for cashless system security - Google Patents*. https://patents.google.com/patent/US11393283B2/en?q=(cashless)

Hogan, E. J. (1996, May 30). *US5704046A - System and method for conducting cashless transactions - Google Patents*. https://patents.google.com/patent/US5704046A/en?q=(cashless+transactions)

Ll, W. R. C. (2007, February 27). *AU2016201106B2 - Improved methods and architecture for cashless system security – Google Patents.*

https://patents.google.com/patent/AU2016201106B2/en?q=(cashless+transactions)&oq=cashless+transactions&page=4

Xie, B. W. (2016, June 1). *TW201743253A - Contactless on-site transaction method, vendor device and buyer device using a near field wireless communication means to complete the on-site cashless transactions rapidly without invoking high-cost equipments such as card reader, POST system, and networking devices - Google Patents*. https://patents.google.com/patent/TW201743253A/en?q=(cashless+transactions)&oq=cashless+transactions

Zu, Gcr, Ogoc, L., Jam, Anonymous, Gamba, Z. E., Ken, & Neypes, G. (2021, May 16). What is gcash? an absolute beginner's guide - gcashresource.GCR. https://gcashresource.com/what-is-gcash-an-absolute-beginners-guide/

The Role of Estrogen Receptor Ligands, Ethinylestradiol (EE) and Estetrol (E4) on Endothelial Cell Function and Angiogenesis

Aida Dama

Albanian University, Albania, https://orcid.org/0000-0002-1993-3420

Abstract: Endothelial homeostasis and the mechanisms related to it have drawn the attention of researchers as a way to prevent and/or ameliorate cardiovascular diseases. Female hormones play an important role in this aspect. Ethinylestradiol (EE) and estetrol (E4) are the two main estrogenic agents used in combined oral contraceptives. These compounds have different binding affinity to and efficacy on estrogen receptors (ER) subtypes. The impact of EE and E4 on human endothelial function has been little investigated. EE and E4 (10-9–10-7 M) significantly enhanced migration of human umbilical vein endothelial cells (HUVECs) using scratch and Boyden chamber assays. Mechanistically, both agents increased accumulation of phosphorylated protein tyrosine kinase 2 on tyrosine 397 (FAK Y397), a key player in endothelial cell motility, after 30-min treatment. Of note, effects of EE and E4 on endothelial migration and signalling proteins were abolished by addition of the GPER antagonist G36 (10-6 M). Thus, EE and E4 induced comparable endothelial responses in vitro, suggesting no apparent alterations of vascular remodelling and regeneration capacity by oral contraceptives containing these agents.

Keywords: Endothelial cells, Ethinylestradiol, Estetrol, Angiogenesis, PFKFB3

Citation: Dama, A. (2023). The Role of Estrogen Receptor Ligands, Ethinylestradiol (EE) and Estetrol (E4) on Endothelial Cell Function and Angiogenesis. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023-- International Conference on Life Sciences, Engineering and Technology* (pp. 145-149), Denver, CO, USA. ISTES Organization.

Introduction

7β-oestradiol (E2) elicits protective cardiovascular and metabolic effects through interaction with various cell types and receptors, including oestrogen receptors (ERs) ERα and ERβ, as well as the recently discovered G protein-coupled oestrogen receptor (GPER) and membrane ERs (Cignarella, Kratz, & Bolego, 2010). GPER is involved in both acute and chronic effects of E2, and its role in cardiovascular function is increasingly recognized (Dama, Baggio, & Boscaro, 2021). While E2 effects on several aspects of endothelial function are well characterized (Zahreddine, Davezez, & Buscato, 2021), the action profile of the estrogenic ligands ethinylestradiol (EE) and estetrol (E4) has been little investigated. EE is contained in a large number of combined oral contraceptive formulations and menopausal hormone therapy medications, whereas E4 is a natural oestrogen that is produced exclusively during pregnancy by the foetal liver. E4 (formulated as the

monohydrate) is a component of oral contraceptives that also contain drospirenone, which were approved by the FDA and the EMA in 2021. EE and E4 as estrogenic agents, exhibit varying binding affinities and efficacy on ER subtypes (Dama, Baggio, & Trevisi, 2023). The estrogenic agent may impact on the cardiovascular safety of combined oral contraceptives (Dinger, Do Minh, & Heinemann, 2016). This study aims to examine the effect of estrogen receptor ligands such are Ethinylestradiol (EE) and Estetrol (E4) on glycolytic protein abundance and how they, in turn affect endothelial functions (i.e., angiogenic process).

Material and Methods

For chemotaxis assay cells were seeded on 48-well modified microchemotaxis chambers where lower chambers were filled with M199 medium and upper ones with human umbilical vein endothelial cell (HUVEC) suspension. Cell migration was stained with Diff-Quick stain. Scratch assay was used to investigate cell migration and gap closure for a maximum time of 6 h after performing a scratch by using 200 uL micro tips on the cells' layer. ImageJ was used for further quantifications. Western blot technique was used to study protein levels of PFKFB3 and p-FAK397. Cells were lysed using a specific lysis buffer and the lysate was loaded in prepared agarose gel and let running for a specific time in running buffer. After the transfer, membranes were blocked in probed using the required antibodies. Quantifications were made in ImageJ. All statistical analysis were made with Prism GraphPad 5.

Results

Endothelial cell migration is an essential component of angiogenesis. The effect of EE and E4 on HUVEC migration was tested using either wound healing or Boyden chamber migration assays. In particular, to test non-directional integrin-mediated cell migration, HUVECs were exposed to mechanical stress by performing a scratch on the cell monolayer and afterwards treated with test agents. EE and E4 promote angiogenic response of endothelial cells by improving cell migration in both, scratch and Boyden chambers assays (Fig. 1 A, B). Mechanistically, both EE and E4 increased accumulation of phosphorylated protein tyrosine kinase 2 on tyrosine 397 (FAK Y397), a key player in endothelial cell motility, after 30-min treatment (Fig.1 C).

The contribution of GPER to the effects of EE and E4 on HUVEC migration was analysed in Boyden chamber migration assays. Effects of EE and E4 on endothelial migration were abolished by addition of the GPER antagonist G36 (10-6 M), suggesting that GPER was involved in the angiogenic response to EE and E4 (Fig. 1D).

Conclusion

The study concludes that ER ligands, namely EE and E4, promote HUVEC migration via GPER-dependent mechanisms, which may involve unique signalling pathways. These findings indicate that the two primary

estrogenic agents utilized in combined oral contraceptives possess comparable abilities to facilitate vascular remodelling and regeneration (Fig .2).

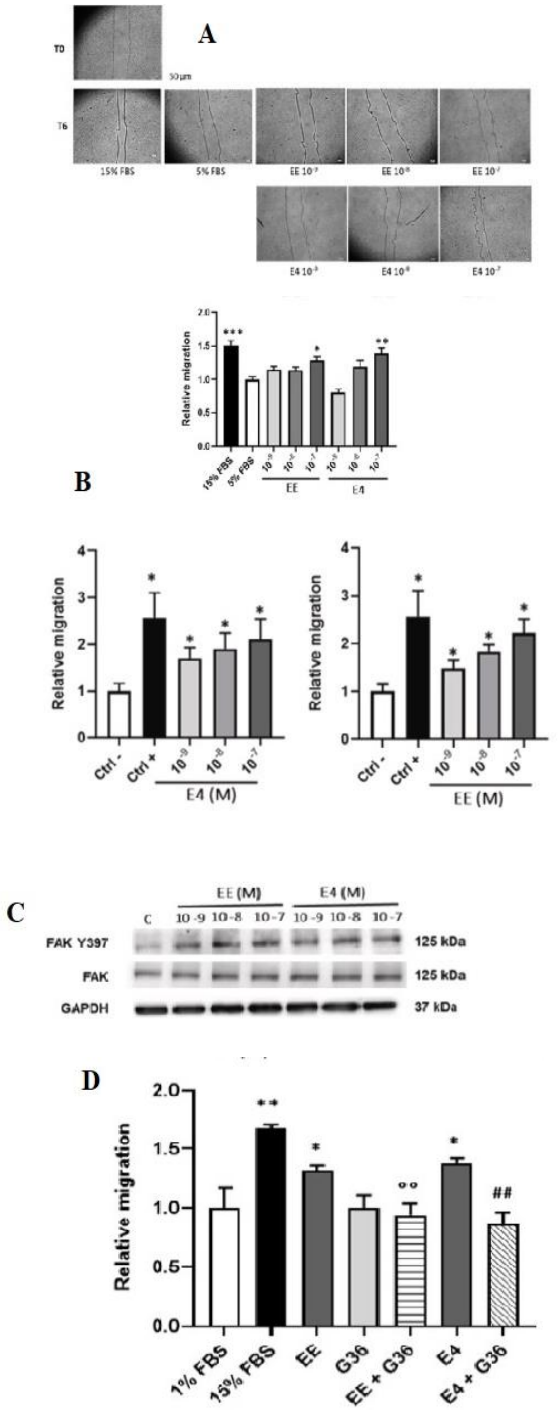


Figure 1. Scratch assays in HUVECs cultured in 5% FBS phenol red-free M199 medium and treated with increasing concentrations of EE or E4 for 6 h **(A);** Effect of the estrogenic ligands EE and E4 on HUVEC migration assessed by Boyden's functional assay after incubation **(B);** Effect of estrogenic ligands on the accumulation of FAK Y397 **(C);** Chemotactic migration of HUVECs in response to treatment with EE (10^{-7} M) and E4 (10^{-7} M) in the presence or absence of the GPER antagonist G36 (10^{-6} M) as assessed by Boyden's functional assay **(D).**

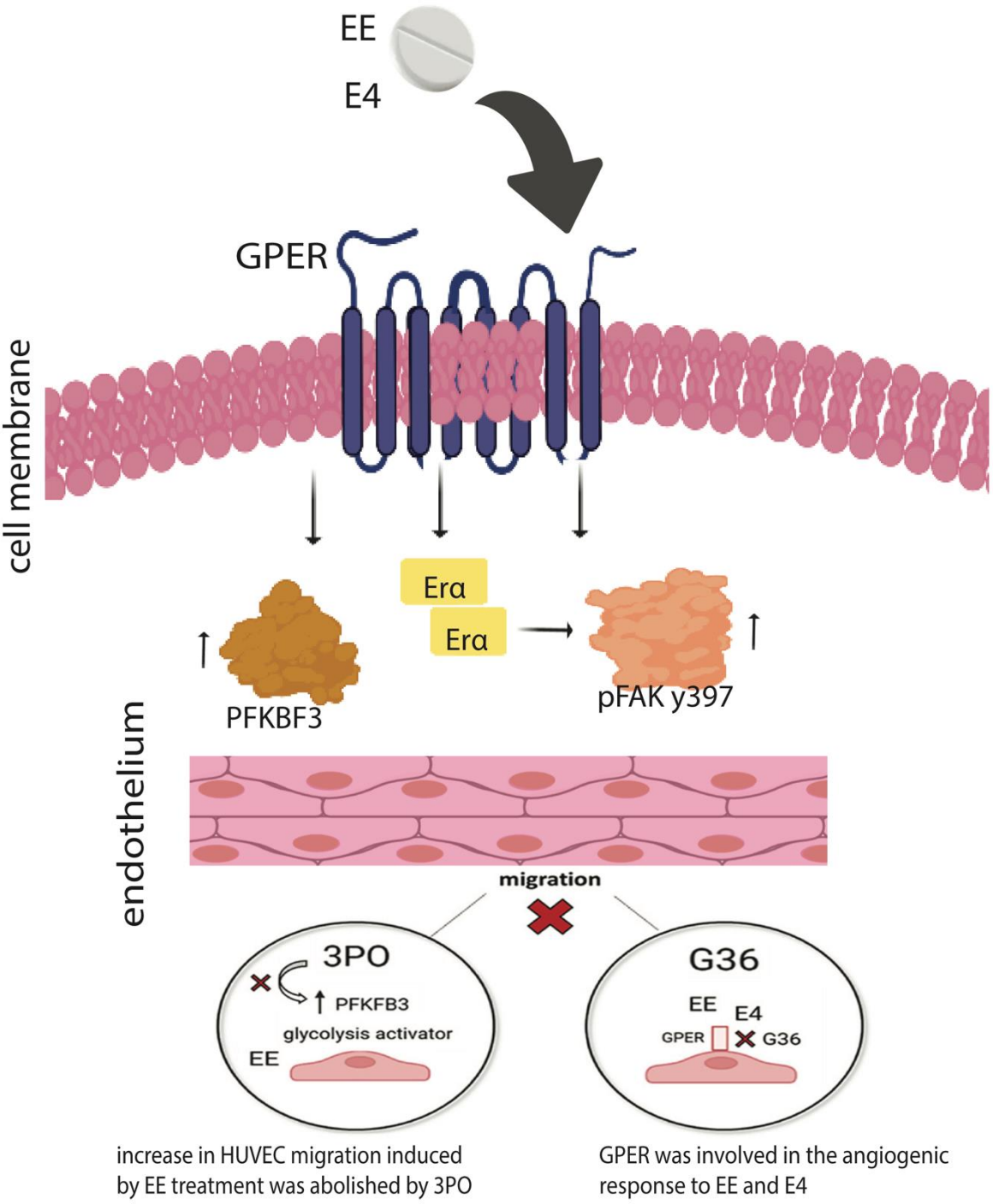


Figure 2. Estrogenic ligands bind to GPER receptor and induce protective effects in the vascular wall by modulating FAK and PFKFB3 proteins and ERα transcription factor.

References

Cignarella A., Kratz M., Bolego C. Emerging role of estrogen in the control of cardiometabolic disease. *Trends*

Pharmacol Sci. 2010; 31(4):183-9.

Dama A., Baggio C., Boscaro C., Albiero M., Cignarella A. Estrogen Receptor Functions and Pathways at the Vascular Immune Interface. *Int J Mol Sci. 2021*; 22(8):4254.

Zahreddine R., Davezez M., Buscato M., Smirnova A., Laffargue D., Henrion D., Adlanmerini F., Lenfant J.F., Arnal F., Fontaine C. A historical view of estrogen effect on arterial endothelial healing: from animal models to medical implication. *Atherosclerosis*, 338 (2021), pp. 30-38, 10.1016.

Dama A., Baggio C., Trevisi L., Bolego C., Cignarella A. Regulation of human endothelial cell migration by oral contraceptive estrogen receptor ligands. *Eur J Pharmacol.* 2023; 17:175591.

Dinger J., Do Minh T., Heinemann K. Impact of estrogen type on cardiovascular safety of combined oral contraceptives. *Contraception*, 2016; 328-339.

Comparison of Turkish and Finnish Mathematics Teachers' Approaches to Teaching in Class

Eyüp Yurt
Bursa Uludağ University, Türkiye, https://orcid.org/0000-0003-4732-6879

Abstract: This study aims to compare the in-class teaching methods used by mathematics teachers in Turkey and Finland. By using a causal comparison design, the responses of Turkish and Finnish teachers regarding their teaching approaches to mathematics lessons in TIMSS 2019 were analyzed and compared. The study involved eighth-grade mathematics teachers from Turkey and Finland who participated in TIMSS 2019, with 389 teachers from Finland and 181 teachers from Turkey included in the research. The study revealed that Turkish and Finnish mathematics teachers put similar efforts into creating a classroom environment where students can engage in discussions. However, Turkish teachers showed more emphasis on teaching techniques such as relating mathematical concepts to student's everyday lives, encouraging students to explain their answers, guiding them to complete challenging exercises to improve their skills, relating new information to their previous knowledge, and allowing students to use their problem-solving methods, compared to Finnish teachers. According to the results obtained, some suggestions are presented.

Keywords: TIMSS 2019, Teaching approaches, Turkish and Finnish mathematics teachers

Citation: Yurt E. (2023). Comparison of Turkish and Finnish Mathematics Teachers' Approaches to Teaching in Class. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023-- International Conference on Life Sciences, Engineering and Technology* (pp. 150-159), Denver, CO, USA. ISTES Organization.

Introduction

Teaching mathematics is one of the most critical issues in education systems, especially at the primary and secondary school level (NTCM, 2000). In-class teaching approaches of mathematics teachers are fundamental to improving students' mathematical skills, increasing their academic success, and making them better problem solvers in their future lives. Therefore, comparing the classroom teaching approaches of mathematics teachers in different countries can give an idea about new strategies to be developed to increase students' mathematics achievement.

This study aims to compare the in-class teaching approaches of Turkish and Finnish mathematics teachers. While the Turkish education system adopts a traditional classroom-oriented teaching method (Kara et al., 2017), it is known that the Finnish education system uses a student-centered teaching method (Sahlberg, 2021). Therefore, according to 2019 TIMSS data, examining the differences between the teaching methods of Turkish

and Finnish mathematics teachers can help develop more effective teaching strategies for student success.

Trends in International Mathematics and Science Study (TIMSS)

TIMSS (Trends in International Mathematics and Science Study) is an international exam that aims to measure the achievement of 4th and 8th-grade students in mathematics and science. TIMSS is designed to determine how well students have mastered which subjects in mathematics and science fields and in which subjects they are weak (Mullis & Martin, 2017). The TIMSS exam is held every four years, and the countries taking the exam are chosen to represent an international sample. The exam includes many countries from Europe, Asia, Africa, and North and South America.

Results in the TIMSS test may affect countries' mathematics and science curricula and approaches to teaching. Therefore, TIMSS results can help countries review their education policies and raise education standards (Martin, von Davier & Mullis, 2020). In addition, TIMSS results may also affect teachers' approaches to teaching in the classroom. Teachers can make changes in their lessons, considering the TIMSS results, to increase student success. For example, they can look at TIMSS results to identify student's weak points in math and change their teaching approach to help them learn better.

TIMSS 2019 Mathematics Performance of Türkiye and Finland

According to TIMSS 2019, Singapore showed the highest success with 616 points among students from 39 countries in the mathematics exam. Countries following Singapore include Taiwan, South Korea, Japan, and Hong Kong. All these countries are from Asia, and Russia also performed well. Of the 39 participating countries, 14 scored above the TIMSS scale average, meaning they performed relatively well (Mullis et al., 2020).

In the mathematics test, the average score of Finnish 8th-grade students is 509. This result has placed Finland in 14th place among 39 countries participating in TIMSS 2019. Finnish eighth-grade students' mathematics score average is above the international average (MoNE, 2020). Finland's high performance in many of its exams has drawn the attention of other countries. It is possible to say that Finland's teaching approach and education system set an example for other countries.

Turkey ranked 20th among 39 participants, with an average score of 496. With this performance, Turkey was at the same level as the TIMSS scale midpoint (500 points). Among the countries where Turkey outperforms in mathematics are 18 countries, including France, New Zealand, and Romania. Countries performing at the same level as Turkey are Norway, Sweden, Southern Cyprus, Portugal, Italy, and Kazakhstan. On the other hand, Turkey outperformed 14 countries, including Israel, the United States of America, England, and Finland. According to TIMSS 2019 results, students' achievement in mathematics and science in Turkey varied according to the quality of the school environment. Factors such as school management, teacher qualification, and school resources (such as laboratories and libraries) affect students' success (MoNE, 2020).

The Effect of In-Class Teaching Approaches on Student Performance

In-class teaching approaches can directly affect students' math performance because the teaching approach teachers can affect how students learn mathematical concepts, their participation in the lesson, and their level of interest and success (Gedik & Aykaç, 2017; Özsoy, 2003). For example, teacher-centered teaching approaches may be less effective in students' learning of mathematical concepts. This is because, in teacher-centered approaches, students' active participation is less, and opportunities for students to develop self-learning skills are reduced.

On the other hand, student-centered active teaching approaches such as peer learning and collaborative group work activities may be more effective in developing students' learning higher-order competences (see Latifi et al., 2021, 2023; Noroozi et al., 2012, 2018, 2020; Valero-Haro et al., 2019, 2022). These approaches provide students with the skills to explore learning and self-learning and help students better understand mathematical concepts (Elmoudden, 2023; Kasım & Öztürk, 2023; Pirci & Torun, 2020; Shaqour & Dwiek, 2023). Studies show that student-centered teaching approaches positively affect students' mathematics achievement (Niess, 2005; Zakaria, Chin & Daud, 2010). Therefore, it is recommended that teachers manage their mathematics lessons using student-centered teaching approaches.

Purpose of the Research

This study aims to compare the in-class teaching approaches of Turkish and Finnish mathematics teachers. Comparing the teaching approaches of mathematics teachers in different countries can contribute to teacher education programs and teachers' professional development. Comparing teachers' approaches to teaching can help design teacher education programs more effectively and enable teachers to interact better with students from different countries.

According to Turkey's TIMSS 2019 results, students' performance in mathematics remained below the international average. These results show that studies on Turkey's education system and teaching methods should continue. The results obtained in this research may be helpful for mathematics teachers and students. Mathematics teachers can learn about teachers' teaching methods in other countries and receive advice to help them develop more effective teaching strategies. On the other hand, students can improve their math skills because of their teachers' teaching more effectively. This study may also shed light on researchers. The study's results can be used to understand the differences between the teaching approaches of mathematics teachers in different countries and to develop better teaching strategies. In addition, the study's results can help design teacher education programs and policies in mathematics teaching more effectively.

As a result, comparing the in-class teaching approaches of Turkish and Finnish mathematics teachers can help to understand the approaches to mathematics teaching in different countries and to develop more effective strategies to improve the mathematics skills of teachers and students. This study is an important step that can be

used to identify best practices in mathematics teaching, help develop teacher education programs, and contribute to developing new strategies to increase students' mathematics achievement.

Method

This study was carried out using a causal comparison design, a model used to investigate the causal relationship between two or more variables. This model enables researchers to determine the nature and direction of the relationship between variables and measure one variable's impact on others (Gürbüz & Şahin, 2014). In this research, based on the causal comparison design, the answers given by Turkish and Finnish teachers to the questions about learning approaches in mathematics lessons in TIMSS 2019 were compared and examined.

Sample

The participants in this research study were eighth-grade mathematics teachers from Turkey and Finland who participated in the 2019 TIMSS. The study included 389 teachers from Finland and 181 teachers from Turkey. The average professional experience of the Finnish teachers was 14.51 years (SD=9.18), while that of the Turkish teachers was 10.15 years (SD=6.68). The demographic characteristics of the teachers are presented in Tables 1, 2, and 3.

Table 1. Distribution of Turkish and Finnish Teachers by Gender

			Frequency	Percent
Gender of teacher	Finnish	Female	212	54,5
		Male	176	45,2
		Missing	1	0,3
	Turkish	Female	97	53,6
		Male	83	45,9
		Missing	1	0,6

When Table 1 is examined, it is understood that 54,5% of Finnish teachers are female and 45,2% are male. On the other hand, 53.6% of Turkish teachers are female, and 45.9% are male. It was observed that the distribution by gender was similar in both countries.

Table 2. Distribution of Turkish and Finnish Teachers by Age

			Frequency	Percent
Age of teacher	Finnish	Under 25	2	0,5
		25–29	35	9,0
		30–39	111	28,5
		40–49	139	35,7
		50–59	79	20,3
		60 or more	22	5,7
		Missing	1	0,3
	Turkish	Under 25	10	5,5
		25–29	53	29,3

	30–39	80	44,2
	40–49	33	18,2
	50–59	3	1,7
	Missing	1	1,2

When Table 2 is examined, it is understood that the majority of Finnish teachers are in the 30-39 (28,5%), 40-49 (35,7%), and 50-59 (20,3%) age groups. The majority of Turkish teachers are also in the 25-29 (29.3%), 30-39 (44.2%), and 40-49 (18.2%) age groups. It has been observed that Turkish teachers participating in TIMSS 2019 are younger.

Table 3. Distribution of Turkish and Finnish Teachers by Education Level

			Frequency	Percent
Education level of teacher	Finnish	Upper secondary education	6	1,5
		Short-cycle tertiary education	3	0,8
		Bachelor's or equivalent level	23	5,9
		Master's or equivalent level	345	88,7
		Doctor or equivalent level	11	2,8
		Missing	1	0,3
	Turkish	Bachelor's or equivalent level	168	92,8
		Master's or equivalent level	12	6,6
		Missing	1	0,6

When Table 2 is examined, most Finnish teachers (88.7%) have a master's degree. On the other hand, many Turkish teachers stated they have a bachelor's degree (92.8%). It is striking that Finnish teachers have higher education levels.

Measuring Tool

In this research, the answers that eighth-grade mathematics teachers gave to the "About Teaching the TIMSS Class" questionnaire in the 2019 TIMSS were examined. The questionnaire began with the question, "How often do you do the following in teaching this class?" (IEA, 2018). The questionnaire aims to determine at what level teachers use different teaching approaches in their lessons. The questionnaire is in a 4-point Likert type (Every or almost every lesson =1, About half the lessons =2, Some lessons =3, Never =4) and consists of 7 items. The scores given to the items were reversed so that high scores indicate positive results. For the Finnish sample, Cronbach's alpha coefficient was 0.72; For the Turkish sample, Cronbach's alpha coefficient was calculated as 0.82. Accordingly, it can be said that the internal consistency of the answers given to the items is at enough level.

Statistical Analysis

The data analysis in this study was conducted using the TIMSS 2019 User Guide as a reference (Fishbein, Foy &

Yin, 2021). The skewness and kurtosis coefficients were calculated to assess the distribution of responses to the questionnaire items related to teaching approaches in math class. To meet the assumption of normal distribution, the skewness and kurtosis coefficients are recommended to fall within the range of ±1.5 (Tabachnick & Fidell, 2007), which was satisfied in this study. The teaching approaches mean scores of Turkish and Finnish teachers were compared using an independent groups t-test, with Cohen's d values calculated to determine the effect size. Generally, d values of 0.2, 0.5, and 0.8 indicate small, moderate, and large effect sizes, respectively (Cohen, 1988). All statistical analyses were performed using the SPSS 25.0 software package.

Results

To fulfill the aims of this study, an independent groups t-test was utilized to compare the responses of Turkish and Finnish mathematics teachers to questionnaire items about teaching approaches in math class. The results of this analysis are presented in Table 4.

Table 4. Comparison of the Mean Scores of Turkish and Finnish Mathematics Teachers from the Teaching Approaches Questionnaire

How often do you do the following in teaching this class?	Country	N	M	SD	t(690)	p	Cohen d
Relating the lesson to students' daily lives	Turkey	179	3,29	0,81	5,54	0,00*	0,50
	Finland	386	2,89	0,78			
Asking students to explain their answers	Turkey	179	3,71	0,58	3,67	0,00*	0,34
	Finland	385	3,49	0,71			
Asking students to complete challenging exercises that require them to go beyond the instruction	Turkey	179	2,74	0,90	2,81	0,01*	0,25
	Finland	385	2,53	0,83			
Encouraging classroom discussions among students	Turkey	179	2,82	0,94	-1,19	0,23	0,11
	Finland	385	2,92	0,90			
Linking new content to students' prior knowledge	Turkey	179	3,80	0,44	5,32	0,00*	0,51
	Finland	386	3,53	0,62			
Asking students to decide their own problem solving procedures	Turkey	179	3,51	0,73	10,32	0,00*	0,96
	Finland	386	2,75	0,84			
Encouraging students to express their ideas in class	Turkey	179	3,74	0,56	8,08	0,00*	0,78
	Finland	386	3,19	0,83			

When the table is examined, it is understood that the mean scores of "Encouraging classroom discussions among students" do not differ significantly according to countries (p>0.05). It can be said that Turkish and Finnish

mathematics teachers make similar efforts to create environments where students can discuss in the classroom environment.

By country, "Relating the lesson to students' daily lives", "Asking students to explain their answers", "Asking students to complete challenging exercises that require them to go beyond the instruction", "Linking new content to students' prior knowledge", "Asking students to decide their problem-solving procedures" and "Encouraging students to express their ideas in class" mean scores showed a significant difference.

The results obtained have shown that Turkish teachers put more effort into teaching approaches such as relating mathematical topics to student's daily lives, providing opportunities for students to explain their answers, directing students to complete challenging exercises that will improve themselves, explaining new information by relating it to students' old knowledge, and allowing students to use their methods in the problem-solving process, compared to Finnish teachers. The scores of Finnish and Turkish teachers from the questionnaire items are presented visually in Figure 1.

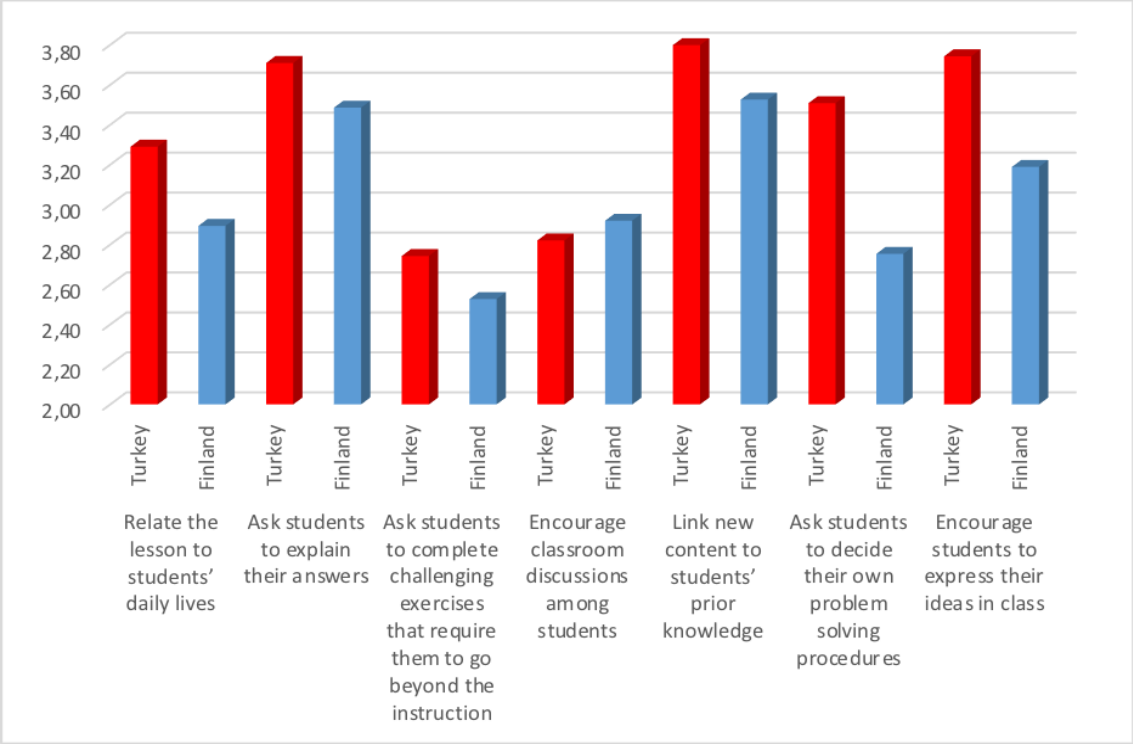


Figure 1. The Mean Scores of Turkish and Finnish Mathematics Teachers from the Teaching Approaches Questionnaire

Conclusion and Recommendations

This study aims to compare the in-class teaching approaches of Turkish and Finnish mathematics teachers.

Based on the causal comparison design, the answers given by Turkish and Finnish teachers to the questions about learning approaches in mathematics lessons in TIMSS 2019 were compared and examined. The participants in this research study were eighth-grade mathematics teachers from Turkey and Finland who participated in the 2019 TIMSS. The study included 389 teachers from Finland and 181 teachers from Turkey.

The study's findings showed that Turkish and Finnish mathematics teachers make similar efforts to create environments where students can discuss in the classroom environment. For all that, Turkish teachers put more effort into teaching approaches such as relating mathematical topics to student's daily lives, providing opportunities for students to explain their answers, directing students to complete challenging exercises that will improve themselves, explaining new information by relating it to students' old knowledge, and allowing students to use their methods in the problem-solving process, compared to Finnish teachers.

It is striking that Turkish teachers give more space to in-class teaching approaches that support and increase student performance compared to Finnish teachers. It is known that effective teaching methods and classroom techniques directly affect students' success (Kablan, Topan & Erkan, 2013; Kardaş & Uca, 2016; Topan, 2013; Ulubey & Toraman, 2015). On the other hand, according to TIMSS 2019 results, Finnish students were found to be more successful than Turkish students. This result indicates that factors other than classroom teaching approaches affect the mathematics achievement of Turkish students. These factors include out-of-school opportunities, study hours, parental support, etc. may be factors.

However, it has been stated that self-reported reports are likely to lead to inflated judgments about the level of performance (Bümen, Çakar & Yıldız, 2014). The validity of the answers given to the questionnaires depends on the sincere answers of the participants. Turkish teachers may have shown the frequency in using in-class teaching techniques than they should have.

As a result, although Turkish mathematics teachers frequently use practical teaching approaches, Turkish students still cannot achieve the desired level in international exams. This result shows that out-of-class factors also influence students' math performance. Students' relationships with their families, the learning environment at home, and other interests of students can also affect math achievement. Therefore, teachers may need to focus on ways to help students understand their home learning environment and their relationships with their families.

References

Bümen, N. T., Çakar, E., & Yıldız, D. G. (2014). Türkiye'de öğretim programına bağlılık ve bağlılığı etkileyen etkenler. *Kuram ve Uygulamada Eğitim Bilimleri*, *14*(1), 203-228.

Cohen, J. 1988. *Statistical power analysis for the behavioral sciences*. 2rd ed. Hillsdale, NJ: Lawrence Earlbaum Associates.

Elmoudden, S. (2023). Teaching Intrapersonal Conflict: A Necessity in a Post COVID World. *International*

Journal on Social and Education Sciences (IJonSES), 5(3), 736-745. https://doi.org/10.46328/ijonses.583

Fishbein, B., Foy, P., & Yin, L. (2021). *TIMSS 2019 User Guide for the International Database* (2nd ed.). Retrieved from Boston College, TIMSS & PIRLS International Study Center.

Gedik, Ö., & Aykaç, N. (2017). Matematik derslerinde kullanılan yaratıcı drama yönteminin öğrencilerin farklı öğrenme düzeylerine ve öz-yeterlik algılarına etkisinin belirlenmesi. *Mersin Üniversitesi Eğitim Fakültesi Dergisi*, *13*(1), 152-165.

Gürbüz, S., & Şahin, F. (2014). *Sosyal bilimlerde araştırma yöntemleri [Research methods in social sciences].* Ankara: Seçkin Yayıncılık.

Gürbüz, S., & Şahin, F. (2014). *Sosyal bilimlerde araştırma yöntemleri*. Ankara: Seçkin Yayıncılık.

IEA [International Association for the Evaluation of Educational Achievement] (2018). *Teacher Questionnaire Mathematics <Grade 8>*. TIMSS & PIRLS Lynch School of Education International Study Center. ttps://nces.ed.gov/timss/pdf/T19_Gr8_MthTchQ_USA_Questionnaire.pdf

Kablan, Z., Topan, B., & Erkan, B. (2013). Sınıf içi öğretimde materyal kullanımının etkililik düzeyi: Bir meta-analiz çalışması. *Kuram ve Uygulamada Eğitim Bilimleri*, *13*(3), 1629-1644.

Kara, K., Karakoç, B., Yildirim, İ., & Bay, E. (2017). Examination of curriculum alignment in terms of theory and practice for the 8th grade mathematics teaching. *Harran Education Journal*, 2(1), 26-40.

Kardaş, M. N., & Uca, N. (2016). Aktif öğrenme yönteminin öğrencilerin başarı, tutum ve uygulamalara yönelik görüşleriyle ilişkisi: bir meta-analiz çalışması. *Uluslararası Türk Eğitim Bilimleri Dergisi*, *2016*(7), 118-130.

Kasım, K. & Öztürk, M.S. (2023). Görsel sanatlar dersinde kültürel miras eğitiminin verilmesine yönelik öğretmen görüşleri [Teachers' views about teaching cultural heritage education in visual arts]. *Bilim, Eğitim, Sanat ve Teknoloji Dergisi (BEST Dergi) [Science, Education, Art and Technology Journal (SEAT Journal)], 7*(2), 143-176.

Latifi, S., Noroozi, O., & Talaee, E. (2023). Worked example or scripting? Fostering students' online argumentative peer feedback, essay writing and learning. *Interactive Learning Environments, 31*(2), 655-669. https://doi.org/10.1080/10494820.2020.1799032.

Latifi, S., & Noroozi, O. (2021). Supporting argumentative essay writing through an online supported peer-review script. *Innovations in Education and Teaching International, 58*(5), 501-511. https://doi.org/10.1080/14703297.2021.1961097.

Martin, M. O., von Davier, M., & Mullis, I. V. (2020). *Methods and procedures: TIMSS 2019 technical report*. International Association for the Evaluation of Educational Achievement.

MoNE [Ministry of National Education] (2020). *TIMSS 2019 Türkiye ön raporu*. Ankara: Milli Eğitim Bakanlığı.

Mullis, I. V. S., Martin, M. O., Foy, P., Kelly, D. L., & Fishbein, B. (2020). *TIMSS 2019 International Results in Mathematics and Science.* Retrieved from Boston College, TIMSS & PIRLS International Study Center.

Mullis, I. V., & Martin, M. O. (2017). TIMSS 2019 *Assessment frameworks*. International Association for the Evaluation of Educational Achievement. Herengracht 487, Amsterdam, 1017 BT, The Netherlands.

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a

technology pedagogical content knowledge. *Teaching and teacher education*, *21*(5), 509-523.

Noroozi, O., Dehghanzadeh, H., & Talaee, E. (2020). A systematic review on the impacts of game-based learning on argumentation skills. *Entertainment Computing*, *35*, 100369.

Noroozi, O., Kirschner, P.A., Biemans, H.J.A., & Mulder, M. (2018). Promoting argumentation competence: Extending from first- to second-order scaffolding through adaptive fading. *Educational Psychology Review*, *30*(1), 153-176.

Noroozi, O., Weinberger, A., Biemans, H.J.A., Mulder, M., & Chizari, M. (2012). Argumentation-based computer supported collaborative learning (ABCSCL). A systematic review and synthesis of fifteen years of research. *Educational Research Review*, *7*(2), 79-106.

NTCM [National Council of Teachers of Mathematics]. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

Özsoy, N. (2003). İlköğretim matematik derslerinde yaratıcı drama yönteminin kullanılması. *Balıkesir Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, *5*(2), 112-119.

Pirci, H. A., & Torun, G. (2020). Cebirsel ifadeler konusunun öğretiminde 5E öğrenme modelinin 6. sınıf öğrencilerinin akademik başarısı üzerine etkisi. *Kastamonu Eğitim Dergisi*, *28*(1), 494-511.

Sahlberg, P. (2021). *Finnish lessons 3.0: What can the world learn from educational change in Finland?*. Teachers College Press.

Shaqour, E. N., & Dwiek, F. M. B. (2023). The Reality of Using Modern Teaching Strategies in Architectural Design Course. Interna*tional Journal on Studies in Education (IJonSE), 5*(3), 301-316. https://doi.org/10.46328/ijonse.134

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics* (5th ed.) Boston: Allyn and Bacon.

Topan, B. (2013). *Matematik öğretiminde öğrenci merkezli yöntemlerin akademik başarı ve derse yönelik tutum üzerindeki etkililiği: Bir meta-analiz çalışması* (Master's thesis, Kocaeli Üniversitesi, Fen Bilimleri Enstitüsü).

Ulubey, Ö., & Toraman, Ç. (2015). Yaratıcı drama yönteminin akademik başarıya etkisi: bir meta-analiz çalışması/The effect of creative drama on students' academic achievement: A meta-analysis study. *Mustafa Kemal Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, *12*(32), 195-220.

Valero Haro, A, Noroozi, O., Biemans, H. J. A., & Mulder, M. (2022). Argumentation Competence: Students' argumentation knowledge, behavior and attitude and their relationships with domain-specific knowledge acquisition. *Journal of Constructivist Psychology, 35*(1),123-145. https://doi.org/10.1080/10720537.2020.1734995.

Valero Haro, A., Noroozi, O., Biemans, H.J.A., & Mulder, M. (2019). First-and second-order scaffolding of argumentation competence and domain-specific knowledge acquisition: a systematic review. *Technology, Pedagogy and Education, 28*(3), 329-345. https://doi.org/10.1080/1475939X.2019.1612772.

Zakaria, E., Chin, L. C., & Daud, M. Y. (2010). The effects of cooperative learning on students' mathematics achievement and attitude towards mathematics. *Journal of social sciences*, *6*(2), 272-275.

Exploring In-Class Assessment Strategies of Science Teachers in Turkey and Finland: A Comparative Analysis

Eyüp Yurt
Bursa Uludağ University, Türkiye, https://orcid.org/0000-0003-4732-6879

Abstract: This study aims to compare the classroom assessment strategies of science teachers in Turkey and Finland. This study aims to understand and analyze the differences and similarities between the classroom assessment strategies of science teachers in both countries. This study employed a causal-comparative research design to examine and contrast the assessment strategies used by science teachers in Turkey and Finland. The study analyzed the teachers' responses to questions related to science instruction in the 2019 TIMSS assessment. The participants in this research study were eighth-grade science teachers from Turkey and Finland who participated in the 2019 TIMSS. The study included 1127 teachers from Finland and 181 teachers from Turkey. The answers that eighth-grade science teachers gave to the "Science Assessment of the TIMSS Class" questionnaire in the 2019 TIMSS were examined. Chi-square analysis was applied to compare the responses of Turkish and Finnish teachers to the survey questions. The results obtained in the study showed that there is a significant relationship between countries and the frequency of homework. Finnish teachers have a higher tendency to give homework once or twice a week, while Turkish teachers have a higher tendency to give homework less than once a week. According to the other results obtained in this study, Turkish science teachers attach more importance to observing students while working, asking students to answer questions during class, giving short and regular written assessments, and assigning long-term projects, compared to Finnish science teachers. In light of the obtained results, some suggestions have been developed.

Keywords: TIMSS 2019, In-Class Assessment Strategies, Turkish and Finnish Science Teachers.

Citation: Yurt E. (2023). Exploring In-Class Assessment Strategies of Science Teachers in Turkey and Finland: A Comparative Analysis. In V. Akerson, A. Bicer, & S. Turgut (Eds.), *Proceedings of ILSET 2023--International Conference on Life Sciences, Engineering and Technology* (pp. 160-172), Denver, CO, USA. ISTES Organization.

Introduction

Today, the education system is an important issue worldwide, and each country is trying to shape its education system. Science teaching, which has an important place in the education system, is fundamental to developing students' scientific thinking skills and enabling them to use scientific knowledge effectively (Acar-Erdol & Yildizli, 2018; Akman & Açıkgöz, 2022; Akman et al., 2022; Cakir, Ozturk, & Unal, 2019; Osborne, NRC, 2012; Ozturk, 2023; Simon & Collins, 2003). For this reason, in-class assessment strategies of science teachers

also gain importance. This article aims to compare the in-class assessment strategies of Turkish and Finnish science teachers. Turkey and Finland use different teaching strategies with different education systems and cultural structures. For this reason, comparing in-class assessment strategies of Turkish and Finnish teachers is vital in understanding how teaching strategies and cultural differences are reflected in assessment strategies. This article aims to compare the in-class assessment strategies of Turkish and Finnish science teachers and to reveal the similarities and differences between the assessment strategies of teachers in both countries. As a result of these comparisons, it will be tried to determine how there are differences in classroom assessment strategies according to the teaching strategies of both countries and how these differences affect students' success.

Trends in International Mathematics and Science Study

Trends in International Mathematics and Science Study (TIMSS) is an international exam conducted to measure the success of 4th and 8th grade students in mathematics and science. The Center for International Education Assessment (IEA) organizes the exam every four years (Mullis & Martin, 2017). TIMSS aims to determine the current status of the participating countries in mathematics and science education, to identify the weaknesses and strengths in their education systems, and to follow the changes in students' knowledge and skills. In the exam, questions consisting of mathematics and science subjects are asked of the students, and the student's performance is compared at the international level.

Regarding science, the TIMSS exam is intended to measure students' knowledge, understanding, and skills in science. It can also be considered a tool to determine the basic concepts and skills students should acquire in science courses. In addition, TIMSS results can be an essential resource for identifying strengths and weaknesses in science education and identifying opportunities for improvement in education systems (Mullis et al., 2020).

According to the 2019 TIMSS results, Singapore has the highest science achievement among 39 participating countries, with 608 points. Taiwan, Japan, and South Korea from other Asian countries follow Singapore, respectively, and show significantly higher science performance than their lower countries. Of the countries that participated in TIMSS 2019 at the eighth-grade level, 16 outperformed the average by scoring higher than the TIMSS midpoint of the scale. Four countries, Hong Kong, Italy, New Zealand, and Norway, performed at the same level as the scale midpoint. The eighth-grade science performance of 19 participating countries is lower than the scale's midpoint (MoNE, 2020).

Finland ranked 6th out of 39 participants, with an average score of 543 at the eighth-grade level. On the other hand, Turkey was ranked 15th among 39 participants, with an average score of 515 at the eighth-grade level. This performance has enabled Turkey to be significantly above the TIMSS midpoint (500 points). Turkey outperformed 22 countries, including Italy, Norway, France, New Zealand, and Romania. Ireland, the United States, Sweden, Portugal, England, Israel and Hong Kong are performing at the same level as Turkey. However, Turkey's science performance is lower than nine countries, including Finland, Lithuania, Hungary, and Australia (MoNE, 2020).

Purpose of the Research

This study aims to compare science teachers' classroom assessment strategies in Turkey and Finland. This study aims to understand and analyze the differences and similarities between the classroom assessment strategies of science teachers in both countries. This comparative analysis can help understand the differences in science education in both countries and help teachers develop classroom assessment strategies.

This article's importance lies in comparing in-class assessment strategies between countries with different cultural and educational systems, such as Turkey and Finland. Such comparisons can help understand the differences between education systems in different countries and develop in-class assessment strategies by comparing teachers' practices in different countries. In addition, this study may provide insights into how science teachers can effectively use classroom assessment strategies to increase student learning.

Method

This research employed a causal comparison design, a methodology utilized to explore the causal relationship between multiple variables. This design facilitates researchers to identify the direction and nature of the relationship between variables and to evaluate the impact of one variable on others (Gall, Borg & Gall, 1996). Using this approach, this study compared and analyzed the responses of Turkish and Finnish science teachers to questions regarding assessment strategies in science lessons in the 2019 TIMSS.

Sample

The participants in this research study were eighth-grade science teachers from Turkey and Finland who participated in the 2019 TIMSS. The study included 1127 teachers from Finland and 181 teachers from Turkey. The average professional experience of Finnish teachers was 14,88 years (SD=9,39), while Turkish teachers were 12,02 years (SD=8,86). The demographic characteristics of the teachers are presented in Tables 1, 2, and 3.

Table 1. Distribution of Turkish and Finnish Teachers by Gender.

			Frequency	Percent
Gender of teacher	Finnish	Female	728	63,7
		Male	401	35,2
		Missing	13	1,1
	Turkish	Female	95	52,5
		Male	86	47,5

When Table 1 is examined, it is understood that 63,7% of Finnish teachers are female and 35,2% are male. On the other hand, 52,5% of Turkish teachers are female, and 47,5% are male. It is striking that the proportion of female teachers is higher in the Finnish sample.

Table 2. Distribution of Turkish and Finnish Teachers by Age.

			Frequency	Percent
Age of teacher	Finnish	Under 25	5	0,4
		25–29	100	8,8
		30–39	314	27,5
		40–49	383	33,6
		50–59	247	21,6
		60 or more	79	6,9
		Missing	14	1,2
	Turkey	Under 25	3	1,7
		25–29	46	25,4
		30–39	82	45,3
		40–49	36	19,9
		50–59	8	4,4
		60 or more	6	3,3

When Table 2 is examined, it is understood that the majority of Finnish teachers are in the 30-39 (27,5%), 40-49 (33,6%), and 50-59 (21,6%) age groups. The majority of Turkish teachers are in the 25-29 (25,4%), 30-39 (45,3%), and 40-49 (19,9%) age groups. It has been observed that Turkish teachers participating in TIMSS 2019 are younger.

Table 3. Distribution of Turkish and Finnish Teachers by Education Level.

			Frequency	Percent
Education level of teacher	Finnish	Upper secondary education	8	0,7
		Short-cycle tertiary education	4	0,4
		Bachelor's or equivalent level	44	3,9
		Master's or equivalent level	1038	90,9
		Doctor or equivalent level	34	3,0
		Missing	14	1,2
	Turkish	Short-cycle tertiary education	2	1,1
		Bachelor's or equivalent level	163	90,1
		Master's or equivalent level	14	7,7
		Doctor or equivalent level	2	1,1

When Table 2 is examined, most Finnish teachers (90,9%) have a master degree. On the other hand, many Turkish teachers stated they have a bachelor's degree (90,1%). It is striking that Finnish teachers have higher education levels.

Measuring Tool

In this research, the answers that eighth-grade science teachers gave to the questionnaire titled "Science Assessment of the TIMSS Class" in the 2019 TIMSS were examined. The questionnaire began with the question, "How much importance do you place on the following assessment strategies in science?" (IEA, 2018). The questionnaire aims to determine at what level teachers use different assessment strategies in their lessons. The questionnaire is in a 3-point Likert type (A lot =1, Some =2, None =3) and consists of 5 items.

Statistical Analysis

In this study, the TIMSS 2019 User Guide was referenced in the analysis of TIMSS data (Fishbein, Foy & Yin, 2021). Chi-square analysis was applied to compare the responses of Turkish and Finnish teachers to the survey questions. Analyzes were carried out using the IBM SPSS 25.0 statistical package program.

Results

Under the purpose of the research, the frequency of homework given by science teachers was compared according to the countries. In the next step, the rate of teachers' preference for some classroom assessment strategies was compared and examined. Chi-square analysis was used for comparisons.

Table 4. Comparison of Homework Frequency of Science Teachers by Country.

			Country		Chi-square	p
			Finland	Turkey		
How often do you usually assign science homework to the students in this class?	I do not assign science homework	f	36	16	32,48	<0,001
		%	3,2	8,8		
	Less than once a week	f	175	49		
		%	15,7	27,1		
	1 or 2 times a week	f	811	108		
		%	72,9	59,7		
	3 or 4 times a week	f	38	6		
		%	3,4	3,3		
	Every day	f	53	2		
		%	4,8	1,1		
	Total	f	1113	181		
		%	100	100		

When examining Table 4, it can be seen that 3,2% of Finnish science teachers do not assign homework, while 15,7% give homework less than once a week, 72,9% give homework 1 or 2 times a week, 3,4% give homework 3 or 4 times a week, and 4,8% give homework every day. It is understood that 8,8% of Turkish science teachers

do not assign homework, while 27,1% give homework less than once a week, 59,7% give homework 1 or 2 times a week, 3,3% give homework 3 or 4 times a week, and 1,1% give homework every day.

A significant relationship exists between countries and homework frequency (Chi-square=32,48; p<0,001). Finnish teachers have a higher tendency to give homework once or twice a week, while Turkish teachers have a higher tendency to give homework less than once a week.

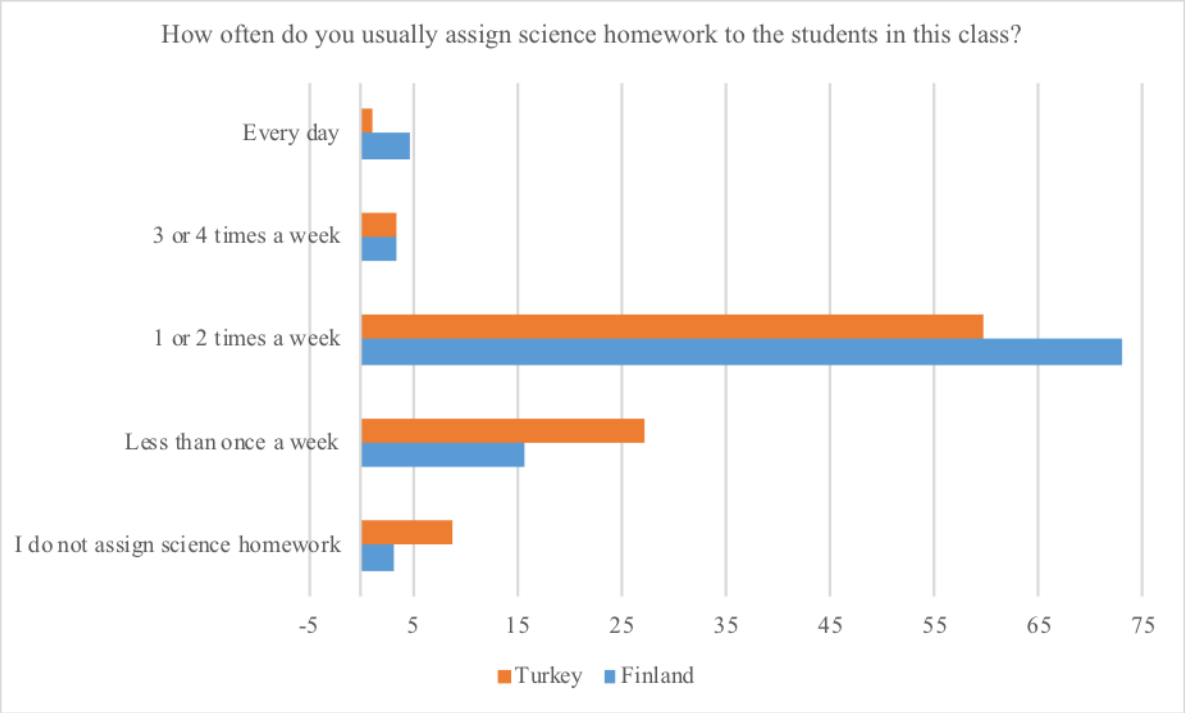


Figure 1. Homework Frequency of Science Teachers by Country.

Table 5. Science Teachers' Levels of Importance Given to Asking Students to Observe Students While Working by Countries.

			Country		Chi-square	p
			Finland	Turkey		
How important is it for you to observe students while they are working?	A lot	f	836	159	17,65	<0,001
		%	74,9	87,8		
	Some	f	279	21		
		%	25,0	11,6		
	None	f	1	1		
		%	0,1	0,6		
	Total	f	1116	181		
		%	100	100		

When Table 5 is examined, 74,9% of Finnish teachers stated that it is important to observe students while they are working and 25,0% of them are important. On the other hand, 87,8% of Turkish teachers stated that

observing students while working is a lot important, and 11.6% is some important. There is a significant relationship between countries and Levels of importance to observing students while working (Chi-square=17,65; p<0,001). It has been observed that Turkish science teachers attach more importance to observing students while they are working.

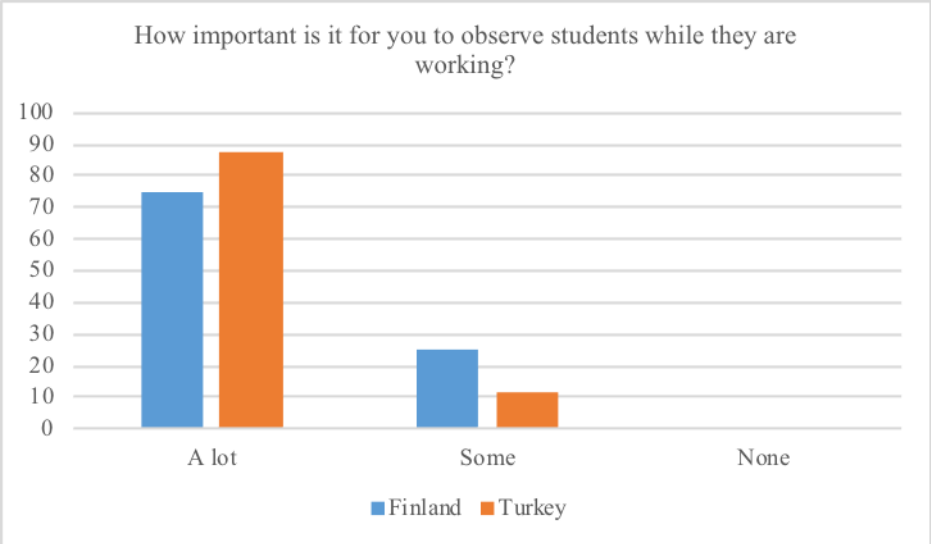


Figure 2. Science Teachers' Levels of Importance Given to Asking Students to Observe Students While Working by Countries.

Table 6. Science Teachers' Levels of Importance Given to Asking Students to Answer Questions During Class by Countries.

			Country		Chi-square	p
			Finland	Turkey		
How important is it for you to ask students to answer questions during class?	A lot	f	705	173	74,44	<0,001
		%	63,3	95,6		
	Some	f	391	8		
		%	35,1	4,4		
	None	f	18	0		
		%	1,6	0		
	Total	f	1114	181		
		%	100	100		

When Table 5 is examined, 63,3% of Finnish teachers stated that it is important to ask students to answer questions during class and 35,1% of them are important. On the other hand, 95,6% of Turkish teachers stated that asking students to answer questions during class is a lot important, and 4,4% is some important. There is a significant relationship between countries and levels of importance in asking students to answer questions during

class (Chi-square=74,44; p<0.001). It has been observed that Turkish science teachers attach more importance to asking students to answer questions during class.

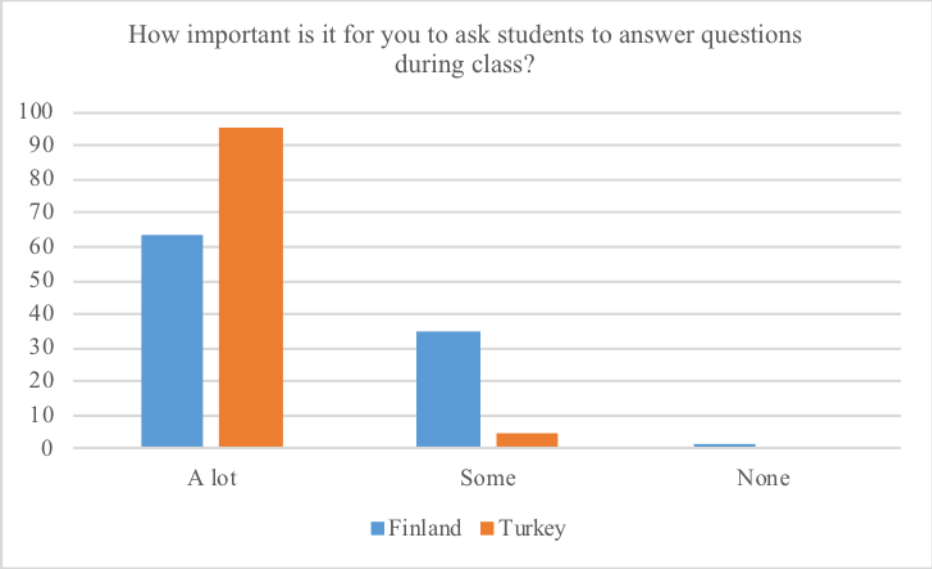


Figure 3. Science Teachers' Levels of Importance Given to Asking Students to Answer Questions During Class by Countries.

Table 7. Science Teachers' Levels of Importance Given to Short, Regular Written Assessments by Countries.

			Country		Chi-square	p
			Finland	Turkey		
How important is it for you the short, regular written assessments?	A lot	f	189	87	96,11	<0,001
		%	17,0	48,1		
	Some	f	751	88		
		%	67,4	48,6		
	None	f	174	6		
		%	15,6	3,3		
	Total	f	1114	181		
		%	100	100		

When Table 5 is examined, 17,0% of Finnish teachers stated that the short, regular written assessments and 67,4% of them are important. On the other hand, 48,1% of Turkish teachers stated that short, regular written assessments are a lot important, and 48,6% are some important. There is a significant relationship between

countries and levels of importance given to the short, regular written assessments (Chi-square=74,44; p<0.001). It has been observed that Turkish science teachers attach more importance given to short, regular written assessments.

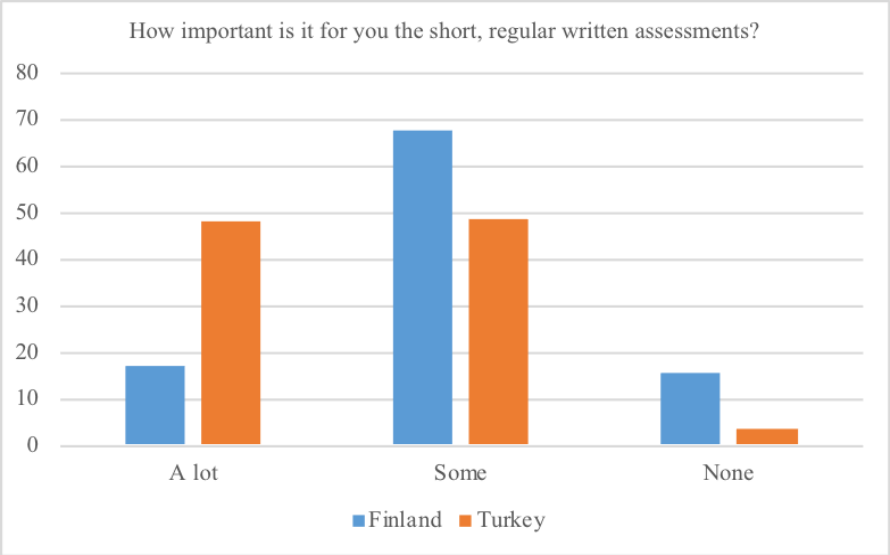


Figure 4. Science Teachers' Levels of Importance Given to Short, Regular Written Assessments by Countries

Table 8. Science Teachers' Levels of Importance Given to Longer Tests by Countries.

			Country		Chi-square	p
			Finland	Turkey		
How important is it for you the Longer tests?	A lot	f	673	100	3,35	0,19
		%	60,5	55,2		
	Some	f	420	75		
		%	37,8	41,4		
	None	f	19	6		
		%	1,7	3,3		
	Total	f	1112	181		
		%	100	100		

When Table 5 is examined, 60,5% of Finnish teachers stated that it is a lot important the longer tests, and 37,8% of them are important. On the other hand, 55,2% of Turkish teachers stated that the longer tests are a lot important, and 41,4% are some important. There is a none significant relationship between countries and levels of importance given to longer tests (Chi-square=3,35; p>0,05). Turkish and Finnish science teachers give similar importance to longer tests such as unit tests or exams.

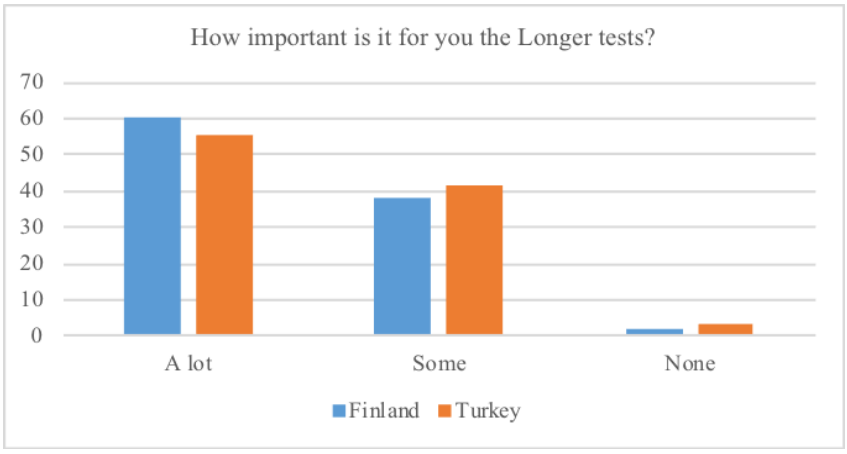


Figure 5. Science Teachers' Levels of Importance Given to Longer Tests by Countries.

Table 9. Science Teachers' Levels of Importance Given to Long-term Projects by Countries.

			Country		Chi-square	p
			Finland	Turkey		
How important is it for you the long-term projects?	A lot	f	163	77	105,05	<0,001
		%	14,6	42,8		
	Some	f	629	96		
		%	56,4	53,3		
	None	f	324	7		
		%	29,0	3,9		
	Total	f	1116	180		
		%	100	100		

When Table 5 is examined, 14,6% of Finnish teachers stated that it is a lot important long-term projects, and 56,4% are important. On the other hand, 42,8% of Turkish teachers stated that long-term projects are a lot important, and 53,3% are some important. There is a significant relationship between countries and levels of importance given to long-term projects (Chi-square=105,05; p<0.001). It has been observed that Turkish science teachers attach more importance given to long-term projects.

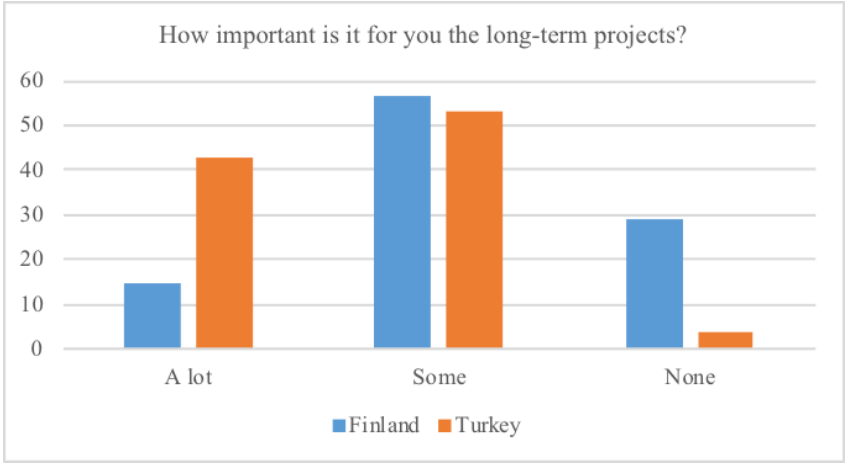


Figure 6. Science Teachers' Levels of Importance Given to Long-term Projects by Countries.

Conclusion and Recommendations

This study aims to compare science teachers' classroom assessment strategies in Turkey and Finland. This study aims to understand and analyze the differences and similarities between the classroom assessment strategies of science teachers in both countries. This study aimed to compare and analyze the assessment strategies employed by science teachers from Turkey and Finland in their science lessons. A causal-comparative research design was used, and the data was gathered from the teachers' responses to questions related to science instruction in the 2019 TIMSS assessment. The participants in this research study were eighth-grade science teachers from Turkey and Finland who participated in the 2019 TIMSS. The study included 1127 teachers from Finland and 181 teachers from Turkey. Chi-square analysis was applied to compare the responses of Turkish and Finnish teachers to the survey questions.

The results obtained in the study showed that there is a significant relationship between countries and the frequency of homework. Finnish teachers have a higher tendency to give homework once or twice a week, while Turkish teachers have a higher tendency to give homework less than once a week. This difference may be due to the differences in the two countries education systems. While the Finnish education system adopts a learning model in which students are not responsible for homework, the Turkish education system accepts homework as an important learning tool and requires homework to be given frequently. The result obtained is essential in terms of understanding the differences between the educational strategies of Turkish and Finnish teachers. In addition, it is necessary to investigate how different approaches to students' homework frequency can affect their learning processes.

According to the other results obtained in this study, Turkish science teachers attach more importance to observing students while working, asking students to answer questions during class, giving short and regular written assessments, and assigning long-term projects, compared to Finnish science teachers. These results show that there are differences between science teachers in Türkiye and Finland. These differences can be caused by many factors, such as education systems, cultural differences, or the difference in teachers' training.

Based on these results, it can be recommended that Turkish science teachers follow the students' work more closely in the classroom to encourage more interaction in the students' learning process. Scientific research shows that inclusion of peer learning, peer review, and peer assessment as active learning strategies are associated with the development of students' higher-order competences (see Latifi et al., 2021, 2023; Noroozi et al., 2012, 2018, 2020; Valero-Haro et al., 2019, 2022). In addition, they can support students' learning process by effectively using different assessment strategies such as more regular written assessments, longer tests such as unit tests or exams, and long-term projects. In Finland, however, teachers' less inclination to assign homework may help relieve students of the burden of homework. However, since homework can contribute to students' learning, teachers in Finland can develop strategies that allow students to add more interaction to the learning process by giving them less homework rather than removing them altogether.

The study's findings indicate that Turkish science teachers emphasize observing their students as an assessment strategy more than their Finnish counterparts. This suggests that Turkish teachers may utilize various assessment strategies to observe a broader range of learning objectives, such as students' critical thinking, problem-solving, and cooperation skills. In addition, it can be suggested that teachers in both countries focus on students' weaknesses, identify their learning needs, and organize their learning processes accordingly. In addition, more interactive and student-centered learning strategies such as discussion, problem-solving, assignments, and project-based learning can be encouraged to enable students to take a more active role in the learning process.

References

Acar-Erdol, T., & Yildizli, H. (2018). Classroom Assessment Practices of Teachers in Turkey. *International Journal of Instruction*, *11*(3), 587-602.

Akman, Ö., & Açıkgöz, B. (2022). Classroom Teachers' Metaphorical Perceptions Regarding the Concepts of Independence and Struggle. In M. Shelley, H. Akcay, & O. T. Ozturk (Eds.*), Proceedings of ICRES 2022-- International Conference on Research in Education and Science* (pp. 52-70), Antalya, TURKEY. ISTES Organization.

Akman, Ö., Ekici, K., Koçak, Z., & Erdem, C.C. (2022). Metaphor Perceptions of Social Studies Teachers Regarding the Conceptions of Freedom and Justice. In M. Shelley, H. Akcay, & O. T. Ozturk (Eds.), *Proceedings of ICRES 2022-- International Conference on Research in Education and Science* (pp. 137-152), Antalya, TURKEY. ISTES Organization.

Cakir, E., Ozturk, M.S., Unal, M. (2019). Interpainting as a Creating Method in Digital Illustration: Reinterpretations from Movie Scenes. *Science, Education, Art and Technology Journal (SEAT Journal), 3*(2), 78-88.

Fishbein, B., Foy, P., & Yin, L. (2021). *TIMSS 2019 User Guide for the International Database* (2nd ed.). Retrieved from Boston College, TIMSS & PIRLS International Study Center.

Gall, M. D., Borg, W. R., & Gall, J. P. (1996). *Educational research: An introduction*. Longman Publishing.

IEA [International Association for the Evaluation of Educational Achievement] (2018). *Teacher Questionnaire Mathematics <Grade 8>*. TIMSS & PIRLS Lynch School of Education International Study Center. ttps://nces.ed.gov/timss/pdf/T19_Gr8_MthTchQ_USA_Questionnaire.pdf

Latifi, S., & Noroozi, O. (2021). Supporting argumentative essay writing through an online supported peer-review script. *Innovations in Education and Teaching International, 58*(5), 501-511. https://doi.org/10.1080/14703297.2021.1961097.

Latifi, S., Noroozi, O., & Talaee, E. (2023). Worked example or scripting? Fostering students' online argumentative peer feedback, essay writing and learning. *Interactive Learning Environments, 31*(2), 655-669. https://doi.org/10.1080/10494820.2020.1799032.

MoNE [Ministry of National Education] (2020). *TIMSS 2019 Türkiye ön raporu*. Ankara: Milli Eğitim Bakanlığı.

Mullis, I. V. S., Martin, M. O., Foy, P., Kelly, D. L., & Fishbein, B. (2020). TIMSS 2019 international results in

mathematics and science. Boston College, TIMSS & PIRLS International Study Center.

Mullis, I. V., & Martin, M. O. (2017). TIMSS 2019 *Assessment frameworks*. International Association for the Evaluation of Educational Achievement. Herengracht 487, Amsterdam, 1017 BT, The Netherlands.

Noroozi, O., Dehghanzadeh, H., & Talaee, E. (2020). A systematic review on the impacts of game-based learning on argumentation skills. *Entertainment Computing*, *35*, 100369.

Noroozi, O., Kirschner, P.A., Biemans, H.J.A., & Mulder, M. (2018). Promoting argumentation competence: Extending from first- to second-order scaffolding through adaptive fading. *Educational Psychology Review*, *30*(1), 153-176.

Noroozi, O., Weinberger, A., Biemans, H.J.A., Mulder, M., & Chizari, M. (2012). Argumentation-based computer supported collaborative learning (ABCSCL). A systematic review and synthesis of fifteen years of research. *Educational Research Review, 7*(2), 79-106.

NRC [National Research Council] (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International journal of science education*, *25*(9), 1049-1079.

Ozturk, O.T. (2023). Examination of 21st Century Skills and Technological Competences of Students of Fine Arts Faculty. *International Journal of Education in Mathematics, Science, and Technology (IJEMST), 11*(1), 115-132. https://doi.org/10.46328/ijemst.2931

Valero Haro, A, Noroozi, O., Biemans, H. J. A., & Mulder, M. (2022). Argumentation Competence: Students' argumentation knowledge, behavior and attitude and their relationships with domain-specific knowledge acquisition. *Journal of Constructivist Psychology*, *35*(1), 123-145. https://doi.org/10.1080/10720537.2020.1734995.

Valero Haro, A., Noroozi, O., Biemans, H.J.A., & Mulder, M. (2019). First-and second-order scaffolding of argumentation competence and domain-specific knowledge acquisition: a systematic review. *Technology, Pedagogy and Education*, *28*(3), 329-345. https://doi.org/10.1080/1475939X.2019.1612772.

istes Organization

www.istes.org

www.ijemst.net

www.ijres.net

www.ijtes.net

www.ijte.net

www.ijonse.net

www.ijonest.net

www.ijonses.net

International Conference on Life Sciences, Engineering and Technology

April 13-16, 2023 Denver, CO, USA

istesoffice istesoffice istesoffice

www.ilset.net